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Understanding private landowner strategies for wild pig management using cluster analysis and structural equation modeling

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Title page

Title: Understanding Private Landowner Strategies for Wild Pig Management using Cluster Analysis and Structural Equation Modeling

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Abstract: Wild pigs (*Sus scrofa*) pose a significant threat, causing substantial ecological and economic damage to natural ecosystems, agriculture, and forestry through destructive behaviors of wallowing and rooting. Addressing this widespread issue urgently requires effective and sustained management strategies, especially involving private landowners, who are a critical stakeholder group in the West Gulf Coastal Plain (WGCP). This study aims to identify landowner typologies in wild pig management and to examine factors influencing their intentions to engage in such efforts in Arkansas, Louisiana, and East Texas. We employed a mixed method of cluster analysis and structural equation modeling (SEM) based on the Theory of Planned Behavior (TPB). Cluster analysis revealed three distinct landowner groups based on their familiarity with and experiences of wild pig damage and management efforts: *Unaware Bystanders*, *Frontline Responders*, and *Cautious Observers*. SEM was employed to assess the belief structures influencing behavioral intentions across the entire sample and within each identified cluster. Results indicated that beliefs and attitudes were the most influential predictors of intended behavior, which varied across the landowner clusters. The findings highlight the heterogeneity in landowner responses and offer practical implications for developing targeted outreach strategies, policy interventions, and collaborative management approaches aligned with the needs and motivations of different landowner groups.

Key words: Wild pigs (*Sus scrofa*); Private landowners; Western Gulf Coastal Plain; Theory of Planned Behavior; Cluster analysis; Structural equation modeling

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1. Introduction

Wild pigs (*Sus scrofa*), also known as “feral swine” or “feral hogs” [1], are an invasive species of growing concern given their destructive activities and fast spread in the United States [2]. They were initially introduced to North America for agricultural and hunting purposes [3]. With high reproductive rates, behavioral adaptability, and a lack of natural predators [4], their population has expanded rapidly, reaching around seven million in the United States, half of which are distributed in the West Gulf Region (WGR), where Arkansas, Texas, and Louisiana are located [2]. The presence of wild pigs has caused severe damage to natural resources, agriculture, and forestry through wallowing and rooting [5]. Overall, the expansion of wild pigs imposes challenges on different stakeholders, including natural resources managers and landowners (especially private landowners), with extensive ecological and economic damage in the areas where they inhabit.

Ecologically, wild pigs pose significant threats to natural ecosystems as well as agrosystems through a variety of destructive behaviors. Wild pigs cause the most severe damage through rooting, grubbing, and wallowing, according to Tian et al. [5]. This is because rooting and grubbing are their primary ways of finding food, which leads to significant soil disruption and harm to plant life [6,7,8]. Besides, crop consumption is another pervasive damage to agricultural landowners [7,9], which can be further intensified by the fact that large sounders can inflict extensive damage on cultivated fields [10,11]. In addition to direct consumption, wild pigs damage crops through rooting, trampling, and wallowing [6]. Pasturelands can be similarly destroyed by wild pigs as they can disrupt soil structure, uproot desirable forage species, and expose subsurface plant parts, insects, and invertebrates through rooting, ultimately leading to the destruction of pasture ecosystems [12]. Wild pigs also pose a serious biosecurity risk due to their potential to transmit infectious diseases to domestic livestock. Notable diseases include swine brucellosis, pseudorabies, classical swine fever, and African swine fever [11]. These pathogens are associated with severe outcomes such as reproductive failure, congenital abnormalities, and mortality in both livestock and wildlife populations [13]. Wild pigs' destructive behaviors to forested ecosystems include girdling trees by rubbing against them, damaging lateral roots through rooting and chewing, and stripping bark by tusking [6]. For example, wild pigs have been reported to depredate seedlings of both coniferous species, such as pines [14], and hardwoods, including cherrybark oak (*Quercus pagodaefolia*), swamp chestnut oak (*Q. michauxii*), water hickory (*Carya aquatica*), and swamp tupelo (*Nyssa sylvatica* var. *biflora*) within wetland restoration areas [5].

Economically, wild pigs have caused an extensive loss to agriculture and forestry alone. Annual damage to agriculture, primarily crops, was estimated at US$52 million in Texas [15], US$75 million in Alabama [16,17],

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US$81 million in Georgia [18], and US$26 million in Tennessee [19], respectively. Anderson et al. [20] reported that the economic damage to livestock producers was around US$40 million per year nationwide, including predation and disease-related impacts. In a survey of producers of six crops across 11 states, McKee et al. [8] estimated crop production losses of USD 203 million in 2022. In a separate survey of producers of additional crops across 12 states in 2019, McKee et al. [9] estimated losses of USD 272 million. Specific to different land uses, Tian et al. [5] reported that economic damage to landowners due to wild pigs was estimated at US$67.13/ha, US$42.96/ha, US$27.31/ha, and US$57.54/ha for cropland, forestland, pastureland, and multiple land types, respectively.

Both ecological and economic damage caused by wild pigs underscore the urgent need for effective and sustained management strategies among different stakeholders, especially for private landowners, who represent a critical stakeholder group in wild pig management in the WGR. Understanding landowners' attitudes, perceived control, normative beliefs, and behavioral intentions is essential for designing and implementing management mechanisms. Many studies have been published on exploring landowners' perspectives and attitudes toward wild pigs and their management. For example, landowners generally held a negative attitude toward wild pigs and agreed that they are a nuisance and threat and should be eliminated when possible [12,18,21,22,23,24, 25]. Tian et al. [5] and Caplenor et al. [23] both reported that landowners were concerned about wild pig damage to both the environment and the local economy, and they supported education and incentive-based control programs and favored active management strategies. However, considering the heterogeneity of landowners in terms of their management objectives and demographic characteristics [26,27,28], a segmentation-based understanding of their behavioral intentions towards wild pig management is necessary to develop and deliver more effective outreach and education services.

Therefore, the objective of this study is to identify landowner typologies in the context of wild pig management. Employing a social-behavioral framework, we identified distinct segments of landowners based on their familiarity with and experiences of wild pig damage and management efforts. By integrating behavioral theory with cluster analysis, this study elucidates the heterogeneity in landowner responses and offers practical implications for developing targeted outreach strategies, policy interventions, and collaborative management approaches aligned with the needs and motivations of different landowner groups.

2. Conceptual Framework

The Theory of Planned Behavior (TPB) conceptualizes how individual behaviors originate from underlying beliefs [29]. TPB posits that an

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individual's behavior is most accurately predicted by their intention to engage in that behavior. Specifically, intention representing an individual's motivation or plan to engage in a specific action serves as the strongest predictor of actual behavior [30,31] and is shaped by three categories of subjective beliefs: attitudes toward the behavior, subjective norms (SN), and perceived behavioral control (PBC). Attitudes toward the behavior reflect an individual's evaluation or perception of the action and hold a central position within the TPB framework [31], as they reflect the extent to which an individual evaluates the behavior as favorable or unfavorable within a given context [30,32]. Subjective norms encapsulate both the perceived social pressures to engage in the behavior and the individual's willingness to conform to those pressures [30]. Additionally, subjective norms emerge from the behaviors and statements of significant people in an individual's life [33], reflecting one's perception regarding whether important others approve or disapprove of engaging in a particular behavior [34]. Regarding PBC, which describes an individual's assessment of the ease or difficulty associated with performing the behavior, potentially affecting the actual behavior directly or indirectly through influencing intention. To be specific, PBC refers to an individual's perception of the ease or difficulty associated with performing a specific behavior [30,35]. PBC comprises two main components: (1) an individual's perceived level of control over executing the behavior, and (2) the individual's confidence in their ability to perform or refrain from performing the behavior [35].

TPB has previously been applied to identifying factors influencing landowners', including private and family landowners', actual or intended behaviors. For example, Karppinen [36] reported that TPB effectively explained landowners' choice of reforestation methods in a study conducted in Finland. The results indicated that attitudes represented the strongest explanatory factor, while subjective norms and perceived behavioral control had smaller yet comparably reciprocal effects on reforestation intentions. Likewise, Castilho et al. [37], who studied attitudes and behaviors of rural residents toward various motivations for hunting and deforestation in protected areas in Brazil, concluded that management strategies intended to alter local behaviors for forest protection must consider both attitudes and norms of the community. Similarly, Primmer and Karppinen [38] employed TPB in their research and found the significant influence of foresters' attitudes and subjective norms on biodiversity protection; Karppinen and Berghäll [39], used TPB to investigate intentions related to forest improvement measures in Finland, found subjective norms to be the

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predominant explanatory factor, with attitudes having comparatively less explanatory power. Other examples of applying TPB in forest landowners' research include sustained-yield management practices [40], forest regeneration [41], riparian zone improvements [42], flood control measures [43], forest protection in Brazil [37], and protective initiatives for forested watershed areas in Malaysia [35]. Insights derived from these applications have informed the development and execution of more targeted and effective communication and intervention strategies [44].

In this study, we utilize TPB to examine social determinants and the factors influencing private landowners' intentions to engage in wild pig management. Specifically, we analyze data obtained from a survey of private landowners in Arkansas, Louisiana, and East Texas to identify strategies that could effectively promote intervention efforts. Based on these empirical insights, three hypotheses are formulated for this study. The following are the alternative hypotheses; their corresponding null hypotheses representing 'no effect" or "do not significantly influence" are omitted to reduce length.

Hypothesis 1 (H1a): Perceptions of wild pigs significantly influence private landowners' attitudes toward wild pig management actions, and attitudes significantly influence their intention to manage wild pigs.

Hypothesis 2 (H2a): Subjective norms significantly influence private landowners' intention to manage wild pigs.

Hypothesis 3 (H3a): Perceived behavioral control significantly influences private landowners' intention to manage wild pigs.

In addition to testing these hypotheses, we also attempt to estimate the extent to which a factor influences landowners' attitudes and intentions if the factor has a significant effect.

3. Results

After removing ineligible responses, we obtained 361 valid responses from Arkansas, 301 from Louisiana, and 223 from East Texas. This resulted in state-level adjusted response rates of 21.05%, 24.08%, and 24.73%, respectively, with an overall adjusted response rate of 22.6%. Among the usable surveys received from the three states, 86% were male, the average ownership tenure was 39 years, and the average acreage size was around 797 acres. Approximately 24% of respondents reported an age between 45 and 54, with 62% between 55 and 64. The percentage of landowners with

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vocational training (associate degree) and college education was 49%, while the percentage of reporting having a bachelor's (27%) and advanced degree (15%) was 42%. About 45% of the respondents had an annual household income between US$50,000 and US$100,000.

3.1 Cluster Analysis Results

Cluster analysis was conducted based on survey items assessing private landowners' reported efforts in managing wild pigs in previous years, observations of wild pig presence on their own and neighboring properties, experiences of wild pig-induced damage, and self-reported familiarity with wild pigs. The analysis yielded three distinct audience segments (Table 2). The first group (n = 91) consisted of landowners with low awareness and limited engagement with wild pig issues; this group was labeled "Unaware Bystanders." The second group (n = 217) included landowners who were actively involved in wild pig management and control efforts and was designated as "Frontline Responders." The third group (n = 104) represented landowners who expressed concern but remained relatively passive in their response to wild pig issues; this group was identified as "Cautious Observers."

Table 2. Mean scores of key variables by cluster.

Variables	Mean Unaware Bystanders (n =91)	Frontline Responders (n =217)	Cautious Observers (n =104)
How much effort have you put into reducing or controlling wild pigs on your land in the previous years (1 = a little, 2 = some, and 3 = a lot)	1.05	2.69	1.74
Whether you have experienced damage from wild pigs on your property (1 = Yes, 0 = No)	0.02	0.95	0.75
Your familiarity level with wild pigs (1= not familiar at all, 2 = somewhat familiar, 3 = very familiar)	2.13	2.91	2.75
To what extent have you noticed wild pigs on your land (1 = less than 5% of my land; 2 = about 25% of my land, 3 = about half of my land, 4 = more than 75% of my land)	2.23	4.52	2.64
To what extent are wild pigs present on neighboring land or near	2.12	4.82	3.94

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your property (1 = not at all, 2 = slightly, 3 =somewhat, 4 = moderately, 5 = greatly)	

In addition, we examined the socio-demographics and ownership characteristics of the three groups to identify the typological differences using ANOVA analysis. The results suggested that there was no distinct difference among the three groups in terms of gender, annual household income, and tenure (Table 3). However, there were significant differences among the three segments in age, education, and acreage size (Table 3).

Table 3. ANOVA analysis of demographic and land characteristic variables among the three clusters.

Variable	p-value	Cluster 1 (Mean)	Cluster 2 (Mean)	Cluster 3 (Mean)
Age (1 = 34 years or younger, 2 = between 35 and 44, 3 = between 45 and 54, 4 = between 55 and 64, 5 = 65 years or older)	0.002**	4.70[a]	4.04[b]	4.24[ab]
Gender (1 = male, 2 = female)	0.575	1.10	1.06	1.05
Education (1 = less than high school/GED, 2 = high school/GED, 3 = some college, 4 = associated degree, 5 = bachelor's degree, 6 = advanced degree)	0.070*	3.78[a]	3.85[a]	4.34[b]
Annual household income (1 = less than $20k, 2 = $20k to $49,999, 3 = $50k to $79,999, 4 = $80k to $100k, 5 = more than $100k)	0.476	3.77	3.82	4.01
Acreage (acres)	<0.001***	441.38[a]	1325.16[b]	627.16[a]
Tenure (year)	0.507	38.00	38.13	34.29

* Significant at p < 0.10, ** p < 0.05, *** p<0.001; [a, b] means with different subscripts are statistically different.

Unaware Bystanders: The members in this group scored lower on all parameters than the other two landowner clusters. This group consisted of landowners who had minimal engagement in wild pig management, infrequently experienced wild pig damage, reported low levels of familiarity with wild pigs, and rarely observed signs of wild pigs on their own or neighboring properties. Approximately 71.3% of landowners in this group were 65 years or older (the highest among the three groups), 23% reported between the ages of 55 and 64, while 2.3% were between 45 and 54 (the lowest among the three groups). In terms of gender, 87% identified

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themselves as male and 11.6% as female. Regarding education level, 24% attained a high school diploma or less, whereas 31% held a bachelor's degree. Annual household income exceeded US$100,000 for 40% of respondents, and between US$50,000 and US$100,000 for 38%. The average landholding size among this group was approximately 162 hectares (400 acres), with an average ownership tenure of 37 years.

Frontline Responders: This group scored the highest across all measured variables among the three groups/clusters. Unlike the Unaware Bystanders group, members of this group had prior experience with wild pig damage, had observed signs of wild pig activity on both their own and neighboring properties, demonstrated a high level of familiarity with wild pigs, and had actively engaged in management or control efforts. Approximately 50.7% of landowners in this group were aged 65 years or older, which is lower than in the first group. About 24.4% were between 55 and 64 years, and 14.4% were between 45 and 54 years—proportions notably higher than those observed in the first group. In terms of gender, 91% identified themselves as male and 6% as female. Regarding educational attainment, 29.4% completed some college or held an associate's degree, 26.5% held a bachelor's degree, and 14.7% reported an advanced degree. Annual household income surpassed US$100,000 for 43.1% of respondents, while 40.4% reported an income between US$50,000 and US$100,000. The average landholding size for this group was approximately 499 hectares (1,233 acres), with an average ownership tenure of 38 years.

Cautious Observers: This group exhibited moderate scores across all measured parameters. Compared to the Frontline Responders group, these landowners had also observed signs of wild pig activity on both their own and neighboring properties, but to a lesser extent. They reported experiencing less damage, demonstrated lower levels of familiarity with wild pigs, and engaged in less management effort. Approximately 51.5% of landowners in this group were aged 65 years or older, 30.7% were between 55 and 64 years, and 8.9% were between 45 and 54 years. In terms of gender, 94% identified themselves as male and 5% as female, the lowest proportion of female respondents among the three clusters. Regarding educational attainment, 20.8% completed some college or held an associate's degree, 33.7% held a bachelor's degree, and 19.8% had an advanced degree. Annual household income exceeded US$100,000 for 48.5% of respondents—the highest proportion among all groups—while 39.2% reported income between US$50,000 and US$100,000. The average

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landholding size for this group was approximately 274 hectares (677 acres), with an average ownership tenure of 36 years.

3.2 Structural Equation Modeling Results

3.2.1 Whole-Sample Structural Equation Modeling

TPB was applied to modeling landowners' intentions to manage wild pigs using the Structural Equation Modeling (SEM) model fitted to all respondents' survey data. According to Schermelleh-Engel & Moosbrugger [45] and Tan et al. [46], the recommended thresholds and acceptable values for the SEM model fit indices are $\chi^2/df \leq 3.0$, RMSEA < 0.08, and SRMR < 0.08. The structural equation model exhibited good fit with $\chi^2/df = 1.55$, robust CFI = 0.985, TLI = 0.983, RMSEA = 0.043, and SRMR = 0.068. The measurement model also demonstrated adequate reliability and validity across five latent constructs. All results are summarized in Table 4.

Table 4. Results of the SEM for the whole sample of landowners .

Construct	Factor	Coefficient	p-value	Path	Coefficient & p-value
Beliefs	BF1	0.197	0.004	Attitudes ← Beliefs	0.776 ($p < 0.001$)
	BF2	0.332	0.001	Intentions ← Attitudes	1.430 ($p = 0.010$)
	BF3	0.462	<0.001	Intentions ← SN	0.452 ($p = 0.030$)
	BF4	0.480	<0.001	Intentions ← PBC	0.252 ($p = 0.127$)
Attitudes	AT1	0.302	<0.001		
	AT2	0.646	<0.001		
	AT3	0.252	<0.001		
	AT4	0.666	<0.001		
	AT5	0.261	<0.001		
PBC	PBC	1.074	<0.001		
SN	SN1	0.762	<0.001		
	SN2	0.432	<0.01		
Behavior Intention	BI1	0.157	0.004		
	BI2	0.212	0.003		
	BI3	0.270	0.001		

PBC denotes perceived behavioral control. SN represents social norms. All symbols are described in Table 3.

Perceptions and beliefs of wild pig risk and damage, including that wild pigs are a threat (BF1), damage the natural environment (BF2), harm the economy (BF3), and should be eliminated (BF4) were all positively and

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significantly (loadings between 0.197–0.480) associated with attitudes toward management actions ($\beta = 0.776$, $p < .001$). The construct between beliefs and attitudes (beliefs → attitudes) aligned with TPB. Regarding the hypothesized directional path of attitudes → intention, results indicated that attitudes significantly predicted behavioral intentions ($\beta = 1.430$, $p = 0.010$). Specifically, private landowners' favorability/acceptance toward specific control actions, including sharpshooting (AT1), legal toxicants (AT2), capture and kill (AT3), aerial control (AT4), and technical assistance (AT5), were found to be significantly and positively correlated with management intentions.

In terms of subjective norms (subjective norms → intention), we found a modest but significant effect on intentions ($\beta = 0.452$, $p = 0.030$). However, perceived behavioral control did not have a statistically significant effect on intentions ($\beta = 0.252$, $p = 0.127$). These results provide empirical support for key relationships posited by the Theory of Planned Behavior in the context of landowners' responses to wild pig management.

3.2.2 Three Clusters Respondents SEM

The overall model fit indices for the SEM model for each cluster are summarized in Table 5. The SEM model for all three clusters, including Unaware Bystanders, Frontline Responders, and Cautious Observers, demonstrated an acceptable fit, suggesting that the proposed paths and model can explain landowners' behavior in wild pig management.

Table 5. Estimation of the SEM model fit indexes for three clusters.

Cluster	χ^2 (df)	χ^2/df	CFI	TLI	RMSEA	SRMR
Unaware Bystanders	22.796 (31)	0.735	0.814	0.729	0.057	0.077
Frontline Responders	88.31 (73)	1.210	0.827	0.771	0.076	0.065
Cautious Observers	43.605 (72)	0.606	0.969	0.954	0.049	0.067

SEM coefficient estimates differed markedly among the three clusters of landowners (Table 6). The intended management of wild pig behavior of Unaware Bystanders was positively and significantly associated with attitudes ($\beta = 0.234$, $p < 0.01$) and beliefs ($\beta = 1.083$, $p < 0.001$), whereas subjective norms and PBC were not statistically significant. Likewise, for the cluster of Frontline Responders, similar significant and positive associations were found between intention and attitudes ($\beta = 0.269$, $p <$

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0.001) and beliefs ($\beta = 0.790$, $p < 0.001$). By contrast, among the cluster of Cautious Observers, attitudes ($\beta = 0.436$, $p < 0.01$) and perceived behavioral control ($\beta = 0.285$, $p < 0.05$) had significant direct effects on behavioral intentions, while subjective norms were non-significant.

Table 6. Results of the SEM model for three clusters of landowners

Path	Unaware Bystanders (β)	Frontline Responders (β)	Cautious Observers (β)
Attitudes → Intentions	0.234**	0.269***	0.436**
Subjective Norms → Intentions	0.115	0.114	0.104 *
PBC → Intentions	0.046	0.049	0.285*
Beliefs → Attitudes	1.083***	0.790***	0.116

* Significant at $p < .05$ = *, $p < .01$ = **, $p < .001$ = ***.

4. Discussion

Understanding and identifying private landowners' behavioral intentions in wild pig management could provide guidance and a foundation for policymakers, state forestry agencies, and Extension/outreach programs to develop and implement communication strategies and interventions that are more effectively tailored to motivate behavioral change at the state and multi-state levels. In this study, we integrated cluster analysis with structural equation modeling based on TPB to identify the belief structures influencing behavioral intentions among the full sample of survey respondents and within distinct groups or clusters in Arkansas, Louisiana, and East Texas. The combined approach enables a more nuanced understanding of how behavioral motivations vary across segments of the respondents, thereby informing the development of more targeted and effective outreach strategies in the study region.

The findings indicate that TPB provides a suitable theoretical framework for identifying latent, subjective factors influencing private landowners' intentions to manage wild pigs. Across all clustering partitions, the structural equation models based on the TPB framework demonstrated good and acceptable model fit to the survey data. These results align with prior research employing TPB to examine the determinants of family landowners' behavioral intentions [39,47,43]. Although our analysis does not evaluate the relationship between intentions and actual behavior, behavioral intentions nonetheless offer valuable insight for informing educational and outreach strategies.

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Beliefs and attitudes emerged as the most influential predictors of intended behavior across the full sample, followed by subjective norms. This finding is consistent with prior research examining family forest landowners' engagement with energy and carbon markets, where attitudes were also found to be the most significant factor [47,48]. In addition, Holt et al. [49] found that subjective norms have an important impact on landowners' intentions to harvest trees threatened by invasive insects. The importance of normative influences on shaping behavioral intentions suggests that policymakers should consider the use of social "nudges" as a strategic intervention tool [50]. Such nudges have demonstrated effectiveness in promoting pro-environmental behaviors in other contexts, including increasing farmers' intentions to remain engaged in agri-environmental programs [51]. Social nudges may be implemented through peer-to-peer interactions among landowners, especially landowners within the same community, such as a similar religious community, forest landowners' community, forest/agriculture association, etc. Peer-to-peer approaches not only leverage the power of social norms but also address common barriers associated with centralized outreach efforts, such as low responsiveness to electronic communication [52].

In contrast, perceived behavioral control was not a statistically significant predictor of behavioral intention in our study. The lack of influence of perceived control was not a surprise, and there was precedent in the literature [43]. In this study, individual survey items of landowners' confidence in managing wild pigs capture aspects of PBC did significantly load onto the control factor, suggesting that while the construction was measured reliably, it did not translate into predictive power for intentions. Notably, PBC is the most recent addition to the TPB, which evolved from the earlier two-factor Theory of Reasoned Action [53].

When TPB constructs were analyzed separately for the three groups or clusters, variations emerged. Groups of Unaware Bystanders and Frontline Responders were influenced by their beliefs and attitudes; neither subjective norms nor perceived behavioral control had a statistically significant effect on these individuals. The landowners in the group of Unaware Bystanders tend to have rare experience and knowledge with wild pigs, including low recognition and damage, minimal engagement, and the smallest land size (average of 162 hectares) compared to other clusters. Outreach targeting low-awareness and low-experience landowners should emphasize education and strategies for increasing their knowledge of wild pigs. For example, mass communication tools (i.e., social media, radio public service announcements, and local newspapers) can introduce the concept of wild pig threats in accessible, non-technical language. Increasing

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education opportunities, such as brochures and factsheets, and newsletters, can help expose landowners to key concepts without requiring immediate action or prior interest. Meanwhile, providing opportunities to increase peer-landowner communication is another strategy, such as through workshops or Extension meetings.

On the contrary, the landowners in the Frontline Responders group were those who had much wild pig experience in terms of damage, high familiarity and knowledge, and had actively engaged in management or control efforts, as well as with the largest acreage land size among the three groups (average of 499 hectares). The findings were consistent with the Elaboration Likelihood Model, which posits that individuals with greater topic involvement are more likely to engage in central, rational processing of information [54,55]. Accordingly, outreach targeting experienced private landowners should emphasize evidence-based information on the efficacy of wild pig management techniques through different actions, such as trapping, and leverage their existing knowledge. Moreover, these individuals may serve as trusted peer messengers for less experienced landowners, such as Unaware Bystanders.

In contrast, the group of Cautious Observers is those who reported moderate experience and familiarity with wild pigs and with mid-sized properties (averaged at 274 hectares), were primarily influenced by attitudes and subjective norms. This finding aligns with Karppinen and Berghäll [39], who reported a significant impact of social norms for relatively small forestland owners. This group of landowners remains hesitant to take action on wild pig management, and the possible reasons might be uncertainty with management effectiveness and limited confidence, and a lack of motivation to commit to proactive behavior. For those landowners, social network–based interventions may be especially effective. Peer-to-peer communication, public recognition, and visible outcomes from early adopters could foster a culture of compliance and encourage behavior through mechanisms such as social praise [52]. Financial or technical incentives should be structured to reward initial engagement (e.g., attending a site assessment or enrolling in a program), not just full-scale intervention. This can help bridge the gap between intention and behavior.

A key limitation of this study is the use of a single indicator to represent PBC constructs in the structural equation model, which is due to the data constraints in the survey. Latent variables are ideally measured using multiple indicators to capture the full conceptual breadth of the construct and to allow for the estimation of measurement errors [56,57]. By using only one item for PBC, the model treats these constructions as perfectly measured, potentially underestimating error variance and inflating the

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precision of path estimates. However, this study demonstrated acceptable model fit and structural paths within SEM despite using a single-item PBC, which is justifiable and acceptable as shown in previous research [58,59,60]. Future research should consider employing multi-item scales for each TPB construct to improve measurement reliability and allow for more nuanced analyses of how different facets of PBC influence behavioral intentions.

The findings in this study suggest that policymakers aiming to influence private landowners' behavior in response to feral wine management may benefit from segmenting their target audience based on ownership characteristics and tailoring interventions accordingly. By aligning outreach strategies with specific landowner profiles, it is possible to foster better-coordinated, landscape-scale management through the aggregation of individual, autonomous decisions. Implementing such a strategy, however, requires a robust understanding of ownership patterns, and future research could enhance its utility by generalizing landowner typologies to broader geographic units. Importantly, our results indicate that beliefs, attitudes, and subjective norms are significant influential factors on landowners' intended behavior, highlighting the importance of leveraging social dynamics in the design of large-scale (multi-state) interventions and outreach strategies.

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5. Methods

5.1 Sample and Data Collection

To assess private landowners’ experiences and perspectives regarding wild pigs, we conducted a mail-based survey targeting landowners who owned at least 12 hectares (30 acres) of land in Arkansas, Louisiana, and East Texas, which constitute the majority of the Western Gulf Coastal Plain within the West Gulf Region. A stratified random sample of private landowners was drawn from the statewide populations of the three states, using name and address data obtained from Dynata Inc. The survey instrument was developed after a thorough literature review of previously conducted surveys in other states [22, 18,23], and the inclusion of questions tailored to the specific context and management priorities in the study region. Additional inputs and pretests of the survey were from professionals of the University of Arkansas System Division of Agriculture, Cooperative Extension Service, and the Arkansas Game and Fish Commission. Following the Dillman Tailored Design Method [61], the survey instruments were reviewed and approved by the University of Arkansas at Monticello’s

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Institutional Review Board (IRB# FNRf-01). The survey materials were distributed in 2021 and included a cover letter ensuring confidentiality and voluntary participation, a 10-page questionnaire, an electronic consent form, and a prepaid return envelope. All participants reviewed and signed the informed consent form before completing the questionnaire. Two weeks after the initial mailing, a follow-up postcard was sent to all selected recipients to encourage participation. A total of 4,500 survey packets were mailed: 2,000 to landowners in Arkansas, 1,500 in Louisiana, and 1,000 in East Texas.

The questionnaire consists of questions in five sections: (1) landowners' experiences and familiarity with wild pigs, (2) attitudes toward wild pigs, (3) management efforts and activities, (4) perspectives of wild pigs on neighboring properties, and (5) demographic information (age, gender, education, and household income). Questions associated with private landowners' perceptions and attitudes toward management actions of wild pigs used a five-point Likert scale (i.e., 1= strongly disagree, 5 = strongly agree). For all variables, a higher value indicated a higher awareness or engagement with wild pig issues. Subjective norms were examined using statements like "my neighbors are willing to help each other on wild pig management." The intention was explored by "I am willing to cooperate with my neighbors to control feral hogs together." Regarding the confidence in managing wild pigs, we included a question asking about private landowners' level of confidence in their ability to manage/control wild pigs on their property. The survey instrument was provided in the Supplementary File S1. Survey instrument.

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5.2 Analytical Methods

5.2.1 Cluster Analysis

Market segmentation is a commonly applied strategy in the field of marketing, and the purpose is to segment a heterogeneous population (i.e., private landowners) into homogeneous groups according to their shared characteristics [62]. The primary objective of this approach is to identify distinct segments of individuals using a range of demographic and behavioral variables, thereby enabling more targeted and effective outreach strategies and policy formulation. Cluster analysis, including Hierarchical Cluster Analysis (HCA) and k-means cluster analysis, is a commonly applied method in market segmentation [63,64,65,66]. The clusters, in principle, can capture the structure of data, indicating that the objects within the same segment/group share similar characteristics while those in different

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segments/groups have different characteristics. For example, k-means cluster analysis is to partition observations into distinct groups such that intra-cluster variability is minimized while inter-cluster variability is maximized [67] (Equation 1).

$$C(k) = \sum_{k=1}^{k} \sum_{i=1}^{c_k} (||x_k - u_i||)^2 \quad (1)$$

where $(||x_k - u_i||)^2$ is the squared Euclidean distance between the observation x_i and the centroid of its assigned cluster, c_k is the number of data points in the k^{th} cluster, and c is the number of cluster centers.

A two-step cluster approach was employed in this study to segment private landowners based on their attitudes and behavioral tendencies toward wild pig management. Specifically, we used the Hierarchical Ward's minimum variance method to determine the optimal number of clusters and then employed k-means cluster analysis to determine each cluster's membership. The kmeans and hclust functions in R were used to conduct cluster analysis. Three clusters were identified and determined according to the cluster analysis (Table 2). The Analysis of Variance (ANOVA) was followed to test the distinction among the subclusters in terms of demographics and owner characteristics of tenure and acreage size (Table 3).

5.2.2 Structural Equation Modeling

Structural Equation Modeling (SEM) is an extremely common and highly appropriate statistical technique for testing the TPB [68] and is a statistical technique that allows for the simultaneous estimation of multiple interrelated dependence relationships among observed and latent variables [68]. The advantage of the SEM method is its ability to account for measurement error by explicitly estimating error variance parameters while simultaneously incorporating both latent constructs and observed variables within the model framework. The exogenous (Equation 2) and endogenous (Equation 3) measurement models are presented below:

$$X = \Lambda_x \xi + \delta \quad (2)$$

$$Y = \Lambda_y \eta + \epsilon \quad (3)$$

where X represents the vector of observed exogenous indicators and Y is the vector of observed endogenous indicators; ξ and η denote the vector of latent exogenous and endogenous variables, respectively; Λ_x and Λ_y are the factor loading matrices for exogenous and endogenous variables, respectively; δ and ϵ are the measurement errors associated with X and Y, respectively.

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The SEM model is displayed as:

$$\eta = B\eta + \Gamma\xi + \zeta \quad (4)$$

where B is the matrix of coefficients for relationships among endogenous variables and Γ denotes the matrix of coefficients for relationships from exogenous to endogenous variables; ζ represents the vector of structural disturbances (errors in equations); η and ξ have the same meaning as in Equations (2) and (3).

Compared to other econometric models (i.e., logistic regression), another advantage of the SEM model is its ability to simultaneously handle multiple dependent variables [62], making it more suitable for this study. Multiple observed indicators for beliefs, attitudes, subjective norms, perceived behavioral control (PBC), and intentions were used for private landowners when constructing the measurement model. A structural model was estimated to examine hypothesized directional paths of beliefs → attitudes → intention, subjective norms → intention, and PBC → intention. Detailed descriptions of variables included in the SEM model are summarized in Table 1. The SEM model was estimated using the Maximum Likelihood (ML) estimator with the lavaan package in R.

Table 1. Summary of variables included in the SEM model.

Construct	Statements included in the survey
Beliefs	-I agree that wild pigs are a nuisance and a threat (BF1). -I agree that wild pigs harm the natural environment (BF2). -I agree that crops and livestock damage caused by wild pigs will harm the economy (BF3). - I agree that wild pigs should be eliminated wherever possible (BF4).
Attitudes toward management methods	- I support targeted sharpshooting on the ground over bait sites (AT1). - I support the use of legal toxicants (e.g., warfarin, sodium nitrite) (AT2). - I support capture and kill (AT3). - I support aerial control using helicopters (AT4). - I support providing technical assistance for landowners/farmers to control wild pigs (AT5).
Perceived behavioral control	- I feel confident implementing control methods myself (PBC).
Subjective norms	- My neighbors are willing to help each other with wild pig management (SN1). - My neighbors trust each other (SN2).

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Behavioral intentions	- I am willing to cooperate with my neighbors to manage/control wild pigs together (BI1). - I feel obligated and am willing to manage wild pigs on my property (BI2). - I am willing to learn more about how to manage/control wild pigs (BI3).

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