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Forest carbon incentive programs for non-industrial private forests in Oregon (USA): Impacts of program design on willingness to enroll and landscape-scale program outcomes

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ABSTRACT

Privately-owned forests in the Pacific Northwest (PNW) are important potential carbon sinks and play a large role in carbon sequestration and storage. Non-industrial private forest (NIPF) owners constitute a substantial portion of overall forest landownership in productive regions of the PNW; however, little is known about their preferences for non-market incentive programs aimed at increased carbon storage and sequestration, specifically by limiting timber harvest, and how those preferences might impact the outcome of forest carbon programs. We simulated landscape-scale outcomes of hypothetical forest carbon incentive programs in western Oregon (USA) by combining empirical models of NIPF owners' participation with spatially explicit forest carbon storage and sequestration data. We surveyed landowners to determine their willingness to enroll in various hypothetical forest management incentive programs that varied in terms of harvest restrictions, contract length, annual payment and incentive payment amounts, and cost-share percentages, as well as the program framing (e.g., carbon versus forest health). We used multinomial logistic regression to model whether landowners might enroll based on program attributes, landowners' attitudes toward climate change and forest management, past and planned future forest harvest activities, and socio-demographics. We found that 36% of respondents stated that they would probably or definitely enroll in at least one of the hypothetical programs they were shown while 21% of respondents refused all programs that they were offered. Our final model of landowner willingness to enroll indicated that higher annual and higher cost-share payments were the strongest positive predictors of whether landowners would enroll vs. not enroll. Landowners' willingness to enroll was not influenced by program framing as either a “forest carbon” or a “forest health”; however, landowner attitudes toward climate change were the next strongest positive predictor of enrollment after annual and cost-share payments. By simulating landowner enrollment in six policy relevant program scenarios, we illustrate that carefully designed forest carbon incentive programs for NIPF owners could have tangible carbon protection benefits (16.25 to 50.31 MMT CO2e cumulative) at relatively low costs per MT CO2e ($3.60 to $7.70). We highlight tradeoffs between maximizing enrollment in forest carbon incentive programs and providing longer term protection of carbon. This research contributes to the literature on the design of potential forest carbon incentive programs and communication about forest carbon management, as well as aims to aid policy makers and program administrators that seek ways to engage private landowners in carbon-oriented forest management.

1. Introduction

Natural climate solutions, i.e., conservation, restoration, and improved management of ecosystems that increases carbon sequestration and storage in the biosphere, are one way to achieve a portion of the emissions reductions needed if we are to meet global targets limiting global average temperature rise to 2 °C or less (Griscom et al., 2017). In global, national, and regional studies, forest-based carbon sequestration consistently ranks among the most effective natural climate solutions (Cameron et al., 2017; Fargione et al., 2018; Graves et al., 2020; Griscom

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et al., 2017; IPCC, 2018; Le Quéré et al., 2009). To realize the potential benefit from additional carbon storage and sequestration in forests, forest carbon management activities need to be implemented soon (Griscom et al., 2017) and will require participation and support from landowners of forests where carbon can be sequestered and stored. In the United States, non-industrial private forests (NIPF) comprise 39% of all forestland in the United States (Butler et al., 2021) and forest management decisions by NIPF owners (e.g., whether and when to harvest trees, whether to convert forests to an alternate land uses) have important consequences for terrestrial carbon sinks (Christensen et al., 2019).

A wide range of policy instruments could incentivize carbon sequestration and storage in NIPF. Policies aimed at affecting forest management among NIPF owners are generally classified as educational, technical assistance, financial, and regulatory (Kilgore et al., 2007; Schneider and Ingram, 1990) and current strategies, proposed and in practice, include carbon taxes (Li et al., 2021; van Kooten et al., 1995), carbon subsidies (Kim et al., 2008; Mason and Plantinga, 2013), combined tax-subsidy programs (van Kooten et al., 1995), carbon rental systems (Sohngen and Mendelsohn, 2003), as well as direct incentive programs and carbon offset markets (Charnley et al., 2010). Voluntary incentive programs that provide compensation to NIPF owners either based on adoption of practices aimed at forest carbon management (e.g., payment for practice) or based on the amount of carbon sequestered (e.g., payment for performance) may prove to be a valuable and effective tool in NIPF (Charnley et al., 2010; Langpap and Kim, 2010). These are differentiated from potential market-based instruments which encourage carbon sequestration through the sale of offset credits (Charnley et al., 2010; Markowski-Lindsay et al., 2011; Thompson and Hansen, 2012; van Kooten, 2018). Practice-based incentive programs may provide a policy option that balances risk and return on investment while reducing the monitoring burden on program administrators and NIPF owners (Wise et al., 2019). Despite the potential for practice-based incentive programs to appeal to a broad range of NIPF owners, most studies have focused on carbon offset programs and there has been minimal work assessing NIPF willingness to participate in carbon-oriented forest management under direct practice-based incentive programs. The practice-based incentive programs presented in this study include common components of technical assistance program (e.g., management plans, cost-share) as well as financial incentives (e.g., payments based on enrollment) targeted to shift NIPF owner behavior toward maintaining existing in-forest carbon stores and increasing forest carbon sequestration.

In this study, we assess NIPF owners' willingness to participate in hypothetical practice-based incentive programs in the Pacific Northwest region of the United States. Wet forests of the coastal Pacific Northwest are some of the most naturally carbon-rich forests in the world but, primarily due to current and legacy impacts of forest harvesting, current carbon storage volumes are much less than their ecological potential (Smithwick et al., 2002). Older forests store significantly more carbon than younger forests (Janisch and Harmon, 2002; Smith et al., 2006) and deferring timber harvest or lengthening timber harvest rotations to encourage the development of older forests has been highlighted as a potential forest management practice that could result in substantial carbon benefits (Stephenson et al., 2014). Deferred timber harvest can be achieved through multiple mechanisms ranging from lengthening harvest cycles or changing harvest strategies to partial harvest and increased retention of both living and dead biomass (Diaz et al., 2018; Diaz et al., 2009; Harmon et al., 2009; Janisch and Harmon, 2002). In addition to reducing the near-term carbon emissions, deferring timber harvest can result in long-term increases to in-forest carbon stocks and more diverse forest structure (Christensen et al., 2019; Gray et al., 2016; Harmon et al., 2009; Law et al., 2018; Luyssaert et al., 2008; Oliver et al., 2014; Stephenson et al., 2014) while simultaneously enhancing wildlife habitat, improving soil and water quality, and conserving biodiversity (Franklin et al., 2018; Frey et al., 2016; Segura et al., 2020). Below, we briefly review studies of NIPF owner willingness to participate in carbon markets alongside literature related to NIPF owner engagement with incentives programs. This review serves to motivate the selection of program attributes evaluated in our study as well as inform our hypotheses related to NIPF owner willingness to enroll in hypothetical practice-based incentive programs aimed at timber harvest deferral in the Pacific Northwest.

Estimates of NIPF owner participation rates in carbon offset markets vary widely and depend on several variables related both to carbon offset program design and NIPF owner characteristics. Generally, NIPF owners are deterred from participating in carbon markets due to limited or uncertain revenues from carbon, early withdrawal penalties, and long contract lengths as well as stringent management plan requirements and high costs and resources associated with project implementation and accounting (Charnley et al., 2010; Dickinson et al., 2012; Fletcher et al., 2009; Khanal et al., 2019; Khanal et al., 2017; Markowski-Lindsay et al., 2011; Miller et al., 2012; Wise et al., 2019). Financial revenue from carbon markets can be complicated for NIPF owners to predict, as it can range widely depending on current carbon stocking, property characteristics, as well as variable carbon prices and fluctuating demand for carbon offsets, all of which deters NIPF owners due to decreased financial viability and increased price risk (Kerchner and Keeton, 2015). NIPF owners have reported limited familiarity with carbon offset markets which may lead to lower willingness to enroll (Fletcher et al., 2009; Galik et al., 2013; Kilgore et al., 2007; Markowski-Lindsay et al., 2011). However, this relationship was not true among NIPF owners in the Lake States (USA) where modeled participation in carbon offset programs was high (40–60%) despite most people being unfamiliar with carbon markets (Miller et al., 2012) nor among NIPF owners in California, where approximately 60% had knowledge of the carbon markets but only 20% said that they were likely to enroll in carbon markets (Kelly et al., 2015). Dickinson et al. (2010, 2012) found that only 5% of NIPF owners gave high ratings to various carbon market scenarios due to low expected revenues, extensive time commitments, early withdrawal penalties, and antipathy toward required management plants. Similarly, Markowski-Lindsay et al. (2011) found very low participation rates (less than 10%) in carbon offset market scenarios that closely resembled current market options (e.g., the California Climate Action Reserve and Voluntary Carbon Standard) and found that NIPF owners preferred greater net revenue, no withdrawal penalty, and shorter contracts with no additionality requirement.

In studies of carbon market feasibility and NIPF owners, carbon market program attributes like revenue and contract length are consistently found to be strong predictors of NIPF owner willingness to participate (Kelly et al., 2015; Khanal et al., 2017; Soto et al., 2016; White et al., 2018). However, NIPF owner attitudes toward climate change, non-timber management objectives, risk tolerance, and financial motivations are often important modulating factors (Kelly et al., 2015; Miller et al., 2012; White et al., 2018). NIPF owners who are concerned about climate change place less importance on revenue and withdrawal penalties in carbon offset markets than those not concerned about climate change (White et al., 2018) and may require lower payments to participate (Miller et al., 2012). NIPF owners who express skepticism about climate change are less likely to enroll in carbon markets (Kelly et al., 2015), whereas those that believe forests/trees are "good for climate change" may be more likely to participate in carbon market programs (Markowski-Lindsay et al., 2011). Many NIPF owners do not have timber production as a primary goal and may have multiple land management objectives (Alig, 2003). NIPF owners with non-timber management goals may be more likely to participate in carbon market programs (, Kelly et al., 2015; Markowski-Lindsay et al., 2011; Miller et al., 2012) perhaps because many of the strategies that lead to increased carbon sequestration might also enhance non-timber benefits from their forests or because they do not perceive a direct tradeoff between income generation from timber harvest and carbon sequestration.

Similar to participation in carbon markets, participation by NIPF owners in practice-based incentive programs is negatively influenced by contract lengths and positively influenced by cost share and initial upfront payment amounts (Mitani and Lindhjem, 2021). As compensation increases in incentive programs, participation among NIPF owners also increases and one-time up-front payments may be more effective for increasing participation than annual payments (Mitani and Lindhjem, 2021). NIPF owner participation in practice-based incentive programs is positively related to non-timber management goals and these owners might be willing to participate at lower incentive payment rates. In a study focused on western Oregon and Washington, NIPF owners motivated by objectives other than timber production could be enlisted into incentive programs aimed at delaying timber harvest for 10 years in the interest of improving riparian habitat at a lower cost than NIPF owners with mainly timber objectives (Kline et al., 2000). Similarly, Khanal et al. (2017), while highlighting that carbon sequestration incentive programs should aim to be at least revenue-neutral, found that NIPF owners with recreational management goals and other non-timber management goals would be likely to participate at lower revenue levels. Incentive programs that highlight technical and management planning assistance, cost sharing, and direct contact with a forester consistently have been found to positively influence participation by NIPF owners (Daniels et al., 2010; Langpap and Kim, 2010). Similarly, lack of awareness of incentives and lack of understanding of how a particular incentive program would apply to them and their land management can drive lower participation among NIPF owners (Langpap and Kim, 2010).

Understanding the factors that influence participation decisions by NIPF owners is a critical to designing successful and well-received incentive programs (Langpap, 2006). Furthermore, program design can, by influencing participation rate, influence the eventual outcome and performance of forest carbon incentive programs at landscape scales (Amacher et al., 2003). For example, programs that include longer contracts may negatively influence participation rates which may lead to reduced program outcomes across the region as compared to a shorter contract with higher participation rates (Shah and Ando, 2016). Outcomes of incentive programs aimed at modifying forest management practices can be evaluated at landscape scales using landscape simulation models (Conway and Lathrop, 2005; Lewis and Plantinga, 2007). Landscape simulations draw inspiration from landscape ecology (Gardner et al., 1987; Peterson et al., 2003) and have been used extensively to assess a range of consequences from land-use policy and corresponding land-use change (Diebel et al., 2008; Gibon et al., 2010; Janssen et al., 2005; Wallin et al., 1994). In the simplest form, landscape simulation models allocate an expected proportion of landscape change (i.e., land use/land cover transitions) based on some set of rules (Borah et al., 2018; Castellazzi et al., 2010; Gibon et al., 2010; Van Dessel et al., 2008). Landscape simulation models have been used to evaluate the potential outcomes of incentive programs aimed at private landowner conservation behaviors (Bell et al., 2019; Pattanayak et al., 2004; Smith et al., 2016; Spies et al., 2007) as well as to evaluate potential land use and forest management response to carbon offset markets and market conditions (Borah et al., 2018; Cho et al., 2018; Latta et al., 2016). However, to our knowledge, the use of landscape simulations to assess the outcome of forest carbon incentive programs remains rare in the forest policy and climate policy literature (but see Cho et al., 2019).

We examine differences among NIPF owner willingness to participate in incentive programs aimed at increasing carbon storage and sequestration based on program attributes and variables related to NIPF owners that are consistently found important in the literature. We hypothesized that NIPF owners' willingness to enroll in incentive programs would be positively related to incentive payments and cost share and negatively related to contract length and more restrictions on timber harvest. We also hypothesized that willingness to enroll would be higher if programs were framed as "forest health" initiatives as opposed to "forest carbon" initiatives. We expected willingness to enroll to be negatively related to future harvest plans, current forest productivity, and the importance that NIPF owners placed on investment-related goals, but positively related to NIPF owners' concern about climate change and the importance they placed on amenity-related goals. Given published research on NIPF owners, we expected that owners with larger acreages would be likely to have different harvest and management practices than owners with smaller acreages (Butler et al., 2016; Langpap and Kim, 2010) and that NIPF ownership size would affect willingness to participate. We further expected that willingness to enroll would be influenced by NIPF owners' age (−), education (+), and income (+). We conducted a survey using best-worst choice (BWC) to characterize the influence of program attributes and NIPF owner variables on NIPF owners' willingness to enroll in hypothetical forest carbon incentive programs. BWC is a hybrid method which allows for estimating NIPF owner willingness to enroll in a program as a whole but also to assess NIPF owner preference for specific incentive program attributes.

We combined modeled willingness to enroll from survey data with landscape simulations and spatially explicit data on forest carbon to evaluate the outcomes of hypothetical practice-based incentive programs. By extending our study from willingness to participate at the program level to landscape-scale carbon storage and sequestration benefits, we provide policy makers with the ability to compare projected participation rates under different programs with program costs, potential carbon benefit, and compare the relative cost ($ per MT CO_2e) of these incentive program scenarios.

2. Methods

2.1. Study area

Our study area encompassed 16.3 million acres of forestland in western Oregon (Fig. 1), of which NIPF comprise 18%. We focus on NIPF owners with between 50 and 5000 acres of forest (20.2–2023.4 ha), who collectively own 60% of the NIPF in our study area. The study area comprises four major ecoregions (i.e., Coast Range, Western Cascades, Willamette Valley, and Klamath Mountains) which are characterized by a marine-influenced climate with high rainfall (Thorson et al., 2003). There is substantial variation in forest productivity (Mg C ha^{-1} yr^{-1}; Latta et al., 2009) on NIPF land within and among ecoregions in the study area (Fig. 2) and the four ecoregions vary in terms of dominant forest types, historical fire regimes, and current land use. The forests in the Coast Range are predominantly highly productive coniferous forests historically characterized by historically infrequent, high severity fire regimes (Rollins and Frame, 2006) (Table A.1). Similarly, forests of the Western Cascades are almost entirely coniferous with dominant species varying by elevation and site history, and the majority (70%) historically characterized by infrequent, mixed to high severity fire regimes and the remainder characterized by historically frequent, low to mixed severity fire regimes (Table A.1). The Willamette Valley, characterized by mild, wet winters and warm, dry summer, is dominated by agricultural land use. The forests of the Willamette Valley are varied; remnant oak woodland and savannahs are common forest types throughout the valley while coniferous forests dominate the foothills of the Coast Range on the west and the Western Cascades to the east. The variation in forest types is reflected in the historical fire regime, with most of the Willamette Valley forests characterized by frequent, low severity fires and the remainder characterized by infrequent, mixed to high severity fires (Table A.1). The Klamath Mountains ecoregion contains steep climatic and biophysical gradients and the forests vary from highly productive, mesic conifer forests in the western portion of the ecoregion to less productive, drier conifer forests in the interior and eastern portion of the ecoregion. The forests of the Klamath Mountains are predominantly characterized by very frequent to frequent, low to mixed severity fire regimes (Table A.1). Given the differences in productivity, land use, and historical fire regimes, we expected there to be differences in NIPF management and owner responses among ecoregions and stratified our

Fig. 1. Study area includes 16.3 million acres of forestland in western Oregon, shown here overlaid with ecoregion boundaries.

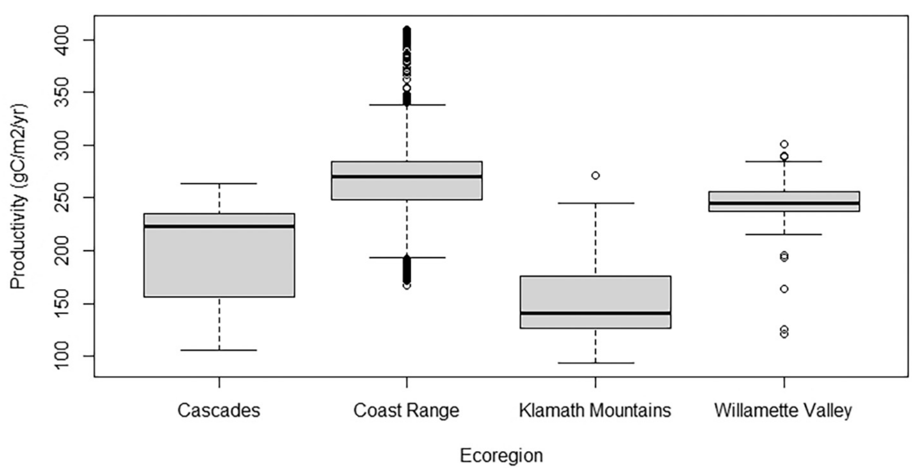

Fig. 2. Forest productivity (Latta et al., 2009) on non-industrial private forest ownerships varies across ownerships and ecoregions in western Oregon.

sampling design accordingly.

2.2. Survey design and data collection

We constructed the survey sample frame based on property parcel maps and information provided by state and municipal agencies. We focused on individuals who own between 50 and 5000 acres of forest land, as determined by intersecting parcel data with 2000–2017 forest cover data (Hansen et al., 2013). The 50-acre cutoff excluded NIPF owners whose forest land holdings were unlikely to be considered for timber harvest and where the economies of scale make forest management activities less likely (Alhassan et al., 2019; Charnley et al., 2010; Dickinson et al., 2012). Because we expected differences in response across ownership size and ecoregion, we stratified our sample by ownership size (50–500 acres, 50–5000 acres) and ecoregion (Table A.2) and used stratified random sampling to select 1500 NIPF owners from the initial list of over 10,500.

We used a mail-survey questionnaire to collect information from NIPF owners about their forest land, forest management history and goals, attitudes toward climate change and forest management, as well as information about themselves (i.e. socio-demography). The bulk of the questionnaire elicited NIPF owners' preferences for incentive programs through a BWC task, described in more detail below. We pretested the final survey instrument using cognitive interviews and informal review ($n = 10$). We deployed the mailing starting in July 2020 using a modified Dillman tailored design method (Dillman et al., 2014). Respondents had the option to complete the survey and mail it back to us, or to complete the survey online using a web address and passcode included in the mailing.

We used best-worst choice (BWC) to assess NIPF owner preferences for incentive program attributes. BWC is a hybrid method grounded in utility theory that combines best-worst scaling (BWS) (e.g., Finn and Louviere, 1992; Soto et al., 2016) and full-profile conjoint (Louviere et al., 2015; Luyssaert et al., 2008). BWC has recently been applied to understanding NIPF owner preferences for carbon market programs (see Soto et al., 2016; White et al., 2018) and allows researchers to compare the NIPF owners' preferences across all program attributes and attribute levels, estimated as their relative utility, as well as estimate the impact of program attribute levels on the eventual outcome measure, i.e., 'accepting' or 'rejecting' an incentive program. In our survey, programs were presented as best-worst choice profiles where respondents first chose a 'best' and 'worst' attribute from the listed program features (i.e., BWS task) and then stated whether they would enroll in the program if it were available to them using a 5-point scale (definitely yes, probably yes, unsure/maybe, probably not, definitely not) (i.e., full-profile conjoint, Louviere et al., 2008, 2015).

Our study aimed to assess NIPF owner willingness to enroll in practice-based incentive programs aimed at deferring timber harvest on a portion of their forestland over the program period and thus maintain forest carbon storage and continued sequestration on their forestland. We designed hypothetical forest carbon incentive programs by varying five key attributes: the initial signing payment, the fixed annual payment per acre enrolled, the cost share for forest management plan preparation, the contract length, and the stringency of harvest limitations (i.e., change in management required by the program) (Table 1). We developed our list of program attributes and levels of each attributes through a literature review of NIPF owner willingness to participate in forest carbon management in other regions, including both in carbon markets and incentive program, and practice-based incentive programs. We also reviewed several current and proposed forest carbon and incentive programs for NIPF owners (e.g., the Family Forest Carbon Program, a partnership between The Nature Conservancy and the American Forest Foundation and the USDA Conservation Reserve Enhancement Program (CREP)) to inform our program attributes.

Given the number of variables in Table 1, there were 243 possible hypothetical incentive programs that include each attribute once with one specific level of the attribute. We used an orthogonal main effects plan (OMEP; Street et al., 2005) to keep the survey reasonable length. We created 18 hypothetical program profiles by varying the five program attributes, each with three levels, and including a blocking variable to create three survey versions with six profiles in each. Each respondent was randomly assigned to a survey block and, in addition, each person was randomly assigned to receive programs framed as "Forest Carbon" or "Forest Health" (Fig. A.1). All programs required that NIPF owners have a forest management plan written by a professional forester, sign a contract, and have a forester verify compliance regularly through the program length. All programs included an early withdrawal penalty equal to any incentive payments received and NIPF owners could choose to enroll only a portion of their forested land in the program. Fig. 3 shows an example of a full program profile. For each hypothetical incentive program, respondents were asked to choose the best feature and worst feature and, considering the program as whole, whether they would be willing to enroll in it or not and how many acres they would be likely to enroll.

2.3. Data analysis

We extracted socio-demographic data from survey responses including age, education, gender, income, and political tendency. To characterize respondents' timber harvest plans, we extracted both their response to whether they had harvested timber for sale in the past 10 years (yes/no) and whether they had current plans to harvest timber for personal use or for sale in the next 10 years (yes/no). Forest ownership characteristics included the acres of forest land owned as reported by the respondent. In addition, we overlaid the parcel data with spatially explicit data on aboveground biomass (Hudak et al., 2020) and calculated the average carbon storage (CO_2e per ha) attributed to each respondents' forest ownership. NIPF owner management goals were measured using a five-point importance scale across 12 items adapted from the National Woodland Owners Survey (Table A.3). NIPF owner attitudes toward forest management and sociocultural values were measured using a five-point agreement scale across 8 items adapted

Table 1
Program attributes and attribute levels used to create hypothetical program profiles according to an orthogonal main effects plan (OMEP) which included a blocking variable.

Program attribute	Attribute description	Attribute level descriptions		
Initial Signing Payment	One-time amount earned upon enrollment	No signing incentive	$10 per acre	$20 per acre
Fixed Annual Payment	Amount earned for each year of enrollment in the program	$15 per acre per year	$25 per acre per year	$50 per acre per year
Cost share	Percent of costs covered related to forest management plan preparation and implementation	No cost share	Pays up to 50% of technical assistance for management plan preparation and costs of management activities	Pays up to 75% of technical assistance for management plan preparation and costs of management activities
Contract length	Time commitment of contract	10 years	20 years	30 years
Management	Change in management required by program	Thinning and partial harvest permitted, for personal or commercial purposes, but can not exceed the permitted harvest level. Harvest levels can not exceed the estimated 5-year growth volume for your forest and are specified by your management plan. All harvest, including deadwood removals, must be reported each year.	No commercial timber harvest; thinning and partial harvest allowed for limited personal use. Personal use harvests, including deadwood removals, must be reported and allowable volumes are specified by your management plan.	No timber harvest for duration of contract. Any deadwood removal must be reported.
Block	Blocks were included in the orthogonal main effects design to allow create a design with 6 profiles per survey and still maintain OMEP.	Survey Block A	Survey Block B	Survey Block C

Program Attribute	Program Details	Best feature (Check one)	Worst feature (Check one)
One-time amount earned upon enrollment	**$20/acre**	☐	☐
Amount earned for each year of enrollment in the program	**$15/acre each year**	☐	☐
Percent of costs covered related to forest management plan preparation and implementation	**75% cost share**	☐	☐
Time commitment of contract	**20 years**	☐	☐
Change in management required by program	**No commercial timber harvest. Thinning and partial harvest allowed for limited personal use.** Personal use harvests, including deadwood removals, must be reported and allowable volumes are specified by your management plan.	☐	☐

Would you enroll in this program if it were available to you?

Definitely yes | Probably yes | Unsure/Maybe | Probably not | Definitely not

How many acres would you consider enrolling in this program?

Fig. 3. Example of a BWC program profile included in the survey. Each respondent was asked to evaluate six program profiles.

from Schaaf et al. (2006) and Larson (2010)(Table A.4). Finally, NIPF owner attitudes toward climate change were measured using a five-point agreement scale across 4 items adapted from Markowski-Lindsay et al. (2011) (Table A.5). We used principal components analysis (PCA) to collapse these multidimensional data into composite indices describing NIPF owner management goals, NIPF owner attitudes toward land management, and NIPF owner attitudes toward climate change. Reliability of all indices was tested using Cronbach's alpha and we checked for correlation among indices. If indices were highly correlated, we retained the index with a higher Cronbach's alpha for further analysis. For retained indices, we calculated respondents' index score as their mean response across the items included in each index.

We conducted a series of analyses to (1) use the BWC approach to assess NIPF owners' preferences for program attributes (BWS) and analyze the impact of program design and NIPF owner characteristics, forest management goals/plans, and attitudes on NIPF owner willingness to participate, (2) predict the proportional enrollment of NIPF owners across all possible programs, and (3) assess the landscape-scale carbon benefits and other outcomes related to a suite of policy-relevant program designs. All analyses were conducted using R version 4.0.2 (R Core Team, 2021).

2.3.1. *Program attribute preference and willingness to participate*

Each record in the survey data set corresponds to a respondent who provided answers to multiple survey questions, and, in some cases, item non-response led to missing responses to the BWC scenarios. For analysis of NIPF owner preference for program attributes and the factors that influence NIPF owner willingness to enroll in practice-based incentive programs for forest carbon, we used data from respondents who completed at least half (3 out of 6) of the BWC profiles they received. We tested for differences between respondents who completed at least half of the BWC profiles and partial respondents (i.e., those that did not complete the BWC task) using Kruskal-Wallis and Chi-square tests.

We used paired conditional logit models to analyze the BWS data from our survey respondents. This analysis uses the random utility framework (RUF) and allows us to assess how often one program attribute is preferred over another and to determine attribute and attribute level-scale impact values (Finn and Louviere, 1992; Flynn et al., 2007). Impact values represent the mean utility across all levels of an attribute, where the specific attribute level values represent the deviation from the mean utility (Flynn et al., 2007). We used effects coding wherein one attribute level, from each attribute, is not explicitly included in the model but embedded in the other levels of the attribute. Each omitted effects coded attribute level can be recovered as the negative sum of the other level-scale variables. In BWS analyses, the attribute with the lowest impact on utility is typically omitted to be used as the "reference case" (Flynn et al., 2007; Louviere et al., 2015). This reference case takes on a value of zero on the latent scale of utility. Models were fit using the conditional logit function (*clogit*) within the *survival* R package (Therneau, 2021).

We measured NIPF owners' intent to enroll in a hypothetical incentive program using a five-item Likert scale, which we transformed into 3 nominal categories: Not Enroll (definitely not, probably not), Might Enroll (maybe/unsure), and Would Enroll (probably yes, definitely yes). We used a mixed-effects multinomial logistic regression model to evaluate the factors that influence NIPF owners' willingness to enroll in a forest carbon incentive program. Mixed-effects multinomial logistic regression is a generalization of logistic regression that allows for more than binary responses while incorporating a random effects term (Agresti, 2002). In these models, suppose that a response with categories $j = 1 \ldots. q$ is observed for individual $i = 1\ldots n$. Multinomial logistic regression estimates p_{ij}, the probability that the response for an individual i is equal to j, relative to and the $j = 1$, i.e., the reference category (Elff, 2021). We set the reference category to "not enroll". Thus, our model provides insight into the factors that drive NIPF owners to consider or accept programs as opposed to rejecting them. Models were fit using maximum likelihood estimation using the baseline-category logit function (*mblogit)* within the *mclogit* R package (Elff, 2021). We specified a full model which included variables hypothesized to influence NIPF owner decisions including all program attributes, NIPF owner socio-demographic characteristics, past and planned future harvest activity, attitude indices, and forest ownership characteristics (Table 2). We included a random intercept for each participant to account for multiple observations from each individual. We used backward stepwise selection based on the Akaike information criterion (AIC) to reduce the full model (Burnham and Anderson, 2002). We evaluated model fit using McFadden's pseudo R^2 (McFadden, 1974) and posterior predictive checks and report the correct classification rate (CCR) and the Kappa statistic (Cohen, 1968). We report the coefficient estimates and standard errors from the final model. Because coefficients from the multinomial

Table 2
Characteristics of NIPF owners who responded to our mail survey (n = 307) and those who data were included on the BWC regression analysis (completed at least 3 out of 6 program scenario evaluations (n = 180). Values are summarized as the median (interquartile range) for numeric variables and % of respondents in each category for categorical or ordinal variables. Binary variables are displayed as the % within the non-reference category (1). Test statistics comparing characteristics those who completed the BWC task to those who did not (complete vs. partial respondents) are shown.

Variable group	Variable description		Survey respondents (n = 307)	Regression analysis (n = 180)	Partial vs. complete respondents
Respondent Socio-demographics	Age (years)		69 (61–76)	65 (58–73)	H = 27.02, p < 0.001
	Income (ordinal)	Less than $50,000	18.8%	14.2%	H = 3.80, *p* = 0.07
		$50,000 - $74,999	17.7%	16.3%	
		$75,000 - $99,999	19.9%	19.5%	
		$100,000 - $149,999	16.6%	18.4%	
		$150,000 or greater	26.9%	31.5%	
	Education (binary: 1 = college degree, 0 = no college degree)		72.2%	72.1%	H = 16.4, p < 0.001
Harvest plans	Harvested timber for sale in past 10 years (binary: 1 = Yes, 0 = No)		45.2%	46.2%	H = 0.18, *p* = 0.67
	Plans to harvest in the next 10 years (binary: 1 = Yes, 0 = No)		47.6%	48.9%	H = 0.44, *p* = 0.51
Landowner attitudes	Climate change attitudes (mean composite index score)		4 (3.25–4.75)	4 (3.25–5)	H = 4.36, *p* = 0.04
	Landowner management goals	Amenity goals (index score)	3.67 (3–4)	3.67 (3–4)	H = 0.78, *p* = 0.38
		Investment goals (index score)	3.33 (2.33–4)	3.33 (2.33–4)	H = 1.61, *p* = 0.21
		Home-related goals (index score)	4.0 (3–4.33)	3.67 (3–4.33)	H = 1.72, *p* = 0.19
	Forest management values	Active management (index score)	4.0 (3.67–4.67)	4.0 (3.67–4.67)	H = 0.66, *p* = 0.42
		Protection (index score)	4.33 (4–5)	4.3 (4–5)	H = 0.80, *p* = 0.37
		Societal benefit (index score)	3.33 (2.67–4.0)	3.67 (3.0–4.0)	H = 7.29, *p* < 0.01
Forest ownership characteristics	Area owned (acres)		109 (69–251)	110 (77–200)	H = 2.66, *p* = 0.10
	Mean carbon storage (CO_2e/ha)		280.1 (197.2–375.6)	276.3 (203.4–377.1)	H = 0.06, *p* = 0.8
	Ecoregion	Coast Range	27.5%	29.4%	X^2 = 1.02, p = 0.8
		Klamath Mountains	28.9%	27.8%	
		Western Cascades	10.5%	10.6%	
		Willamette Valley	33.1%	31.7%	
Political Tendency	Very liberal		8.2%	8.3%	X^2 = 7.85, p = 0.10
	Somewhat liberal		17.9%	20.0%	
	Moderate		23.7%	24.4%	
	Somewhat conservative		24.0%	22.2%	
	Very conservative		26.2%	20.0%	

logistic regression model cannot be directly interpreted as marginal effects, we present the odds ratio for each variable, which can be interpreted as the effect of a one-unit change in the variable on the probability that a NIPF owner would enroll or might enroll in a program.

2.3.2. Predicting enrollment

We used the final model to predict the likelihood of each of the survey respondents (*n* = 307) to enroll or consider enrolling across a full factorial of possible program design (243 possible programs). From these, we calculated the likely proportion of NIPF owners who would enroll or consider enrolling in each hypothetical program (i.e., # predicted to enroll/307). From the full factorial of program designs, we selected a suite of six policy-relevant program designs with the goals to: 1) maximize enrollment regardless of required management or contract length, 2) maximize enrollment but require longer contracts (i.e., 20 and 30 years), and 3) maximize enrollment in programs that require no timber harvest (i.e., most restrictive forest management) and 10-, 20-, and 30-year contracts. See Table 4 for the resulting policy-relevant program designs.

2.3.3. Landscape simulations of program outcomes

We estimated landscape-scale outcomes for each policy-relevant program scenario using Monte Carlo simulations which combine the predicted participation (i.e., the proportion of NIPF owners who would enroll vs. not enroll) with NIPF owner parcel data and spatially explicit carbon storage and sequestration data. We focus our landscape simulations on predicted enrollment (i.e., NIPF owners who would enroll versus not enroll) and do not include the NIPF owners who would only consider enrollment. We assume that, at the landscape scale, the proportion of NIPF owners willing to enroll in a forest carbon incentive program is the same as the proportion expected from our empirical survey data. We used Monte Carlo simulations to account for uncertainty associated with NIPF owner enrollment.

We developed a simulation dataset by extracting parcel boundaries for all privately owned forestland less than 5000 acres within our study area. Based on owner names, we merged multi-parcel ownerships into a multipart polygon for analysis. We assume all ownerships are available to participate in hypothetical incentive programs; the resulting simulation landscape consists of ~10,500 NIPF owners. For each ownership, we calculated the total forest area owned (acres) by overlaying the parcel boundaries with forest cover data (Hansen et al., 2013). We extracted mean aboveground biomass from published lidar-based aboveground biomass maps (Mg C ha^{-1}, Hudak et al., 2020) and mean carbon sequestration (Mg CO_2e ha^{-1} yr^{-1}) from imputed maps of forest productivity based on Forest Inventory Analysis data (Latta et al., 2009). Above-ground biomass values were converted to carbon dioxide equivalents (CO_2e) per hectare following guidelines established in the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (Penman et al., 2003), which assumes carbon content to be 50% of the above-ground biomass of each living tree (Smith et al., 2006).

For each program scenario, we used the predicted proportional enrollment to assign NIPF owners as "enroll vs. not enroll". Specifically, we randomly assigned NIPF owners as willing to enroll until we met the expected proportional enrollment for each program. We assumed that NIPF owners enrolled only a portion of their forest land, consistent with the data from survey respondents. In each simulation, for each landowner, we assigned a proportion of forest enrolled drawing from a truncated normal distribution ranging with mean = 0.51 and sd = 0.39

calculated from empirical survey data. We repeated this process for 500 iterations.

For each iteration of NIPF owner enrollment in each program scenario, we calculated the total forest area enrolled (acres), total current carbon storage (MMT CO_2e), and total annual carbon sequestration (MMT CO_2e yr^{-1}) by summing across all enrolled ownerships. We calculated total program costs by summing the incentive and cost-share payments made to individuals under each program scenario based on the enrolled area. We based likely cost-share on allowable cost share amounts for forest management plans by enrolled acreage size under the Natural Resource Conservation Service (NRCS) EQIP CAP-106 from 2019. Our calculated program cost only includes payments made to NIPF owners as incentive or cost share and does not include any administrative costs.

For each scenario, we report the mean and standard deviation for enrolled area, initial carbon storage, annual sequestration, and program costs from the Monte Carlos simulations. To calculate the estimated carbon sequestration over the length of a contract, we multiplied the mean annual sequestration by contract length and applied a discount for contracts where "Thinning and partial harvest allowed, not to exceed 5-year growth volume" contracts by subtracting the mean annual sequestration multiplied by 5 years. We calculated total carbon protected (MMT CO_2e) by summing the starting carbon storage and the estimated sequestration over the length of the contract. We calculate a simple cost per metric ton of carbon dioxide ($ per MT CO_2e) by dividing the total program cost by the total carbon protected.

3. Results

We received 307 surveys with at least 75% completion (Table A.2). Of those, 180 respondents completed over half of the BWC scenarios presented and were complete enough to use for the multinomial logistic regression. The percent representation of each ecoregion/ownership size strata in the responses was no different than the percent representation in the sample population (Fisher's exact test, p-value: 1.0, Table A.2). Respondents who completed the BWC tasks tended to be younger ($H = 27.45$, $p < 0.001$, median age: 65 vs. 73) and more likely to have a college degree versus the partial respondents ($H = 16.4$, $p < 0.001$) (Table 2). In addition, they differed with respect their scores along the Societal Benefit index. None of the variables that differed between the partial respondents and those that completed the BWC section were included in our final model of NIPF owner willingness to enroll. The survey respondents consisted mostly of males (72.3%) over the age of 55, and most respondents had obtained bachelor's degrees or higher and earned above $75 K (Table 2). Respondents' political tendency was more commonly conservative leaning than liberal, with 23.7% identifying as moderate**.** The median forestland ownership size was 109 acres with most respondents owning between 50 and 500 acres, which is reflective of the sampling approach.

Most respondents (69.4%) reported more than one forest type on their forestland. Dominant forest types, which we define as comprising at least 50% of an ownership, tended to be Douglas fir (59.2% of respondents) or mixed conifer/hardwood forests (14.2% of respondents). Nearly half (45.2%) of respondents reported having harvested timber for sale in the past 5 years. Similarly, 47.6% of respondents planned to harvest trees either for sale in the next 10 years (Table 2).

PCA on NIPF owner responses yielded three factors describing land management goals: amenity-related (6 items), investment-related (3 items), and home-related (3 items) (Table A.3). We retained the amenity-related goal index (Cronbach's $\alpha = 0.72$) and the investment-related goal index ($\alpha = 0.79$). NIPF owner attitudes toward forest management were measured using a five-point agreement scale across 8 items. PCA yielded three indices: active management (3 items, $\alpha = 0.71$), protection (3 items, $\alpha = 0.65$), and societal benefit (3 items, $\alpha = 0.63$) (Table A.4). The active management index was correlated with the investment-related goal index ($r = 0.6$); we retained the investment-related goal index for the analysis. The responses were summarized to a composite climate change index by taking the mean across all 4 items ($\alpha = 0.82$) (Table A.5).

We found political tendency was significantly related to the NIPF owner management goal and attitudinal indices. Specifically, liberal respondents scored higher on the climate change attitude index ($F = 24.9$, $p < 0.001$) and the societal benefit index ($F = 5.94$, $p < 0.001$). Conservative respondents scored higher than liberal counterparts on the investment goal index ($F = 6.14$, $p < 0.001$) and the active forest management index ($F = 16.2$, $p < 0.001$). Conservative and liberal respondents did not differ in their scores for home-related goals ($p = 0.18$) or the forest protection index ($F = 5.75$, $p = 0.06$), nor were differences in demographic variables among the political tendency of respondents (age ($p = 0.39$), education ($p = 0.10$), income ($p = 0.50$)). For the full model analysis, we retained the indices described above and did not include political tendency.

3.1. Program attribute preference and willingness to participate

Our conditional logit analysis of the BWS data indicated that all of the program attributes were significant ($p < 0.001$). Annual payment was the most preferred attribute followed by cost share. Management change was the least valued attribute, followed by contract length. At the level-scale, attributes varied in terms of significance (Table 3). For the payment related level-scale values (i.e., initial signing payment and fixed annual payment), coefficients were positive but only coefficients for the highest payment levels were significant. This indicates that NIPF owners strongly preferred the higher payment levels compared to the lowest levels ($20 per acre initial signing payment and $50 per acre annual payment) but that the mid-levels were not strongly preferred over the lowest levels. For cost share, both levels of cost share (50% and 75%) had positive and significant coefficients (0.39 and 1.18, respectively), indicating that they are preferred over no cost share. For management changes and contract lengths, coefficients were negative and the only 30-year contract (−0.91) and most restrictive harvest management (−0.91) had significant coefficients.

We found that 36% of respondents ($n = 180$) stated that they would probably or definitely enroll in at least one of the hypothetical programs they were shown while 21% of respondents refused (i.e., probably or definitely would not enroll) all programs that they were offered. Our final model of willingness to enroll included all program attributes, program framing, NIPF owners' plans to harvest timber for sale in the next 10 years, and NIPF owners' scores along the climate change and protection indices as well as the acres owned (log transformed) and the mean carbon storage of NIPF ownership (Table 3). The model had an overall accuracy of 84.6% (95% CI: 0.82, 0.87) and Cohen's $\kappa = 0.75$ indicated substantial agreement in classifying NIPF owner responses.

Willingness to enroll in incentive programs was significantly and positively related to annual payment amount: NIPF owners were 17 times more likely to enroll in and 3 times more likely to consider programs with annual payments of $50 per acre versus programs with $15 per acre (OR: 16.95 and 3.00, Table 3). Inclusion of cost-share payments, and increased cost-share payments, were also significant predictors of whether a NIPF owner would enroll vs. not enroll in an incentive program. Programs that included a 50% or 75% cost share for management plan preparation and implementation were 2.2 to 2.7 times more likely to be considered and 4.3 to 5.6 times more likely to be enrolled in, respectively, as compared to programs that included no cost share (Table 3). NIPF owners' attitude toward climate change was the third biggest factor predicting whether a NIPF owner would enroll or not in an incentive program. A one unit increase in a NIPF owners' climate change attitude resulted in being 4.2 times more like to enroll in a program (OR: 4.22) and almost 2 times more likely to consider enrolling in a program (OR: 1.72). Initial signing payments were not significant predictors of willingness to consider enrolling, however, programs with $20 per acre initial payments were significantly more likely to be enrolled (2.7 times

Table 3
Summary of BWC analysis using conditional logit model to assess NIPF owner preferences for program attribute levels and multinomial logistic (MNL) regression to model NIPF owner willingness to enroll in forest carbon incentive programs. For the MNL, reference response level was set to "No – would not enroll", predictor variable reference levels are indicated for categorical variables in the table.

Variable		Conditional logit model	Multinomial logit model			
		Level-scale analysis	Might enroll		Would enroll	
		Coefficient (standard error)	Coefficients (standard error)	Odds ratio	Coefficients (standard error)	Odds ratio
Intercept			−0.14 (2.04)		−13.20(4.72) **	
Initial Signing Payment	No signing payment[a]	−0.44				
	$10 per acre	0.09 (0.08)	0.32 (0.26)	1.38	0.04 (0.44)	1.04
	$20 per acre	0.35 (0.09) ***	0.46 (0.26)•●	1.58	1.00 (0.41) *	2.72
Fixed Annual Payment	$15 per acre[a]	−0.69				
	$25 per acre	0.02 (0.09)	0.64 (0.25) *	1.90	0.82 (0.46) *	2.27
	$50 per acre	0.67 (0.09) ***	1.10 (0.26) ***	3.00	2.83 (0.44) ***	16.95
Cost Share	No cost share[a]	−1.57				
	50% cost share	0.39 (0.09) ***	0.79 (0.25) **	2.20	1.46 (0.43) ***	4.31
	75% cost share	1.18 (0.09) ***	0.98 (0.26) ***	2.66	1.72 (0.44) ***	5.58
Contract Length	10 years[a]	0.98				
	20 years	−0.07 (0.09)	−0.45 (0.25) ●	0.64	−0.70 (0.41) ●	0.50
	30 years	−0.91 (0.09)***	−0.94 (0.26) ***	0.39	−1.65 (0.45) ***	0.19
Management	Thinning and partial harvest permitted, not to exceed permitted harvest levels[a]	1.08				
	No commercial timber harvest	−0.17 (0.09) ●	−0.54 (0.25) *	0.59	−0.98 (0.41) *	0.38
	No timber harvest for duration of contract	−0.91 (0.08)***	−0.78 (0.26) **	0.46	−1.54 (0.42) ***	0.21
Forest Health Framing (versus Forest Carbon[a])		*na*	−0.13 (0.44)	0.89	−0.16 (0.92)	0.85
Plans to Harvest for Sale		*na*	−0.78 (0.51)	0.46	−0.96 (1.08)	0.38
Climate Change attitude		*na*	0.54 (0.29) ●	1.72	1.44 (0.64) *	4.22
Protection Index score		*na*	0.04 (0.43)	1.04	0.74 (0.93)	2.10
Log(Acres)		*na*	−0.26 (0.28)	0.77	0.54 (0.58)	1.72
Mean Carbon Storage (CO2e/ha)		*na*	−0.004 (0.002) *	1.00	−0.006 (0.003)	0.99
Number of observations		19,380	1075			
Akaike Inf. Criterion		4420	938.7			
McFadden pseudo-R2		*na*	0.23			
Correct classification rate		*na*	84.6%			
Cohen's κ		*na*	0.75			

likely as compared to no signing payment) (Table 3).

Willingness to enroll or consider enrolling was strongly and negatively related to longer contract lengths and more restrictive management requirements (Table 3). The odds of being willing to enroll or consider enrolling were 79% and 54% lower for programs with the most restrictions on management (i.e., "No timber harvest for duration of contract. Any deadwood removal must be reported.") as opposed to programs where thinning and partial harvest were permitted, but not to exceed the estimated 5-year growth volume for [the NIPF owner's] forest and as specified by a management plan. Similarly, NIPF owners were 81% less likely to enroll in and 62% less likely to consider programs with 30-year contracts as opposed to those with 10-year contracts.

3.2. *Predicting enrollment*

Using this model to predict expected enrollment of survey respondents, we found that the average proportion of NIPF owners that would enroll across all possible program combinations (i.e., full factorial excluding framing, 243 combinations) was less than 10% with 30% considering enrollment. The program combination with the minimum expected participation had a predicted enrollment of 2% of NIPF owners with an additional 10% that would consider enrolling. We chose six policy-relevant program designs to evaluate landscape outcomes related to increasing contract length and strict harvest restrictions (i.e., no timber harvest) versus flexible restrictions (i.e., thinning and partial harvest allowed, not to exceed estimated 5-year growth volume). To maximize enrollment, these programs included initial enrollment payments of $20 per acre, annual payments of $50 per acre, and 75% cost share for management plan preparation and implementation. Maximum predicted enrollment (40% would enroll; 54% would consider enrolling) was expected for a 10-year contract that allowed for thinning and partial harvest. Programs that did not allow timber harvest had lower expected enrollment (9% to 25% of survey respondents) that programs that allowed for thinning and partial harvest (26% to 42% of survey respondents) regardless of contract length (Table 4).

3.3. *Landscape simulations of enrollment*

Simulation of the hypothetical program enrollment at the landscape scale resulted in 75,000 to 334,000 acres of forestland enrolled depending on the program (Table 5). Total carbon protected ranged from 16.25 MMT CO_2e to 50.31 MMT CO_2e, with the least attributed to the No Timber Harvest, 30-year contract program and the most attributed to the Maximum Enrollment, 20-year contract program (Table 5). Initial carbon storage and annual carbon sequestration scaled directly with acre enrolled, where the programs with the most acres enrolled also had the highest estimated initial carbon stores and highest annual carbon sequestration (Table 5). We found that cost ranged from $3.58 per MT CO2e to $7.70 per MT CO2e. Our landscape-level outcome results showed that, for all contract lengths (10-, 20-, 30-years), No Harvest programs were expected to deliver lower cost ($/MT CO2e) carbon benefits compared to programs with more flexible management requirements (i.e., "Partial harvest and thinning allowed, not to exceed 5-year growth volume") (Table 5).

4. Discussion and conclusions

We surveyed NIPF owners in western Oregon to determine their willingness to enroll in practice-based forest carbon incentive programs, specifically designed to maintain in-forest carbon stocks and sequestration through limiting timber harvest. Our study offers a timely, updated assessment of NIPF owner willingness to manage for forest

Table 4
Expected participation (% of survey respondents) for a suite of six forest carbon incentive program designs based on predicted willingness to enroll from multinomial logistic regression models. To maximize likely enrollment, all programs had the highest levels of payment (initial incentive, annual payment, cost share).

Program name	Program attributes			Expected % landowner participation based on survey respondents	
	Contract length	Management requirements	Payments to landowner	Would enroll	Might enroll
Maximum Enrollment	10 years	Thinning and partial harvest permitted. Harvest levels can not exceed the estimated 5-year growth volume for enrolled forest as specified by management plan.	Initial Incentive: $20/acre Annual Payment: $50/acre 75% Cost share	42%	52%
Maximum participation with 20-year contract (i.e., 20yr_Max)	20 years			38%	51%
Maximum participation with 30-year contract (i.e., 30yr_Max)	30 years			26%	52%
Maximum participation with most restrictive management (i.e., NoHarvest_Max)	10 years	No timber harvest for the duration of the contract.	Initial Incentive: $20/acre Annual Payment: $50/acre 75% Cost share	25%	57%
Maximum participation with most restrictive management and 20-year contract (i.e., NoHarvest20yr_Max)	20 years			19%	49%
Maximum participation with most restrictive management and 30-year contract (i.e., NoHarvest30yr_Max)	30 years			9%	41%

Table 5
Simulated landscape-level outcomes from six hypothetical forest carbon incentive programs. Values presented are the mean (sd) of 500 landscape simulations of landowner enrollment (i.e, Would Enroll) for each program based on predictions from multinomial logit models using landowner survey data for western Oregon.

Program description	Total acres enrolled	Starting carbon storage (MMT CO2e)	Annual carbon sequestration (MMT CO2e yr-1)	Total carbon sequestration over length of contract (MMT CO2e)	Total C protected (MMT CO2e, 90% CI)	Total cost ($MM)	$ per MT CO2e
Maximum enrollment, 10-year contract	333,910 (6581)	39.61 (0.90)	1.08 (0.02)	5.62 (0.18)	45.04 (43.46–46.83)	180.6 (3.4)	4.01
Maximum enrollment, 20-year contract	300,388 (6074)	35.65 (0.84)	0.97 (0.02)	15.17 (0.51)	50.31 (48.32–52.24)	312.6 (6.4)	6.21
Maximum enrollment, 30-year contract	207,744 (4954)	24.67 (0.68)	0.68 (0.02)	17.56 (0.70)	41.57 (39.78–43.30)	320.1 (7.9)	7.70
No timber harvest, 10-year contract	199,665 (5408)	23.68 (0.78)	0.65 (0.02)	6.78 (0.28)	30.18 (28.63–31.75)	107.9 (2.6)	3.58
No timber harvest, 20-year contract	147,589 (4602)	17.51 (0.64)	0.48 (0.01)	10.15 (0.46)	27.11 (25.64–28.79)	153.6 (4.6)	5.67
No timber harvest, 30-year contract	75,160 (3534)	8.92 (0.49)	0.24 (0.01)	7.89 (0.55)	16.25 (14.88–17.54)	115.8 (5.0)	7.13

carbon in temperate forests of the Pacific Northwest. Past studies focused primarily on willingness to participate in carbon markets or broader tax incentives and few have been conducted in the last decade (Charnley et al., 2010; Husa and Kosenius, 2021; Jayasuriya et al., 2020; Khanal et al., 2017; Li et al., 2021; Markowski-Lindsay et al., 2011; Miller et al., 2012). In that time, climate change has become more emphasized in the media (Pearce et al., 2019; Sabherwal et al., 2021), Americans have increasingly acknowledged the reality of climate change (Ballew et al., 2019), and climate change impacts are being recognized in our global and local experiences (Grotta et al., 2013; Marlon et al., 2019; Pianta and Sisco, 2020). Familiarity and beliefs about climate change can influence NIPF owners' management decisions and, thus, our study helps shed light on the current beliefs and willingness within this societal context (Lenart and Jones, 2014). In addition, we link empirical data on NIPF owners' willingness to participate in practice-based incentives with landscape simulations of program carbon protection outcomes. Decisions by NIPF to enroll or not in a forest carbon incentive program can have impacts at both the individual and societal scale, with revenue benefits accruing at individual scale, costs accruing at the programmatic and societal scales, and carbon and associated ecosystem co-benefits accruing at larger, societal scales (Aguilar and Kelly, 2019). Linking projected NIPF owner enrollment with landscape simulations allows policymakers to assess tradeoffs among benefits and costs of various hypothetical programs.

Using landscape simulations based on empirical models of NIPF owner enrollment, we illustrate that carefully designed forest carbon incentive programs for non-industrial private NIPF owners could have relatively low cost, tangible carbon mitigation benefits ($3.58 to $7.71 per MT CO_2e). Our study predicts that programs which disallow timber harvest would be expected to enroll between 75,000 and 200,000 acres of NIPF, while programs with more flexible management requirements would be likely to enroll 207,000 to 334,000 acres of NIPF. Although willingness to enroll in the most restrictive (i.e., "no timber harvest") programs was lower than willingness to enroll in less restrictive programs, landscape simulations highlighted a tradeoff between increased enrollment, contract length, management requirements, and costs per MT CO2e. Specifically, while the total carbon protected was higher for programs with flexible management requirements (41.57–50.31 MMT CO_2e) than for No Harvest programs (16.25–30.18 MMT CO_2e), costs per MT CO_2e were lower for No Harvest programs. These programs would provide an average $3900 per year in revenue benefit to individual NIPF owners and the overall programmatic costs, in terms of direct payments to NIPF owners, scaled with the area of forest enrolled and the length of contract. The costs per unit carbon are similar to current average carbon offset prices, which have not resulted in much participation in offset programs by NIPF (Wise et al., 2019) and are less than the $10 - $25 per MT CO_2e that has been projected to result in similar enrollment of private lands (Latta et al., 2016).

We found that more than 1/3 of NIPF owners were willing to enroll in at least one hypothetical forest carbon incentive program but program attributes strongly influenced NIPF owner willingness to enroll. Predicted enrollment was highest for programs which paid $50 per acre per year and included an initial incentive payment of $20 per acre as well as 75% cost share. NIPF owner attitudes toward climate change and their orientation toward protection of forests and forest-based benefits like clean air and water were also important drivers in willingness to enroll. We identify factors that can drive NIPF owner participation in forest carbon incentive programs, which are broadly consistent with research on participation by NIPF owners in incentive programs in general (Daniels et al., 2010; Langpap and Kim, 2010).

Our study is consistent with other literature finding that NIPF owners' willingness to participate increases with higher monetary incentives to participate. Higher per acre annual payments significantly increased the probability of enrollment. We found that initial signing incentives (e.g., one-time initial payment in addition to annual payments) did not significantly increase likelihood of enrollment until above $10 per acres. This result indicates that NIPF owners may perceive $10 per acre initial signing payments similarly to no signing payments and suggests a threshold for increasing NIPF owner participation. Other studies have found one-time up-front payments were more effective in increasing initial participation than annual payments for contracts of over 5 years (Mitani and Lindhjem, 2021). The incentive amounts offered in our study are within the range explored by other research on NIPF owners willingness to participate in forest management incentive programs and carbon market programs, which vary substantially across studies and can range from $3 per acre (Miller et al., 2012) to $1000 per acre (Kline et al., 2000; Markowski-Lindsay et al., 2011). Most commonly, studies include annual payment ranges of $5 to $80 per acre (Alhassan et al., 2019; Dickinson et al., 2012; Fletcher et al., 2009; Kang et al., 2018; Kelly et al., 2016; Shaikh et al., 2007; Smith et al., 2017; Soto et al., 2016; White et al., 2018).

Despite the clear relationship between increased financial incentives and increased participation by NIPF owners, we found that a proportion of NIPF owners are likely to participate at low financial incentive levels. In general, NIPF owners who tend to be more oriented toward protecting nature, protecting forests for future generations, and valuing non-market benefits from forests (i.e., clean air and water) would be more likely to enroll or consider enrolling at lower incentive levels. Other studies of NIPF willingness to engage in forest carbon management have found similar relationships between lower incentive requirements for amenity-owners (Khanal et al., 2017) and suggest that the management changes often promoted in forest carbon programs are well matched with NIPF for whom financial gain is not the primary ownership objective (Miller et al., 2012).

Our study confirmed the importance of including a cost share in incentive programs targeted to NIPF owners (Andrejczyk et al., 2016a; Kilgore et al., 2007). In addition to cost share for management plans, respondents in our survey frequently referenced the need and desire for one-on-one technical assistance from an extension or consulting forester. While our study did not specifically address NIPF owner desire for technical assistance, these observations support conclusions made by others that sustainable forestry initiatives can be more successful by funding opportunities for onsite consultation and other forms of NIPF owner assistance (Kilgore et al., 2015; Kilgore et al., 2007). Onsite consultation (i.e., "walking the land") with a forester can build NIPF owners' understanding of incentive program goals and increase the likelihood that NIPF owners enroll and follow management objectives within the incentive programs (Andrejczyk et al., 2016b; Daniels et al., 2010).

NIPF owners can play a significant role in climate mitigation through actions on their forest lands, but less is known about how NIPF owners perceptions of climate change impact their participation in forest management to maintain carbon storage and increase carbon sequestration (Charnley et al., 2010). Climate skepticism, along with a perception of climate change as highly politicized, is common among NIPF owners in the Pacific Northwest (Grotta et al., 2013). Skepticism toward and political polarization surrounding climate change and carbon sequestration could be barriers to successful implementation of policies and programs related to climate change mitigation and adaptation (Fischer and Charnley, 2011; Khanal et al., 2016). However, we found that framing an incentive program as either a "forest carbon" or a "forest health" had no impact on NIPF owners' willingness to enroll. Instead, NIPF owners' attitudes toward climate change, as measured by their beliefs that climate change will impact their forest, that human activities are contributing to climate change, that forest can help reduce climate change impacts, and that humans have responsibility to alleviate climate change impacts, were a very strong predictor of their willingness to enroll in forest carbon incentive programs regardless of program framing. The lack of importance of "forest carbon" versus "forest health" framing might be explained by the fact that most NIPF owners believed that forests can help reduce climate change impacts and thus, could view forest health and forest carbon as synonymous. While NIPF owners might not perceive the framing of the policy as important, forest management actions included in the programs (i.e., reducing timber harvest) might still be rejected by NIPF owners if they associate them with a political or climate change belief system oppositional to their own (Grotta et al., 2013).

The demographic profile of our survey respondents (i.e., mostly males over 55 years old) was similar to NIPF owners in the western US (Butler et al., 2016). However, more respondents had obtained bachelor's degrees or higher, earned above $75 K, and had slightly longer tenure (32.9 yrs). In addition, NIPF owners in our study tended to be "engaged" forest owners, with many having existing forest management plans (31.1%) and more harvesting timber for sale in the past (45%) than NIPF owners of more than 100 acres in the U.S. Pacific Coast region more generally (29%, Butler et al., 2016). Size of forest holdings is a common predictor variable in many models of landowner behavior (Silver et al., 2015) and is a strong predictor of numerous attributes of NIPF (Butler et al., 2016). However, in our study, forest ownership size was not a strong predictor of NIPF owner willingness to enroll in forest carbon incentive programs. We found that NIPF owners with plans to harvest timber in the next 10 years were less likely to enroll or consider enrolling in the forest carbon incentive programs. These owners may have short- to mid-term financial goals that conflict with participation in a program that limits timber harvest (Langpap, 2006) or may require higher rates of compensation to defer timber harvesting (Kline et al., 2000).

We found that NIPF owner participation, measured by the proportion of NIPF owners who would enroll, varied depending on program attributes but ranged from 2% to 40% which is within the range of estimates from other studies. White et al. (2018) found that 14 to 60% of NIPF owners would participate in a carbon market program, depending on program characteristics. Khanal et al. (2017) showed the importance of revenue to NIPF owners in the southern United States, where they found that carbon market scenarios that led to revenue-neutral or loss of revenue resulted in 25% and 16% participation as opposed to revenue-positive scenarios which led to participation by over half the NIPF owners. This study, and others focused on forest carbon markets, found lower expected participation by NIPF owners in forest management programs targeting carbon (i.e., climate mitigation) outcomes then expected NIPF owner participation in incentive programs aimed at a range of conservation outcomes (average 48% predicted participation across a meta-analysis of discrete choice studies) (Mitani and Lindhjem, 2021).

We used survey methods to elicit NIPF owners' willingness to participate in hypothetical programs and add to body of literature aimed at evaluating NIPF owners' participation in incentive programs (Langpap, 2006; Langpap and Kim, 2010). Survey methods, which measure stated intent or hypothetical participation, are consistent with majority of recent literature (Husa and Kosenius, 2021; Mitani and Lindhjem, 2021). It is important to note that average participation in incentive programs by NIPF owners is significantly lower when estimated from observed actions (e.g., actual participation) (Mitani and Lindhjem, 2021), consistent with research suggesting that behavior can deviate from individuals' stated intent (Champ et al., 1997). Thus, our study provides a hypothetical benchmark for comparing and designing incentive programs; realized incentive programs should be monitored and evaluated based on the NIPF behaviors (i.e., actual enrollments and observed management change).

Practice-based incentive programs could increase participation by NIPF owners in forest management with carbon storage and sequestration goals by lowering the requirements as compared to carbon offset markets. Forest carbon offsets are subject to stringent requirements and reporting designed to assure that offsets be "real, additional, quantifiable, permanent, verifiable, and enforceable" (California Air Resources Board (CARB), 2011). The implementation of these requirements creates barriers to participation by smaller NIPF owners (Kerchner and Keeton, 2015; Wise et al., 2019). However, incentive programs for carbon storage and sequestration face challenges in quantifying benefits, demonstrating additional sequestration, and ensuring economic efficiency (Patterson and Coelho, 2009; Wise et al., 2019). One proffered solution is to develop forest carbon incentive programs which accept some amount of risk with respect to non-additionality and non-permanence, while still motivating participation that results in measurable changes to business-as-usual management (Gren and Zeleke, 2016). In our study, we assume that many NIPF owners in western Oregon plan to harvest in the short- to mid-term future and that enrollment in an incentive program that limits timber harvest would result in measurable carbon storage and sequestration benefit despite the risk of some non-additionality and non-permanence. This assumption is consistent with empirical observations from this survey that ~60% of NIPF owners plan to harvest trees for sale or personal use in the next 10 years. We show a tradeoff between contract length, expected enrollment, and total carbon protected over the term of a contract. Shifting toward contracts longer than 10 years, while decreasing overall enrollment, could lead to longer-lasting carbon benefits consistent with greenhouse gas reduction goals from natural and working lands at state and global levels (McDonald et al., 2021; United Nations, 2015).

Practice-based forest carbon incentive programs provide a voluntary mechanism to encourage NIPF owners to adopt forest management to maintain carbon stocks and increase carbon sequestration. Forests can serve as one in a toolbox of strategies, alongside transitioning away from fossil fuels across sectors, to address the urgent need to reduce atmospheric emissions. However, to realize the potential benefit from additional carbon storage and sequestration in forests, forest carbon management activities need to be implemented in the near term (Griscom et al., 2017). Our study provides insight into how policymakers might design programs to facilitate forest-based natural climate solutions among NIPF owners and includes the ability for evaluating tradeoffs among program designs that maximize potential participation and those that may lead to more durable climate mitigation over the next decades. We hope the results of this research will help inform the design of potential forest carbon incentive programs and discussion about the role of NIPF in forest carbon management for climate mitigation in the PNW and elsewhere.

CRediT authorship contribution statement

Rose A. Graves: Conceptualization, Investigation, Formal analysis, Writing. **Max Nielsen-Pincus:** Conceptualization, Writing – review & editing, Resources, Supervision. **Ryan D. Haugo:** Conceptualization, Writing – review & editing, Resources. **Andrés Holz:** Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2022.102778.

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