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Private Forest Owners and Invasive Plants: Risk Perception and Management

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We investigated nonindustrial private forest (NIPF) owners' invasive plant risk perceptions and mitigation practices using statistical analysis of mail survey data and qualitative analysis of interview data collected in Oregon's ponderosa pine zone. We found that 52% of the survey sample was aware of invasive plant species considered problematic by local natural resource professionals; 70% was concerned about these species; and 46% had treated invasive plants on their parcels. Owners' perceptions of invasive plant risks fell along a spectrum ranging from a lack of awareness or concern, to the view that invasive plant infestations have discrete causes and controllable consequences, to the perception that incursions by invasive plants have diffuse causes and uncontrollable effects. Being aware or concerned about invasive plant species were predictors ($p \leq 0.001$) of whether owners treat their parcels to control invasive plants. Holding wildlife habitat and/or biodiversity as an important forest management goal was also a predictor ($p \leq 0.08$) of whether owners treated their parcels to control invasive plants. Some owners were sensitive to the risks of invasive plant infestations from nearby properties, and a surprisingly high percentage of respondents had cooperated with others in forest management activities previously. Our findings suggest three approaches to increasing the frequency of invasive plant mitigation by NIPF owners that hold promise: (1) raising awareness and concern about invasive plants and their impacts on forest management goals that owners care about, such as wildlife habitat and/or biodiversity; (2) providing assistance to help owners mitigate invasive plants they feel unable to control; and (3) engaging owners in coordinated efforts across ownership boundaries to address invasive plant risks.
Nomenclature: Ponderosa pine, *Pinus ponderosa* Dougl. ex C. Lawson.
Key words: Nonindustrial private forest owners, ponderosa pine zone, invasive plant mitigation, forest management policy.

Invasive species are a major concern worldwide (Duncan et al., 2004; Pimentel et al., 2000). The U.S. Department of Agriculture, Forest Service has identified invasive species as one of the four major threats to forest and range lands in the United States (USDA Forest Service, 2004). Invasive plant species are of particular concern for forests and range lands because they are widely believed to affect habitat for native species and livestock forage, and their mitigation imposes great costs to public land management agencies and private landowners alike. (We use the term invasive to refer to alien [nonnative] species whose introduction causes, or is likely to cause, economic or environmental harm or harm to human health [as defined in Executive Order 13112, issued on February 3, 1999].)

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In the western U.S., federal land managers bear a large part of the burden for invasive plant control because about 48% of all western lands are in federal ownership. Understanding the opportunities and constraints associated with managing invasive plants on private lands is also important, however, because invasive species control is a landscape-scale challenge that calls for cooperation across ownership boundaries. Private lands comprise 56% of the nation's forestland, and 62% of this private forestland is owned by individuals and families (Butler, 2008), often referred to as nonindustrial private forest (NIPF) owners. Such lands are often located in low-lying, populated and highly subdivided areas with dense river and road networks; thus, they are characterized by high perimeter to area ratios, which increase the chances of transboundary spread of invasive plant species (i.e., along waterways, on livestock and wildlife, and by foot and vehicle traffic) (Epanchin-Niell et al., 2010).

Despite the importance of NIPF lands for invasive plant mitigation, several barriers to mitigation by NIPF owners on their parcels and at the broader landscape scale have been identified. The economics literature suggests that incentives for controlling invasive plants may be diminishing for private

Management Implications

Understanding the invasive plant risk perceptions and mitigation practices of nonindustrial private forest (NIPF) owners in the U.S. is important because they control a substantial portion of the forestland that invasive plants can affect, and their lands are generally located in areas where transmission via waterways, roads, game, and livestock is common. Our study found that NIPF owners in Oregon's ponderosa pine zone have the potential to help mitigate invasive plants: 52% of survey respondents were aware of invasive plants on their parcels, 70% were concerned about them, and 46% had worked to control them. Awareness and concern explained the likelihood of mitigation, as did holding wildlife habitat and/or biodiversity as an important forest management goal.

Using education and assistance programs to increase awareness, concern, and capacity among NIPF owners may be a worthwhile strategy for increasing the frequency of mitigation efforts. Understanding owners' priority management goals and how invasive species affect them, and targeting such programs at owners whose values are at risk, such as those with wildlife habitat and/or biodiversity goals, may be especially effective. Owners whose primary residence is located on their forest parcels are more likely to treat invasive plants on those parcels. Thus, outreach to nonresidents could be an opportunity for increasing invasive plant mitigation activities. Research to better understand why owners who are aware of and concerned about invasive plants do not attempt to control them may reveal the unique constraints faced by owners having different management goals, which is important for policy development. Finally, engaging owners in cross-boundary, landscape-scale efforts at invasive plant control is important and may be well received.

landowners in the U.S. As private lands become increasingly subdivided, individual owners assume responsibility for a smaller portion of the total damage that infestations incur, but if neighboring landowners do not act to control invasions, they also assume responsibility for a larger share of the control costs (Epanchin-Niell et al., 2010). The sociological literature suggests that NIPF owners in the U.S. engage in limited forms of collective management behavior (Kittredge, 2005; Rickenbach and Reed, 2002). Owners typically make decisions, and manage and market their forest products independently (Jacobson et al., 2000; Rickenbach et al., 2005; Sample, 1994). This independence may make them less interested in cooperative resource management activities.

A variety of incentives and capacity building programs have been developed to encourage invasive plant control on private lands. For example, in Oregon, where our study took place, financial and technical assistance are available through a number of U.S. Department of Agriculture agencies such as the Natural Resources Conservation Service, Farm Service Agency, and Forest Service. In addition, county-level Cooperative Weed Management Areas provide public education, financial assistance, and coordination of local invasive plant control activities on public and private land. However, private landowners are not required by law to report or control invasive plants in Oregon.

For policymakers to engage NIPF owners successfully in invasive plant mitigation through such programs, a better understanding is needed of owners' perceptions of invasive plant risks and the opportunities and constraints landowners face in addressing them. Information is also needed about landowner behavior with regard to individual and collective approaches to invasive plant mitigation. Unfortunately, although numerous studies have addressed the ecological aspects of invasive plant species in forested environments (see Sheley and Petroff [1999] for overviews of the most serious weeds), and some papers address economic aspects (e.g., Duncan et al., 2004; Holmes et al., 2009; Olson, 2004), little documentation exists on how NIPF owners perceive and manage invasive plant species. Steele et al.'s (2006) study of West Virginia woodland owners' awareness and concern about invasive plants is the only study that the authors are aware of that addresses NIPF owners' invasive plant concerns and management actions.

This study is a step toward improved understanding of the opportunities and constraints surrounding invasive plant management on private forest lands, with implications for invasive plant management in broader-scale, mixed-ownership landscapes. We use findings from statistical analysis of mail survey data and qualitative analysis of interviews to investigate how NIPF owners perceive and manage the risks of invasive plants in Oregon's ponderosa pine (*Pinus ponderosa* Dougl. ex C. Lawson) forests, and discuss implications for invasive plant management and policy.

Risk Perception and Invasive Plants. We focused our research on understanding NIPF owners' risk perceptions regarding invasive plants, and the relationship between risk perception and invasive plant mitigation. Risk perception is generally considered a predictor of mitigation behavior in the natural hazards literature (Peek and Miletti, 2002). When individuals perceive great enough risk, they may modify their behavior by engaging in risk mitigation activities such as reducing hazards, preparing for an event, or moving to less hazardous areas (Amacher et al., 2005; Dessai et al., 2004; Fischer, 2011; Grothmann and Patt, 2005; Niemeyer et al., 2005), assuming constraints external to the individual are not insurmountable (Maddux and Rogers, 1983; Slovic, 1987; Tierney, 1999). The process of risk perception in individuals involves objective knowledge and subjective appraisal of the probability and potential severity of an event (Hertwig et al., 2004; Slovic, 1987). Therefore, important components of our risk perception framework were being aware of invasive species on one's property, and being concerned about something bad happening because of them. Although concern implies awareness, people can be concerned about, and attempt to prevent, invasive plant species on their property without knowing whether an invasion has actually occurred. Similarly, people may treat invasive plant species that they

are not particularly concerned about (e.g., in response to appeals by neighbors or county weed programs). For these reasons, we explored awareness and concern as separate components of risk perception.

In cases of complex or poorly understood phenomena such as invasive plant impacts, people may not be capable of appraising the probability and potential severity of a risk event; thus, other indicators of risk perception are needed. We used the importance owners place on land management goals that may be compromised by invasive plants as a lens for examining subjective appraisals of risk. It is well documented that invasive plants can negatively impact forage production and biodiversity in the arid West (Daubenmire, 1975; Franklin and Dyrness, 1973; Harris and Cranston, 1979; Morishita, 1999; ODA, 2011; Pierson and Mack, 1990; Roche et al., 1986; Roche and Roche, 1988; Sheley et al., 1998; Tyser and Key, 1988; Willard et al., 1988; Young et al., 1967). The impacts of invasive species on other values such as timber production, scenic beauty, recreation, and residential uses in western dry forests are less well documented, however. We assumed that invasive plant impacts on scenic quality, recreation, and residential uses are negligible in our study area because the main species of concern are small, unobtrusive grasses and forbs (though two thistle species are possible exceptions because of their larger size and spines). We also had no basis for believing that landowners managing for timber production would perceive invasive plants as a threat. Thus, we incorporated owners' livestock grazing and wildlife habitat and/or biodiversity goals as variables in our construct of risk perception to provide a reference point for owners' concern about invasive plants (i.e., what land management goals and values would be at risk if invasive plants were to encroach on their parcels).

Research Objectives and Hypothesis. Given that landowners' concerns about invasive plants are likely complex and nuanced, and that their abilities to control invasive plants on their parcels are conditioned by the risk of invasions from neighboring ownerships, we sought to understand owners' perceptions of invasive plant risks and motivations to manage them on their own parcels and across ownership boundaries. We also sought to test the following hypothesis: NIPF owners who are aware of or concerned about the presence of invasive plant species on their land, or who hold livestock grazing and wildlife habitat and/or biodiversity as important land management goals, are more likely to treat their parcels to control these species than those who are not aware of or concerned about invasive plants, or do not hold such goals.

Oregon's Ponderosa Pine Zone. We focused on Oregon's ponderosa pine zone east of the Cascade crest because ponderosa pine forests are one of the forest types most impacted by invasive plants in the interior Pacific Northwest (Vavra et al., 2007). A number of forces have contributed to infestations of invasive plant species in these forests including logging, livestock grazing, and ungulate herbivory (Vavra et al., 2007). Fire is an important ecological process in Oregon's ponderosa pine zone. Increasingly, invasive plant infestations are being recognized as both a factor in fire risk (as a fuel type), and as a consequence of fire management activities such as fire suppression, vegetation thinning, prescription burning, building fuel breaks, and post-fire rehabilitation (Crawford et al., 2001; Dodson and Fiedler, 2006; Fulé et al., 2005; Keeley, 2006; Kerns et al., 2006; Moore et al., 2006; Nelson et al., 2008). It is important to point out, however, that invasive plants are not nearly as great a concern in forested areas east of the Oregon Cascades as they are in rangelands where sunlight is more abundant, or in the forested areas on the west side of the Cascades where elevations are lower and precipitation is greater (Parks et al., 2005). Although our research was limited to Oregon's ponderosa pine zone, the ecological and socioeconomic conditions in this area are common throughout the arid American West. Thus, this case may shed light on invasive species management issues on NIPF lands in the West more generally.

Materials and Methods

We employed a multi-method research design that entailed two parallel data collection activities: (1) a mail survey to gather data to describe invasive plant risk perceptions and practices among owners of NIPF lands in the ponderosa pine zone, and their statistical relationship to one another; and (2) qualitative interviews to gain in-depth understanding of the reasons why people hold particular views and management motivations regarding invasive plants to help us interpret the survey results. Before the surveys and interviews were conducted we created a list of the most problematic invasive plant species that occur in Oregon's ponderosa pine forests by contacting 29 natural resource professionals who work in eastern Oregon's ponderosa pine zone. These natural resource professionals included biologists, plant ecologists, and foresters from Forest Service ranger districts, BLM districts, Oregon Department of Forestry service areas, Natural Resource Conservation Service districts, Soil and Water Conservation Districts, County Weed Management Areas, and Oregon State University County Extension offices within the study area. We also consulted the literature to find out why these species are of concern to natural resource professionals. A list of these species and short summaries of the problems associated with them are presented in Table 1. It was beyond the scope of this study to survey invasive plants on individual ownerships, and existing plant survey data were not available for us to analyze.

Mail Survey. The survey was administered to a random sample of NIPF owners in 2008 by Oregon State University and the Oregon Department of Forestry after being

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Table 1. Invasive plant species of concern to natural resource professionals contacted.

Species	Distribution and ecological and/or economic implications
Canada thistle (*Cirsium arvense*)	Abundant in every county in Oregon (ODA 2011). Not usually found in undisturbed forested areas but has the potential to colonize a wide variety of forest habitats within its range following overstory removal and soil disturbance (Young 1967). Can decrease or limit forage and livestock production on rangelands and can limit the use of recreational areas (Morishita 1999).
Knapweeds (*Centaurea* spp.)	Spotted knapweed (*C. maculosa*): Abundant in central, north central and south central Oregon (ODA 2011); known to infest openings in ponderosa pine/bunchgrass forests (Roche and Talbott 1986). Diffuse knapweed (C. *diffusa*): Has limited distribution in central, north central and northeastern Oregon (ODA 2011); more commonly infests ponderosa pine/bitterbrush habitat types (Roche and Roche 1999). Knapweed infestations can reduce plant species richness (Tyser and Key 1988), forage (Harris and Cranston 1979) and wildlife habitat (Sheley et al 1998, Willard et al 1988). Knapweed has caused economic losses of approximately $54 million dollars in the state (ODA 2011).
Downy brome (*Bromus tectorum*)	Not considered a species of primary concern to Oregon Department of Agriculture because of its pervasiveness. Common in the ponderosa pine zone throughout the West. Although not likely to spread or persist in mature (i.e., closed) forests, infestations can be triggered and exacerbated by disturbances that open the understory or remove litter (Pierson and Mack 1990), such as grazing and logging (Daubenmire 1975, Franklin and Dyrness 1973).
Yellow starthistle (*Centaurea solstitialis*)	Abundant in north central and north eastern Oregon and has limited distribution in central and southeastern Oregon (ODA 2011). Infests ponderosa pine forest types and will grow wherever downy brome grows (ODA 2011). Displaces native plants, reduces native wildlife habitat and forage, decreases native plant and animal diversity, limits access to recreational areas, and reduces land value (Roche and Roche 1988).
Medusahead (*Taeniatherum caput-medusae*)	Abundant in every county on Oregon's east side except Klamath, Deschutes, Union, and Wallowa, where it has limited distribution (ODA 2011). Distribution and habitat requirements overlap with those of downy brome; can be found in ponderosa pine forest types (Young and Evans 1970). Out-competes other grasses by extracting the majority of moisture well before perennial grasses have begun to grow, and changes the temperature and moisture dynamics of the soil, greatly reducing seed germination of other species, and creating fuel for wildfires (ODA 2011). Is unpalatable to livestock and can cause injury to the eyes, noses, and mouths of grazing animals (Harris and Goebel 1976).
Dalmatian toadflax (*Linaria dalmatica*)	Abundant in Klamath, Deschutes and Wallowa Counties; not present in Crook County; has limited distribution in other counties on Oregon's east side (ODA 2011). Displaces plant communities and associated animal life, reducing forage in pastures and rangelands that can impact livestock and some big game species, especially on winter ranges. Causes soil erosion, surface runoff, and increased sediment yields (Lajeunesse 1999).
Musk thistle (*Carduus nutans*)	Abundant in southern central and southeastern Oregon and has limited distribution in other eastern and northeastern counties (ODA 2011). Found in pasture, range and timberlands; spreading in sagebrush and pinyon–juniper communities (Dewey 1991). Unpalatable to wildlife and livestock; resultant selective grazing gives musk thistle a competitive edge, leading to severe degradation of native meadows and grasslands as wildlife focus their foraging on native plants (ODA 2011). Competes with desirable forage, and its sharp spines can limit recreation, hinder movement, deter livestock, and presumably wildlife, from grazing (Beck 1999).
Leafy spurge (*Euphorbia esula*)	Abundant in Klamath, Crook and Grant Counties and has limited distribution in a number of other counties on Oregon's east side (ODA 2011). Greatest impacts are in big sagebrush communities (Magee et al. 2008). Capable of invading disturbed sites, including prairies, savannas, pastures, abandoned fields and roadside areas. Toxic to cattle; selective grazing can promote spread of leafy spurge; decreases the diversity of native species (Magee et al. 2008).
Mediterranean sage (*Salvia aethiopis*)	Abundant in south central Oregon and has limited distribution throughout the rest of Oregon's east side except the far north eastern part of the state (ODA 2011). Reduces crop quality and yield (Roche and Wilson 1999). A troublesome pest in pastures and rangelands of eastern Oregon, especially in the southern central part of Oregon, where it replaces grasses when moisture is sparse.

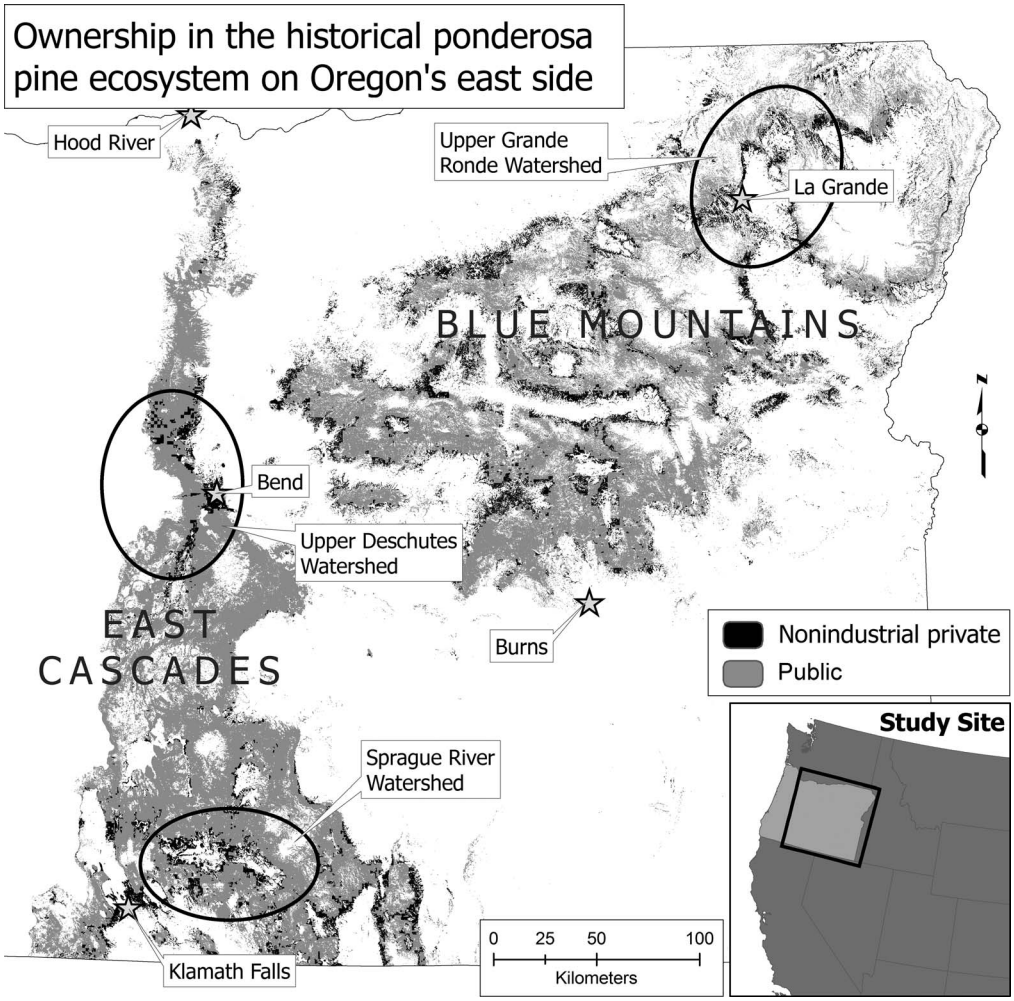

Figure 1. Oregon's ponderosa pine zone.

approved by the Oregon State University Institutional Review Board. It was administered following the total design method (Dillman, 1978): an announcement card, followed 5 d later by the survey; a second survey to nonrespondents 2 wk after the first; and at 4 wk, a thank you card that also served as a final reminder to nonrespondents.

The survey sample was selected by casting random points across a GIS polygon of all NIPF parcels in Oregon's ponderosa pine zone (Figure 1). This polygon was created using layers of pixels that could support characteristic historical ponderosa pine forests (Grossmann et al., 2008; Ohmann and Gregory, 2002; Youngblood et al., 2004), and an ownership layer. The tax lot information associated with each point was then obtained and used to create the sample frame. Of the 1,244 surveys mailed, 234 were disqualified, leaving 1,010 valid surveys. From these, we received 505 valid responses, yielding a response rate of 50%. No follow-up survey of nonrespondents was conducted.

The survey questions concerned owners' past (2003 to 2008) and intended future forest management activities, with a focus on fire and invasive species, and included questions about owners' social arrangements for accomplishing work, and level of concern and awareness of specific invasive plants on their properties. Survey questions also addressed owners' demographic characteristics. Respondents were asked to focus their responses on the parcels associated with the tax lot number identified on their survey. A parcel was defined as the tract of land comprising the tax lot identified, and all connected tax lots owned by them.

We used logistic regression tests to examine the relationship between the risk perception variables (awareness, concern, and management goals) and whether landowners treated their parcels to control invasive plants. Definitions of these variables are presented in Table 2. Logistic regression was used for estimating the regression models because of the binary nature of the dependent variables. Logistic regression estimates the probability of a certain action based on the cumulative logistic probability function of continuous or dichotomous predictor values (Hamilton, 1992).

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Table 2. Variables used in descriptive and logistic regression statistics.

Variable	Type	Definition
Treated	Dichotomous	Whether respondent treated any hectares on his/her parcel to control invasive plants: 1 if > 0 hectares were treated; 0 otherwise
Aware ≥ 1 species	Dichotomous	Whether respondent is aware of at least one of the 9 invasive species on his/her parcel; 1 if aware of ≥ one species present on parcel; 0 otherwise
Aware #species	Continuous	Number of species respondent is aware of on his/her parcel
Concerned ≥ 1 species	Dichotomous	Whether respondent is concerned about at least one of the 9 invasive species on his/her parcel: 1 = "moderately concerned," "concerned" or "very concerned" about ≥ 1 species; 0 = "slightly concerned," "not at all concerned" or "unsure" or chose not to answer the question
Concerned # species	Continuous	Number of species respondent is concerned about on his/her parcel
Grazing important	Dichotomous	Whether respondent considers livestock grazing an important goal on his/her parcel: 1 = "moderately important," "important," or "very important"; 0 = "not at all important" or "slightly important"
Habitat important	Dichotomous	Whether respondent considers wildlife habitat and/or biodiversity an important goal on his/her parcel: 1 = "moderately" "important" or "very important"; 0 = "not at all important" or "slightly important"

Interviews. We conducted key informant interviews in 2007 and 2008 with a purposive sample of owners of NIPF land in three watersheds in the ponderosa pine zone of eastern Oregon. We chose watersheds that contain relatively large proportions of NIPF lands, and represent different ecological, social, and economic conditions on Oregon's east side: the Sprague River Basin in Klamath County, the Upper Deschutes River Basin in Deschutes and Jefferson Counties, and the Upper Grande Ronde River Basin in Union County (Figure 1).

The sample of interview informants included 60 owners (20 from each watershed) who had received public financial or technical assistance for forest management and thus, had developed management plans that addressed invasive plants. We identified the sample with help from local natural resource agencies and organizations. The sample was diverse. Owners' goals ranged from conservation to lifestyle to timber production and grazing. For some owners the land had been in the family since the 1800s; others had purchased it in the past 10 years. The owners' professions included ranching, forestry, medicine, law, education, and others. Parcel sizes ranged from less than (4 ha) to thousands of hectares. Owners also had diverse levels of education and income.

Each interview included a walking tour of the owner's property and averaged two hours. Interview questions addressed owners' forest management approaches, experiences, and concerns about risks to their forestlands (particularly wildland fire and invasive species), ecological knowledge and values about fire and invasive species, and perceptions of opportunities and constraints associated with managing their forests. Digital recordings of the interviews were transcribed verbatim.

We followed a standard qualitative protocol to analyze the private landowner interview data. We used Atlas.ti (Atlas.ti Version5.2, 2008), a software that aids in qualitative data analysis, to identify quotations that had to do with the topics of interest (e.g., wildlife habitat and/or biodiversity as a management goal, or reasons for concern about invasive plants). We linked quotations with codes to categorize them by subject or theme (e.g., reasons why owners who hold wildlife habitat and/or biodiversity as a goal may be or may not be concerned about an invasive plant species, or why owners who are concerned about invasive plants may not do anything to control them). Then we wrote detailed memos about the codes, summarizing the data and explaining their relationship to owners' mitigation behavior.

Results and Discussion

Survey Sample Characteristics. The survey sample was similar to the population of NIPF owners in the West in that the members were mostly retirement-age males, but a greater proportion had obtained a bachelor's degree and earned above the national median annual household income ($50,000). Also, survey respondents' ownerships were large (median of 218 ha interquartile range = 60 ha to 1093 ha) compared to the West where well over half of owners hold land in ownerships less than 4 ha in size (Butler and Leatherberry, 2004). Also, a majority of the survey respondents did not maintain their primary residence on (74.5%) or within one mile of (59.5%) the parcels we asked about and thus can be considered absentee in relation to those parcels. As a comparison, Butler and Leatherberry (2004) report a 32% absentee rate defined as living more than one mile away from one's ownership among family forest owners in the West. The

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Table 3. Characteristics of survey sample (n = 505).

Male (%)	79.6
Bachelor's degree (%)	51.7
Earn at least U.S. median income of $50K (%)	73.5
Age (mean)	63.1
Maintain primary residence on parcel (%)	25.5
Years parcel owned (mean)	21.7
Parcel hectarage (median)	158.6
Ownership hectarage (median)	218.5
Wildlife habitat and/or biodiversity an important goal (%)	88.0
Livestock grazing an important goal (%)	59.8
Timber production an important goal (%)	60.4
Beauty and/or scenery an important goal (%)	92.0
Privacy an important goal (%)	85.3

large proportion of nonresident owners and owners of large tracts of land in our sample as compared to the US West may reflect the social and biophysical conditions in eastern Oregon, where there are few urban areas, land use rules set large minimum tax lot sizes, and an arid climate limits productivity and, therefore, favors forestry and grazing over large areas often remote from population centers. The forest management goals that the largest proportions of survey respondents considered important on their parcels were wildlife habitat and/or biological diversity, beauty and/or scenery, and privacy. A substantial proportion of survey respondents (60%) also considered livestock grazing and timber production important goals. These and other characteristics of the survey sample are presented in Table 3.

Invasive Plant Awareness, Concern, and Treatment. The survey respondents were, on the whole, moderately aware of and concerned about the nine invasive plant species in Oregon's ponderosa pine zone that are of concern to natural resource professionals. Fifty-two percent of survey respondents said they were aware of the presence of at least one of the nine species on their parcels, and almost 70% of the survey respondents were concerned about one or more of the nine species (Table 4). National or West-wide statistics are not available for comparison, but Steele et al. (2006) had similar findings in West Virginia: 62% of their sample of landowners were aware of at least one invasive plant species on or near their woodland, though the range of species owners were able to identify was limited.

Canada thistle [*Cirsium arvense* (L.) Scop.], downy brome or cheatgrass (*Bromus tectorum* L.), and knapweeds (*Centaurea* spp.) were the species that the largest numbers of respondents were concerned about, and believed were present on their parcels (Table 4). However, no single species was of concern to a majority of the respondents. Moreover, a substantial proportion of survey respondents (up to 25%) indicated that they were unsure of their level of concern about many of the species, including medusahead rye [*Taeniatherum caput-medusae* (L.) Nevski], musk thistle (*Carduus nutans* L.), Dalmatian toadflax [*Linaria dalmatica* (L.) P. Mill.], Mediterranean sage (*Salvia aethiops* L.), and leafy spurge (*Euphorbia esula* L.). Forty-two percent of the survey respondents were concerned about exotic plants or weeds contributing to the risk of wildfire on their parcels.

Forty-six percent of the survey respondents had treated portions of their parcels to address invasive plants during the five years prior to the survey (Table 5). Of the owners who had treated their parcels, the mean number of hectares treated was 66 and the median was 10 (interquartile range =2 to 10 ha). Owners engaged in a number of forest management practices known to mitigate invasive plant invasions as well as wildfire risk. Large proportions of the survey respondents had grazed livestock, pulled vegetation by hand, and mowed or crushed vegetation. Some had applied herbicides, conducted controlled burns in the understory, and shaded out plants with other vegetation (Table 5). We did not ask whether they engaged in these

Table 4. Invasive plant species about which survey respondents were aware and concerned.

	Aware	Concerned (and therefore aware)
	%	
At least one of the 9 species of concern to natural resource professionals	52.3	69.9
Canada thistle (*Cirsium arvense*)	43.2	47.9
Downy brome (*Bromus tectorum*)	38.2	41.8
Knapweed (*Centaurea* spp.)	19.4	40.0
Medusahead rye (*Taeniatherum caput-medusae*)[a]	14.3	29.9
Musk thistle (*Carduus nutans*)[a]	11.9	25.0
Starthistle (*Centaurea solstitialis*)	11.5	32.5
Dalmatian toadflax (*Linaria dalmatica*)[a]	9.9	25.1
Mediterranean sage (*Salvia aethiopis*)[a]	7.9	20.2
Leafy spurge (*Euphorbia esula*)[a]	5.3	22.2

[a] Species about which about one quarter of respondents were "unsure" of their level of concern.

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Table 5. Management practices of survey sample (n = 505).

Treated hectares to address invasive plants (%)	46.0
Hectares treated to address invasive plants (median)	1.0
Hectares treated to address invasive plants (mean)	87.0
Grazed livestock (%)	66.7
Pulled vegetation by hand (%)	44.0
Mowed, crushed, ground or chipped vegetation (%)	35.8
Applied herbicides (%)	33.7
Understory burned (%)	23.4
Shaded out vegetation (%)	6.7

practices specifically to control invasive plants, or how effective they thought they were for controlling invasive plants.

Risk Perception Predictors of Invasive Plant Treatment. The logistic regression tests revealed the relationships between the two pairs of awareness and concern variables (whether owners were aware of or concerned about *at least one* of the nine invasive plants natural resource professionals identified as problematic in ponderosa pine areas, and the *number of* invasive plant species owners were aware of or concerned about), the management goal variables of interest (grazing livestock and wildlife habitat and/or biodiversity), and owners' likelihood to treat invasive plants. The likelihood ratio tests suggested that our models that included the land management goals were improved ($p \leq 0.001$) compared to models that did not include these goals. Also, the awareness and concern variables were not collinear (VIF 1.3).

We found that being aware of and concerned about invasive plants, and holding wildlife and/or biodiversity as an important goal were significantly associated ($p \leq 0.08$) with whether owners treated their parcels to control invasive plants. Owners who were *aware* of the presence of at least one of the nine species on their parcels were twice as likely to treat invasive plants ($p \leq 0.001$) as owners who were not aware of these species on their parcels when concern and the two management goals were included in the model and held constant. Owners who were *concerned* about at least one of the nine invasive plants were almost three and one-half times as likely to treat invasive plants ($p = 0.000$) as owners who were not concerned when awareness and the two management goals were included in the model and held constant (Table 6, model 1). With each additional species about which owners were *aware* and *concerned*, the likelihood of treating their parcels increased about 1.3 times ($p = 0.000$) and 1.2 times ($p = 0.000$), respectively, when the other variables were included in the model and held constant (Table 6, model 2). Owners who held wildlife habitat and/or biodiversity as an important management goal were about twice as likely to treat invasive species on their parcels ($p \leq 0.08$) when importance of livestock grazing, and concern and awareness about invasive plants were included in the models and held constant (Table 6, models 1 and 2). However, holding livestock grazing as an important management goal was not significantly associated ($p \geq 0.3$) with treating invasive plants in either model.

Other Predictors of Invasive Plant Treatment. We used manual backward stepwise regression tests to explore a number of other variables that the literature suggests are important to NIPF owner management, but that were not included in our hypothesis. Most of these variables (age, education, household income, parcel size, ownership size, tenure length and a number of other management goals) were not significant and were therefore justifiably excluded from the hypothesis. The fact that parcel and ownership

Table 6. Logistic regression predicting influences on treating invasive plant species ("treated").

	B	SE	Wald X^2	df	*P*-value	Exp(B)
Model 1[a]						
Aware ≥ 1species	0.765	0.224	11.688	1	0.001	2.148
Concerned ≥ 1species	1.210	0.257	22.164	1	0.000	3.355
Grazing Important	0.212	0.224	0.898	1	0.343	1.237
Habitat Important	0.588	0.335	3.074	1	0.080	1.800
Constant	−1.754	0.373	22.124	1	0.000	0.173
Model 2[b]						
Aware # species	0.252	0.061	16.961	1	0.000	1.287
Concerned # species	0.161	0.039	17.394	1	0.000	1.175
Grazing Important	0.161	0.223	0.522	1	0.470	1.175
Habitat Important	0.739	0.337	4.799	1	0.028	2.093
Constant	−1.433	0.353	16.442	1	0.000	0.239

[a] Model X^2=64.727, Nagelkerke R^2 = 0.192.

[b] X^2 = 63.293, Nagelkerke R2 = 0.188.

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Table 7. Awareness and concern on whether owners treated.

Treated hectares on parcel to control invasive plants	Aware ≥ 1 species[a]		Concerned ≥ 1 species[b]	
	Yes	No	Yes	No
Yes	66.4%	37.9%	64.1%	26.6%
No	33.6%	62.1%	35.9%	73.4%

[a] $X^2 = 35.302$, $p \leq 0.001$,
[b] $X^2 = 50.123$, $p \leq 0.001$

size were not significant predictors of management activity is surprising given that other research has found them to be important to forest management (Alig et al., 1990; Amacher et al., 2003; Arano and Munn, 2006; Beach et al., 2005; Butler, 2008; Joshi and Arano, 2009). It is also surprising that income, education, age and length of ownership were not significant predictors. Other studies have found that owners with higher incomes and levels of education are more likely to thin and reforest (Alig et al., 1990; Beach et al., 2005; Butler, 2008) and less likely to harvest (Alig et al., 1990; Joshi and Arano, 2009); younger owners are more likely to reduce hazardous fuels on their parcels (Joshi and Arano, 2009); and owners who have owned their properties for longer are more likely to harvest timber (Conway et al., 2003; Vokoun et al., 2006) and less likely to thin, apply herbicides, and create wildlife habitat and recreation values (Joshi and Arano, 2009).

One demographic variable that was significantly associated with whether owners treated invasive plants but not included in our logistical regression models was "use of a parcel as a primary residence." Research has shown that where one lives in relation to the parcel they manage affects the likelihood of many management practices. In particular, several studies have found that absenteeism reduces the probability of engaging in forest management activities (Conway et al., 2003; Fischer, 2011; Joshi and Arano, 2009; Romm et al., 1987; Vokoun et al., 2006), including harvesting timber, managing for nontimber uses, and reducing hazardous fuels (Fischer, 2011; Jarrett et al., 2009). Although use of one's parcel as a primary residence predicted whether or not owners treated invasive plants that had the largest odds ratio (between 4.2 ($p \leq 0.000$) and 5.4 ($p \leq 0.000$), depending on the model), we found in chi square tests that primary residence was not significantly associated with whether owners were aware of ($p = .894$) at least one invasive plant species on their parcels. This finding suggests that in the case of invasive plants, the convenience of living on one's property affords owners greater opportunity to respond to invasive plant infestations, but is not necessarily related to heightened awareness of invasive species. Thus, we left it out of the logistic regression models used to test our hypothesis.

A More Nuanced View of Risk Perception. Although awareness and concern were clearly identified as predictors of invasive plant mitigation, 34% of owners who were aware of the nine invasive plant species on their parcels, and 36% who were concerned about them, did not treat their parcels (Table 7). Why did some owners who were aware of and concerned about invasive plant species not do anything to control them? The interviews provided an opportunity to examine owners' perceptions of risk in more detail and to investigate why some owners who are aware of and concerned about invasive plants don't do anything about them. The interviews also provided an opportunity to explore why some owners who were not aware or concerned about the nine species on their parcels nevertheless treated their parcels for invasive plants (Table 7).

We found through the interview analysis that owners' perceptions of risk fell along a spectrum. At one end of the spectrum owners were unaware of or unconcerned about invasive plants. "None of that stuff is an issue," explained one owner of 12 ha in the Sprague watershed. "I will occasionally find thistle but I wouldn't say I'm highly concerned [about invasive plants]. I would say mildly concerned; very mildly." An owner of 405 ha in the Upper Grande Ronde watershed said, "I haven't got any opinions on it. I haven't had enough experience with it…It appears to me it is more of a problem on open and agricultural land

Table 8. Social arrangements for forest management among owners who treated invasive plants.

Arrangement	% of respondents that planned, paid for, and/or conducted work using arrangement
Only on one's own or with family members	39.9
With public agencies (e.g. ODF, BLM, NRCS)	41.2
With private forest owners (e.g. neighbors)	22.7
With non-profit groups (e.g. watershed councils)	18.9

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[than in forested areas].'' Owners also explained that invasive plants were of less concern than other risks to their forests. An owner of 283 ha in the Sprague watershed said, ''Right now my big concern is fire. I am just not that knowledgeable about whether those plants are going to cost me money or lose me anything.''

Owners further along the spectrum were aware of invasive plants but not overly concerned. They considered invasive plants a tractable problem with discrete causes, and predictable, controllable, and mild consequences. They were confident of their capability to control the species. For example, an artist who lives on 4 ha in the Upper Grande Ronde watershed hadn't observed any impacts from invasive plants: ''It has never been so thick with the weeds that there were any kinds of issues, other than they don't belong here.'' A different owner observed that invasive plant infestations were associated with logging and grazing on his 3035 ha ranch in the Sprague watershed, and could be controlled: ''If the ground hasn't been logged or overgrazed it is not an issue…We just go in and kill them off and seed it with grass seed and the next year you can't tell that there was a problem.'' Such owners had difficulty articulating specific negative consequences of invasive plants, apart from them being out of place, even though they sometimes treated their parcels to control them.

Other landowners, however, found invasive plants to be an inevitable and stubborn problem with less certain solutions. At this end of the spectrum, owners believed that incursions by invasive plants had diffuse and uncontrollable causes, negative effects that are not well understood, and difficult solutions. One such owner who manages his 405 ha parcel primarily for ecological goals in the Sprague River watershed exclaimed, ''They are huge! Just last year we had 500 h, probably 600, just dealing with thistles.'' ''Logistically you are never going to control them,'' said another owner in the Sprague River watershed. ''Management tools can help hold them in check, but total control of every species is not going to happen, it is not economically realistic…even if you had the time.'' An owner in the Upper Deschutes watershed admitted:

> ''If I can't deal with something, I find it's better not to really be that worried about it…Like cheatgrass; once it's there, how you can deal with it?… If somebody can show me how to deal with it in a realistic and economical way then I will deal with it.''

These interview data demonstrate that some landowners, despite their awareness and concern, may perceive invasive species as uncontrollable and mitigation as futile. Cognitive psychological theory suggests that the perception that one has no control over an event can limit the possibility of action (Maddux and Rogers, 1983; Slovic, 1987; Slovic, 1999). Thus, owners who anticipate negative consequences of invasive plants on their own properties and believe they have the power to mitigate them are more likely to address invasive plants.

We expected that owners who held livestock grazing and wildlife habitat and/or biodiversity as important forest management goals would anticipate negative consequences from invasive plant infestations and thus be more likely to treat their parcels. However, only wildlife habitat and/or biodiversity were significant in our regression analyses. Indeed, over 90% of the landowners who treated their parcels to address invasive plants held wildlife habitat and/or biodiversity as an important management goal. For example, one owner who viewed downy brome as an ''indication of deteriorating ecological conditions'' sprayed herbicides and reseeded infested ground with native grasses. But few owners who held livestock grazing as an important goal treated their parcels to control invasive plants. Although we did not ask about owners' perceptions of the effects of invasive plants on livestock grazing in the survey, the interviews provide insight into owners' perceptions of this relationship. Unexpectedly, interview informants were unclear about the effects of invasive plants on livestock forage. For example, when asked to describe the negative effects of invasive plants on his parcel, an owner of 1012 ha in the Sprague River watershed said: ''I was going to say the cattle don't like Canadian thistle but actually they do eat them…In fact, that is how they spread.'' In contrast, a number of owners considered grazing a tool for invasive plant control. An owner of 55 ha in the Upper Grande Ronde watershed explained that invasive plants were ''not really causing a problem with the forage for the cows…In fact I run cows to keep things grazed down.'' The interview data suggest that owners who hold livestock grazing as an important goal have conflicting beliefs about the relationship between grazing and invasive plants; some believe that grazing spreads invasive plants while others believe grazing helps control invasive plants, and thus do not treat their parcels more often than would be expected by chance.

In contrast to our initial assumptions, we often found that owners felt invasive plants were problematic for the amenity values they derived from their land including scenery and recreational opportunities. An owner of 324 ha in the Upper Deschutes watershed said invasions by thistles and other invasive plants prevent him from growing a ''forest that you can walk through without falling through brush and having noxious weeds all over the place.'' Few owners were concerned about interactions between fire and invasive species. Only three interview informants believed invasive plants could act as a fuel for fire.

Interview data also shed light on the survey finding that the number of species about which owners were aware and concerned was a significant predictor of whether they treated invasive plants. Thirty percent of survey respondents were aware of between one and three species of the nine species we asked about on their parcels, while only 9%

of respondents indicated they were aware of five or more species, despite the fact that most of the nine species are abundant throughout the study area. Although interview informants were aware of patches of thistle, knapweed, and downy brome in their ponderosa pine stands, some species were less well known. Indeed, few interview informants could distinguish between Canadian and musk thistle, and few owners believed they could identify leafy spurge, Mediterranean sage, Dalmatian toadflax, or medusahead rye. Although many interview informants were aware of starthistle (*Centaurea solstitialis* L.) on their parcels, they claimed the species was abundant and problematic only in their pastures and grasslands, not their woodlands. Interview informants were also aware of and concerned about other invasive plant species than the nine that natural resource professionals identified as problematic, for example, white top [*Cardaria draba* (L.) Desv.] and houndstongue (*Cynoglossum officinale* L.). This finding may explain why some owners who were not aware of or concerned about the nine species nevertheless treated their parcels.

Also notable was that many of the interview informants expressed more concern about weedy native species than invasive exotic plants. For example, interview informants were concerned about western juniper (*Juniperus occidentalis* Hook. var. *occidentalis*), a native tree species that has been encroaching on rangelands and ponderosa pine forests in the absence of fire, raising concerns among natural resource professionals (Azuma, 2005). A lawyer in Klamath Falls described encroachment by western juniper, which he recognized as a native species, as a severe problem on his 324 ha parcel in the northeast corner of the Sprague River Watershed:

> It has changed the species composition and I am sure it has added to the erosion…If you get a summer, or when it dries and the winds start blowing, it will be dusty in the juniper areas because there is nothing holding the soil down.

Landscape-Scale Risk Perceptions and Practices. We found that many interview informants were well aware of forest conditions and management practices on neighboring lands, and how these conditions and practices affected their ability to control invasive plants on their own parcels. Many of the interview informants traced infestations to patches of invasive plants on neighboring properties. For instance, an owner of 263 ha in the Sprague River watershed attributed invasive plant infestations primarily to activities on lands beyond their property boundaries:

> ''The biggest problem is seeds coming from other people's property to our property, period… These roads are fairly rough and if people have got something caught in their vehicle the seeds drop out and they get started.''

Similarly, an owner of 65 ha in the Upper Deschutes watershed explained that invasive plants ''blow over from the neighbors. My neighbor with his horses riding out in the back; everyplace there is a horse trail there are weeds.'' A rancher who owns several thousand hectares of rangelands and ponderosa pine woodlands in the Upper Grande Ronde watershed explained that although she did not currently have a knapweed problem in her ponderosa pine stands, she expected an invasion soon because of risks from neighboring properties. ''We have got knapweed coming from on the other side so that is probably the next [invasive plant] we're going to have to deal with.''

Perhaps because of their landscape-scale view of invasive species infestations, some landowners felt that mitigating invasive plants was an obligation of being a good neighbor. An owner of almost 121 ha in the Sprague watershed explained that part of the reason he was controlling invasive plants on his property was for the benefit of his neighbors. ''I would guess that if neighbors were trying to control something on their property, having a seed source next door to them would adversely impact them over a period of time. There would be a spread on to the neighbors.'' An owner in the Upper Grande Ronde watershed treated starthistle on his neighbor's parcel every year because he believed it originated on his own land and felt responsible.

Other interview informants attributed the spread of invasive plants to a lack of understanding of invasive plant invasions as a landscape-scale process that requires coordinated mitigation among neighbors. An owner of almost 324 ha of forestland in the Upper Grand Ronde watershed believed the invasion of one species on his parcel was the result of open range policy and practice (landowners being expected to fence out other people's livestock): ''We have an open gate policy. Well, it just makes a mess. It starts with range cattle coming off the backside through that canyon and spreads as they walk down.''

Several interview informants reported cooperating with neighbors to control invasive species, including a 20-year effort among rangeland owners in the Upper Grand Ronde watershed to control starthistle, and a more recent effort among subdivision residents in the Upper Deschutes watershed to control knapweed and Dalmatian toadflax. Interview informants also described cooperating indirectly through extension agents and county weed managers. An owner of several hundred hectares in the Sprague watershed explained: ''A few of the neighbors helped us with our weeds but the communication is more so through the main management guy and not through us.''

The survey data also document cooperative behavior among our sample of NIPF owners. Substantial proportions of survey respondents said they had communicated and cooperated with others to get forest management work done, although not invasive species control specifically. Twenty-three percent of the sample had worked with other

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private forest owners, about 40% had worked with public agencies, and about 20% had worked with nonprofit groups on forest management (Table 8). Thus, despite the low levels of interest and willingness to cooperate among private forest owners reported in the literature, the owners in our study area show some potential for coordinated management, perhaps because of the multiple landscape-scale risks they perceive to their properties including invasive species and wildland fire (Fischer and Charnley, 2012).

Implications for Policy and Future Research. Among NIPF owners in Oregon's ponderosa pine zone awareness and concern were associated with invasive species mitigation in the simplest sense: whether they treated invasive plants on their parcels. The number of species about which owners are aware and concerned was associated with whether owners treated invasive plants. Interview informants suggested that their perceived ability to have an impact was important to their decision to reduce invasive plant risk. Although we do not make claims about causality or directionality, these findings suggest that many of the owners who are aware of and concerned about invasive plants are able to seek out resources and skills to control them without being constrained by external or institutional barriers. An implication of this finding would be that programs that raise awareness and concern about invasive plants, including the number of species that owners are aware of and concerned about, may have the effect of increasing the likelihood of treatments.

Our sampling strategy favored owners of large parcels, addressing a research bias toward owners of small holdings that characterizes many studies. The majority of NIPF owners nationwide own parcels that are less than 4 ha in size, whereas the majority of the NIPF land is owned by people having 40 ha or more (Butler and Leatherberry, 2004). Our research has implications for policies and programs that seek to impact the greatest possible number of hectares, though they may not apply to the greatest possible number of owners.

Our survey results indicate that NIPF owners who use a parcel as their primary residence are more likely to treat invasive plants on that parcel than those who do not, though use of one's parcel as a primary residence did not predict awareness about invasive plants. Our survey also found that 74.5% of NIPF owners in our study area do not live on their parcels. An implication of this finding is that one way of increasing participation in invasive plant mitigation is to increase outreach about its importance to landowners who live off-site.

Wildlife habitat and/or biodiversity was an important management goal for most survey respondents, and a predictor of whether they treated invasive plants. Nevertheless, 43% of owners who held wildlife habitat and/or biodiversity as an important goal did not report treating their parcels to control invasive plants. This finding suggests that education, incentives, technical assistance, and regulatory programs that frame invasive plant risk in terms of threats to wildlife habitat and/or biodiversity, and that provide information about and assistance with mitigating the consequences of invasive plants for wildlife habitat and/or biodiversity, may resonate with, and therefore motivate, NIPF owners to treat. Owners' management goals are likely to vary by place; more broadly, this finding suggests that framing invasive plant risks in terms of their implications for owners' high priority forest management goals, whatever they are, may be an effective strategy for motivating them to treat.

The implications of our findings for how to target policies and programs to owners who are motivated by livestock grazing are less clear. Despite the extensive literature on the effects of invasive species on forage production, holding livestock grazing as an important forest management goal was not associated with treating invasive plants in our study. One explanation for this is that invasive plants do not greatly impact forage production in ponderosa pine habitat, perhaps because invasive plants are not highly abundant in areas with forest cover. Alternatively, the landowners who hold livestock grazing as an important goal may be those who own open pasturelands which, due their exposure to the sun, are more susceptible to incursions by invasive plants. These owners may feel unable to control the invasive plant species we asked about, either because they are too pervasive, or treatment is too costly. In this case, technical and financial assistance programs would be desirable.

The more that owners perceive that their ability to pursue their forest management goals is threatened by invasive plants, the more likely they will be motivated to control invasive plants, assuming they have the necessary skills and capacity. More research is needed on how invasive plants may affect the goals that owners have for their land, and why owners with certain goals (e.g., livestock grazing) are not more active in mitigating invasive plants. If natural resource professionals can make information available about the impacts of invasive plants on the forest management goals that owners care about, they may have greater success in motivating them.

Another implication of our findings is that increasing owner awareness of the landscape-scale risks of invasive plants, and engaging owners in transboundary mitigation efforts, are worth considering in management planning efforts. The survey results suggest that owners communicate and cooperate with other private and public land owners in forest management, and the interview results suggest that some owners communicate and cooperate on invasive species control in particular. Furthermore, interview informants appeared reasonably sensitive to the risks of invasive plant incursions across ownership boundaries. Thus, raising awareness about the risks of invasive plants posed by conditions on the broader landscape, and

encouraging cooperation among NIPF owners and between NIPF owners and other types of landowners such as public land management agencies, may be fruitful.

Epanchin-Niell et al. (2010) propose two models for addressing invasive species in mixed-ownership landscapes that seem appropriate for NIPF owners given their preferences for peer-to-peer communication and voluntary (as opposed to regulatory) conservation measures (Brook et al., 2003; Fischer and Bliss, 2008; Fischer and Bliss, 2009; West et al., 1988): (1) bottom-up approaches in which landowners and natural resource professionals talk about and coordinate invasive species management with their neighbors, participate in weed control organizations, and engage in civic and political action; and (2) middle-out approaches, in which organizations such as weed control districts are formed to facilitate communication between stakeholders in an area, and to focus institutional support, funding, and outreach. Each of these models requires not only communication and cooperation among private forest owners, but also between private forest owners, natural resource professionals, and other stakeholders. Unfortunately, little information is available about the extent to which owners and natural resource professionals perceive common problems, use similar communication styles, or trust each other in the context of invasive plants, elements that the literature suggests are important for cooperation in mixed-ownership landscapes (Yaffee, 1998). The fact that owners in our study were not familiar with most of the species that the natural resource professionals we spoke to were concerned about suggests a lack of communication and perception of common problems between these two groups. Programs that try to leverage commonalities and build more common ground among landowners, and between landowners and natural resource professionals, could help bridge this gap. Comparative research on how different types of private landowners and natural resource professionals view and come to agreement on invasive species risks is important for informing such program designs, and is a worthy priority for future research.

Given that infestations by invasive species require some human management of the landscape, and that the capacity for people to react and adapt to such invasions is predicated on their perceptions of them and the incentives (and disincentives) before them, how invasive plant invasions are managed is arguably a product of social systems rather than just the species in and of themselves (Robbins, 2004). This study is one step toward understanding the private forest owner component of the social systems that will determine whether and how invasive plants are mitigated in the western United States.

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