Pileated Woodpecker Occupancy and the Occurrence and Recruitment of Key Habitat Attributes in a Managed Forest

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Abstract

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As anthropogenic land use accelerates, it is critical that resource managers evaluate and address the needs of wildlife species. Managed forests have a unique opportunity to provide economic stability in communities while maintaining habitat for forest associated species. Forest management prescriptions include leaving areas of undisturbed mature trees to provide habitat for wildlife. It is essential, yet not often done, to both evaluate the habitat that is left as well as monitor the species that are meant to benefit from this habitat. My thesis aims to fill this gap on a private forest in Western Washington by assessing the occurrence and recruitment of standing dead trees (snags) and a species dependent upon this resource, the pileated woodpecker (*Dryocopus pileatus*).

I estimated the density of snags across Green Diamond Resource Company's (GDRCo) Olympic Tree Farm that operates under a Habitat Conservation Plan (HCP). The HCP has a requirement to retain 4.9 snags per hectare (SPH) >61 cm Diameter at Breast Height (DBH) and 4.9 SPH 30-61 cm DBH to provide habitat for cavity nesting birds. The purpose of this study was to examine if the goals are currently being met and if the forest is on a trajectory to meet those goals throughout the life of the HCP (50 years). I found that the goals for small snags are being met and the goals for large snags are not being met. Net recruitment of snags for both size classes was positive. If these recruitment rates remain the same, snags will increase over time and the goal for large snags will be reached in fifteen years, at year 30 of the HCP.

I also surveyed for pileated woodpeckers on the managed tree farm and modeled its detection and occupancy using PRESENCE (http://www.mbr-pwrc.usgs.gov/software/presenece.html). I estimated that woodpeckers occupied 27.5% of survey locations, which is surprising for a species initially thought to be an obligate of expansive mature forests. The models that performed best included the amount of forest aged 30-45 within 277ha of a survey location, which was negatively correlated with occupancy and the amount of mature forest within 277ha, which was positively correlated with occupancy. With a one percent increase in forest aged 30-45 within the 277ha home range, I found a 10.25% decrease in the likelihood of a site being occupied by pileated woodpeckers. With a one percent increase in mature forest in the 277 ha home range, I found a 3.68% increase in the chance of the site being occupied by pileated woodpeckers. My findings suggest that mature forest reserves are necessary for maintaining pileated woodpecker habitat. Mature forest reserves will become increasingly important as intensively managed forests move to a younger rotation age.

Chapter 1

Snag Abundance and Recruitment

ABSTRACT

I estimated the density of snags across a managed tree farm that operates under a Habitat Conservation Plan (HCP). The HCP has a requirement to retain 4.9 snags per hectare (SPH) >61 cm Diameter at Breast Height (DBH) and 4.9 SPH 30-61 cm DBH to provide habitat for cavity nesting birds. The purpose of this study was to examine if the goals are currently being met and if the forest is on a trajectory to meet those goals throughout the life of the HCP (50 years). I found that the goals for small snags are being met and the goals for large snags are not being met. Net recruitment of snags for both size classes was positive. If these recruitment rates remain constant, SPH will increase over time, meeting the large snag retention goals at year 30 of the HCP.

INTRODUCTION

At the turn on the century, forest management practices in Washington consisted of clear cutting with no mature forest set asides. Since then, with the evolution of forest management and silvicultural practices, as well as regulations, there have been many advances in forest management practices. Mature forest leave areas (areas that are permanently restricted from harvest) are now a requirement in managed forests. Additionally, due to its importance for wildlife, retention of residual woody features is a common component of forest management prescriptions (Ganey, 1999, Taylor and MacLean 2007).

Residual woody features including snags (standing dead trees) and downed wood from fallen trees or pilings left after timber harvest are important for a variety of species. Effective strategies to retain dead wood are needed because this resource is critical for wildlife. Snags provide essential foraging and breeding habitat for many vertebrate species, including cavity nesting birds. Population densities of primary cavity excavating birds are closely associated with snag density (Bevis and Martin 2002). Cavities created by primary excavators are important requirements of other species of birds and

mammals, i.e. secondary cavity nesters (Bevis and Martin 2002). Lack of cavity nesting sites has limited the abundance of some birds in intensively managed forests (Angelstam and Mikusinski 1994). Snags are also of value as a source of coarse woody debris (CWD). CWD is a component in the life history requirements of 179 vertebrates (Thomas 1979, Bull 2002) including birds, reptiles, amphibians, large carnivores, bats and other small mammals.

Within more intensively managed forests, snag retention can be difficult because many snags pose a safety hazard during cutting operations and must be removed. Additionally, obtaining accurate estimates of snags on a landscape is challenging. Recurrent harvest over time has resulted in managed forests having fewer snags than unmanaged forests (Wilhere 2003, Ganey and Vojta 2005, Wisdom and Bate 2008). As snags are scarce on managed forests, meeting retention targets (Ganey 1999, Spiering and Knight 2005) as well as sampling and monitoring snag abundance is challenging. It is difficult to accurately estimate snag density on a landscape because snags are difficult to assess on photos (Bütler and Schlaepfer 2004) and often occur in clumps, due to fungus or insect damage. The patchy distribution of snags makes estimation imprecise. To address this challenge, studies often use large fixed area plots when monitoring snags over time (Raphael and Morrison 1987; Ganey and Vojta, 2005, Parish et al. 2010). Sampling methods used to estimate snag abundance include N-tree distance sampling (Kenning et al. 2005), circular fixed area plots (Bull et al. 1990, Marquardt 2010), rectangular fixed area plots (Bate et al. 2008, Marquardt 2010), horizontal line sampling (HLS) (Husch et al. 2003, Ducey et al. 2002, Marquardt 2010) and modified horizontal line sampling (MHLS) (Ducey et al. 2002, Kenning et al. 2005). Typically, fixed area plots are the preferred sampling method for trees per hectare or abundance (Stage and Rennie 1994, Marquardt 2010). Rectangular plots are recommended for estimating snag abundance (Bate et al. 2002, Ducey et al. 2002, Kenning et al. 2005). Rectangular plots are better for capturing variation that occurs across vegetative gradients (Marquardt 2010), for sampling patchy distributions (Krebs 1989, Bate et al. 2008) and are more efficient than circular plots (Johnson and Hixon 1952). Sampling along a line rather than at a point is more efficient and produces better estimates of snag abundance (Ducey et al. 2002, Kenning et al. 2005).

My study focused on snag abundance and persistence as well as pileated woodpecker (*Dryocopus pileatus*) use of snags. Snag longevity is important to snag abundance and accurate

estimates of snag persistence are a necessary component of any sampling program. Snag abundance is strongly influenced by fire, wind, past logging practices, and disease (Raphael and Morrison 1987, Wilhere 2003, Ganey and Vojta 2005; Vanderwel et al. 2006; Taylor and MacLean 2007). Different tree species decompose at different rates (Raphael and Morrison 1987; Garber et al. 2005; Parish et al. 2010). For example, a large Douglas-fir (*Pseudotsuga meziesii*) snag may persist for over 50 years and a western red cedar *(Thuja plicata)* for over 270 years (Daniels et al. 1997, Parish et al. 2010). In addition to species, snag persistence is related to the height/diameter ratio, top condition and snag size (Raphael and Morrison 1987, Ganey and Votja 2005, Garber et al. 2005, Vanderwel et al 2006, Parish et al. 2010). With these factors in mind, one of the goals in this study was to assess snag longevity throughout the 50 year HCP.

Snags are important to many listed species in Washington State including fisher, purple martin, Vaux's swift, long-eared myotis, long-legged myotis and the pileated woodpecker (WDFW 2016). Since the pileated woodpecker is a primary cavity excavator and a state species of concern, I examined pileated woodpecker use of snags. Management recommendations are most effective if specific to the habitat and geological area (Bull and Jackson 2011). Evans and Conner (1979) reported 0.6 snags per hectare greater than 54cm DBH results in the largest densities of pileated woodpeckers in bottomland forests. Their findings were supported by Renken and Wiggers (1993), whose results indicated 71% of high density woodpecker areas met Evans and Conner standard. Bull and Hothausen (1993) recommended the Forest Service maintain at least 8 snags per hectare with 1.6 snags larger than 51cm diameter at breast height (DBH) for this woodpecker. The purpose of this study was to provide landscape specific management recommendations for snag retention.

METHODS

Study Area

I worked at the base of the Olympic Peninsula in western Washington State, within a managed forest, the Green Diamond Resource Company's Olympic Tree Farm (Fig. 1.1). The dominant tree species are Douglas-fir and western hemlock (*Tsuga heterophylla*); western red cedar and red alder (*Alnus rubra)* are codominant. The Olympic Tree farm consists of 135,021 hectares of managed timberlands. Currently, of the 135,021 hectares, 27,955 hectares are in permanent leave areas to maintain mature forest patches around lakes, streams and wetlands, unstable slopes and wildlife habitat retention areas.

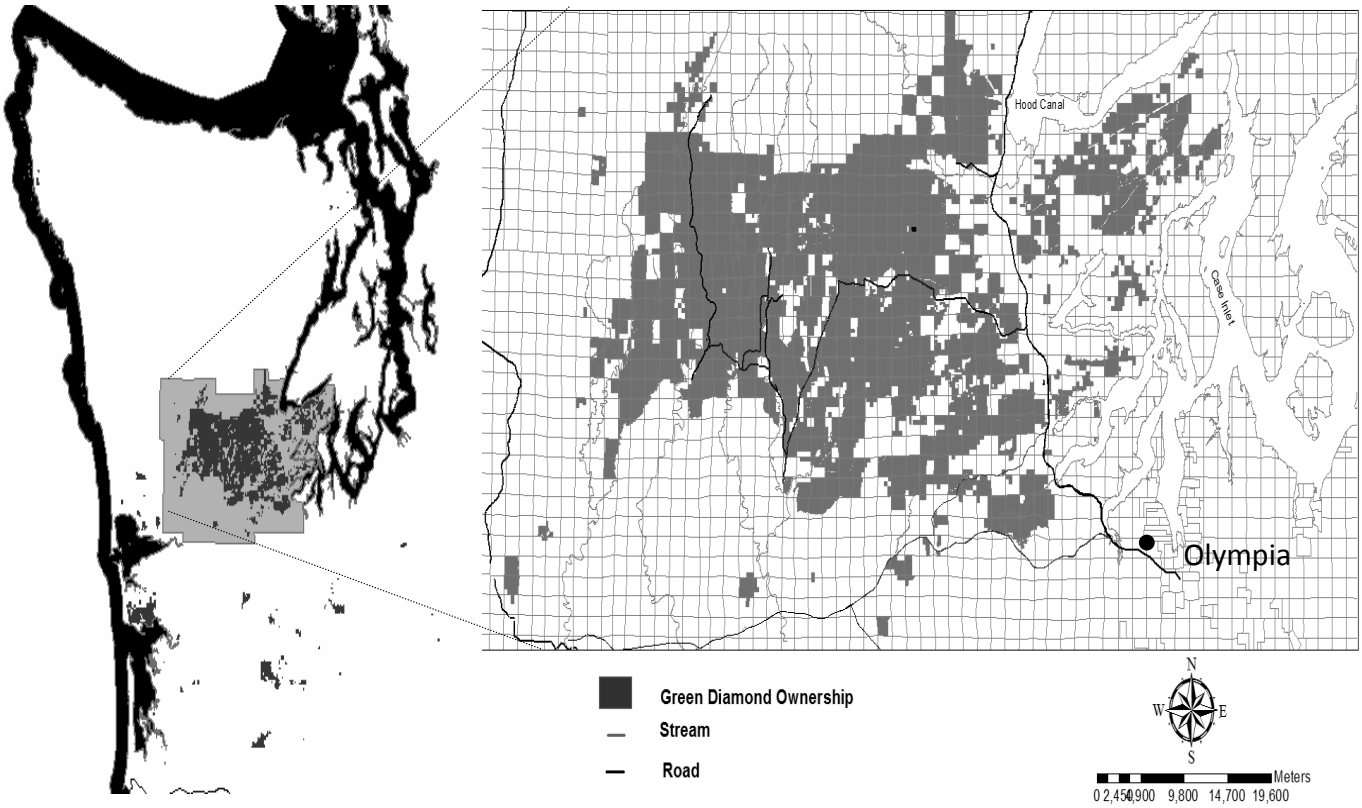

Figure 1.1. Study Area, Green Diamond Resource Olympic Tree Farm.

Survey Design

I surveyed for snags during the summers of 2011-2013. In 2011 my surveys showed small snags (30-61 cm DBH) to be common, therefore I only surveyed for snags >61 cm 2012 and 2013. I randomly selected 70 harvest units (distinct plantations of a certain age that included patches of mature forest) to survey from the total of 3,672 harvest units. Individual survey sites averaged 42 hectares. I surveyed mature forest patches left in plantations and recently harvested stands. In mature stands, I surveyed a transect through the middle of the unit and noted which snags would be in the areas left after harvest and which would be in the area to be harvested.

Within mature forest leave areas surrounding streams, plot spacing was one plot oriented perpendicular to the stream per 100 meters. Marquardt (2010) found spacing one plot per 200 feet led to more accurate results when estimating trees per acre and basal area per acre within riparian areas. Due to the scarcity of snags >61 cm, a nested plot design was used. A 20 meter wide variable length rectangular plot was used to sample snags < 61 cm and a 40 m wide variable length rectangular plot was used for sampling snags >61 cm (Figures 1.2 and 1.3). Systematic sampling with a random start was used on each segment. Due to the potential for difficult layout of plots on mature forest leave areas on unstable slopes with rocky outcroppings, a circular plot is more efficient (Husch et al. 2003). I used 8 meter radius fixed area plots to survey in these areas.

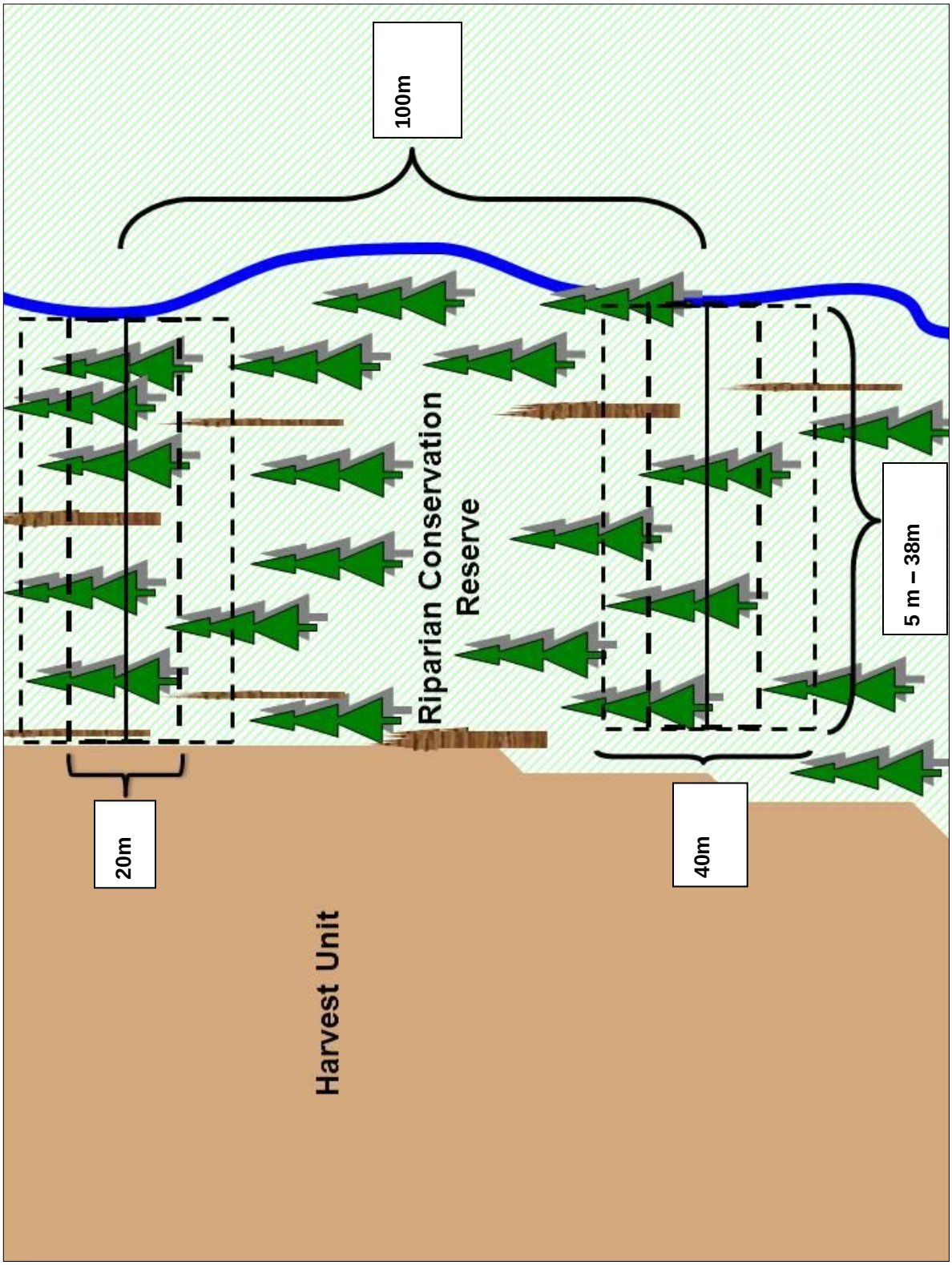

Figure 1.2. Illustration of plot layout.

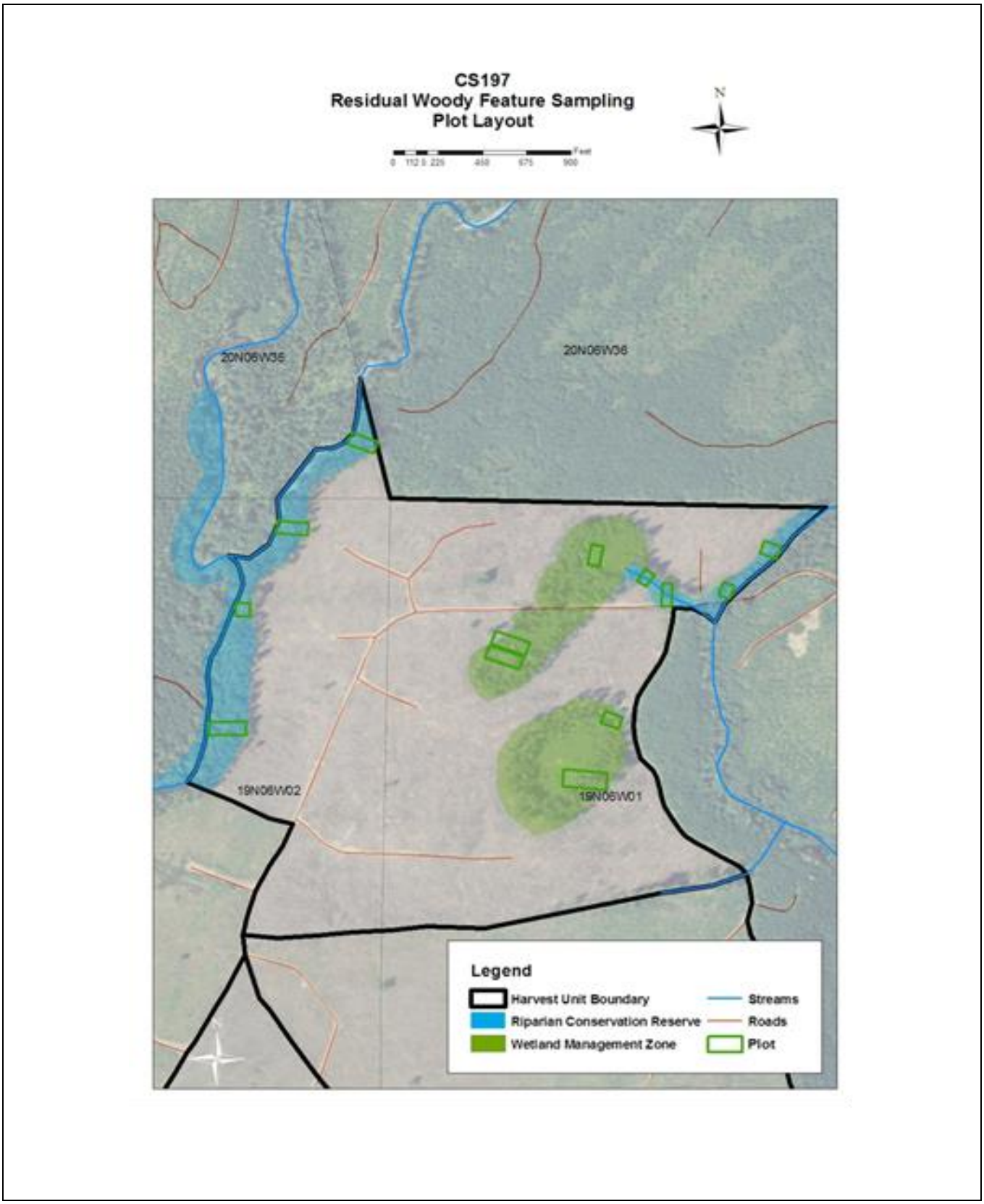

Figure 1.3. Plot layout along mature forest patches at a randomly sampled harvest unit.

Data Collection

I established plot locations using a Garmin 60CS global positioning system and recorded a GPS point at the beginning and end of each plot to ensure they could be located in the future. For plots within mature leave areas surrounding streams, I began measurements at the stream and recorded data for 10 meters on each side of the transect (20 meters for snags >61 cm DBH) ending at the edge of the RCR. Transects were perpendicular to the stream. I measured all snags whose center fell within 10 meters (20 meters for snags >61 cm DBH) from the transect. A dead tree qualified as a snag if it was greater than 30 cm DBH, taller than 6 meters in height and met the Class 1 decay class description under the Five-Class Method (Thomas 1979). Snags that did not meet the size requirement but showed evidence of use (foraging and cavity excavations) were also recorded. Trees with a broken top but a live crown did not qualify as snags. I measured each plot length using a 50 foot steel tape. I recorded each snag's species, height (meters), diameter (cm), decay class (Thomas 1979) and use (foraging and cavity excavations).

During snag surveys in 2012 and 2013, I collected additional information to examine the distribution of pileated woodpeckers across the tree farm. I recorded foraging excavations (characteristic rectangular), nesting cavities (characteristic oval), sightings and audio detections.

Snag Recruitment Surveys

GDRCo set up 75 permanent riparian plots in 2001 and 2002. Plots were 30 meters long and the width of the leave area (5-38 meters) wide. Each tree and snag was marked with a metal tag. Data were collected on species, DBH, height and tree condition. I revisited 15 of these plots and collected data to assess how many new snags had been recruited and how many snags had fallen.

Analysis Methods

I averaged snags per hectare across all areas sampled. In order to assess pileated woodpecker response to timber harvest, I analyzed signs of pileated woodpeckers in landscapes in four different categories: mature forest (>45 years old), mature forest left in recently harvested (within 5 years) area that was adjacent to a unit (average size 42 hectares) of mature forest, mature forest left in a recently

harvested area that was not adjacent to a mature stand., and mature forest left in a plantation over five years old.

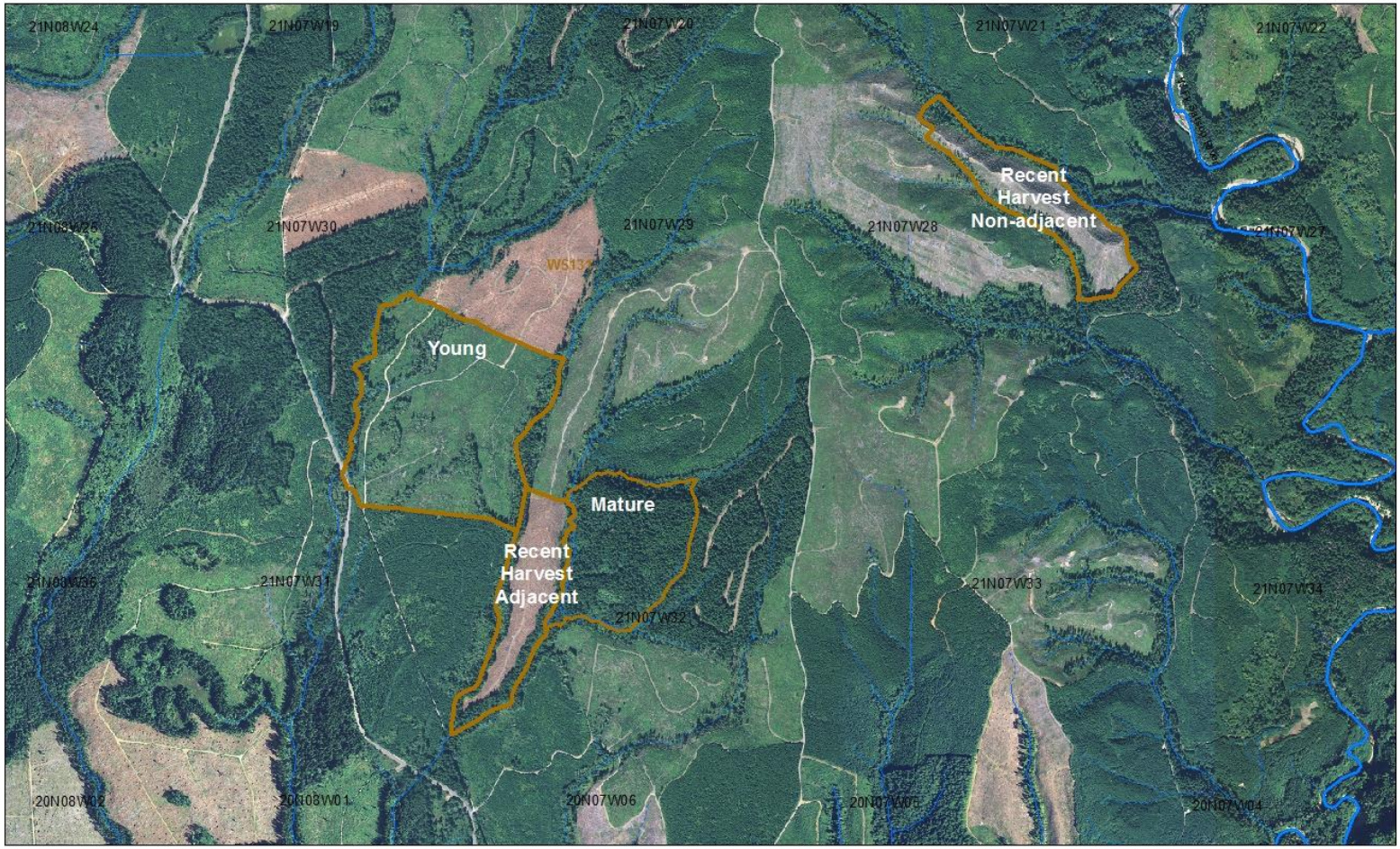

Figure 1.4. Harvest Units Surveyed. Four different stand categories were sampled: mature forest, mature forest left within a recently harvested area adjacent to a mature forest stand, mature forest left in a recently harvest area not adjacent to a mature stand and mature forest left in a plantation over five years old.

RESULTS

I found an average of 14.8 snags per hectare (SPH) for snags 30-61cm DBH and an average of 2.11 SPH DBH 61cm or larger. On permanent plot surveys I found 2.09 small SPH recruited every ten years and 1.38 SPH fallen, resulting in a net recruitment of 0.71 SPH. Small snag goals are currently being met, and are on a trajectory to increase. For snags greater than 61cm DBH, 1.38 SPH were recruited and none were fallen, resulting in a net recruitment of 1.38 SPH (Table 1.1). These estimates assume constant rate of change over time. These recruitment rates show that leave areas are on a trajectory to meet large snag retention goals in 2031, at year 30 of the HCP (Figure 1.5).

All four stand categories exhibited evidence of pileated woodpecker presence (e.g. foraging excavations or nesting cavities) (Figure 1.6 &1.7). The majority of large snags were in the mature forest retained in recently harvested stands (Figure 1.8). It appeared that pileated woodpeckers had used 44% of large snags (Figure 1.9). Snags with oval excavations characteristic of pileated woodpeckers averaged 18.8” DBH for all recorded and 13.1” DBH for newly excavated nesting cavities (Table 1.2). No snags with new nesting cavity excavations were >61cm DBH. All snags with new cavities had a nearby unused snag >61cm, typically of a similar decay class.

Table 1.1. Snag recruitment rates per ten years from permanent plot sampling. Net recruitment was positive for both small (30-61cm diameter) and large (>61cm diameter) snags.

Permanent Plots	
30-61 cm snags recruited per hectare	2.09
30-61 cm snags fallen per hectare	1.38
>61 cm snags recruited per hectare	1.38
>61 cm snags fallen per hectare	0.00
30-61cm snags net recruitment (snags per hectare)	**0.71**
>61 cm snags net recruitment (snags per hectare)	**1.38**

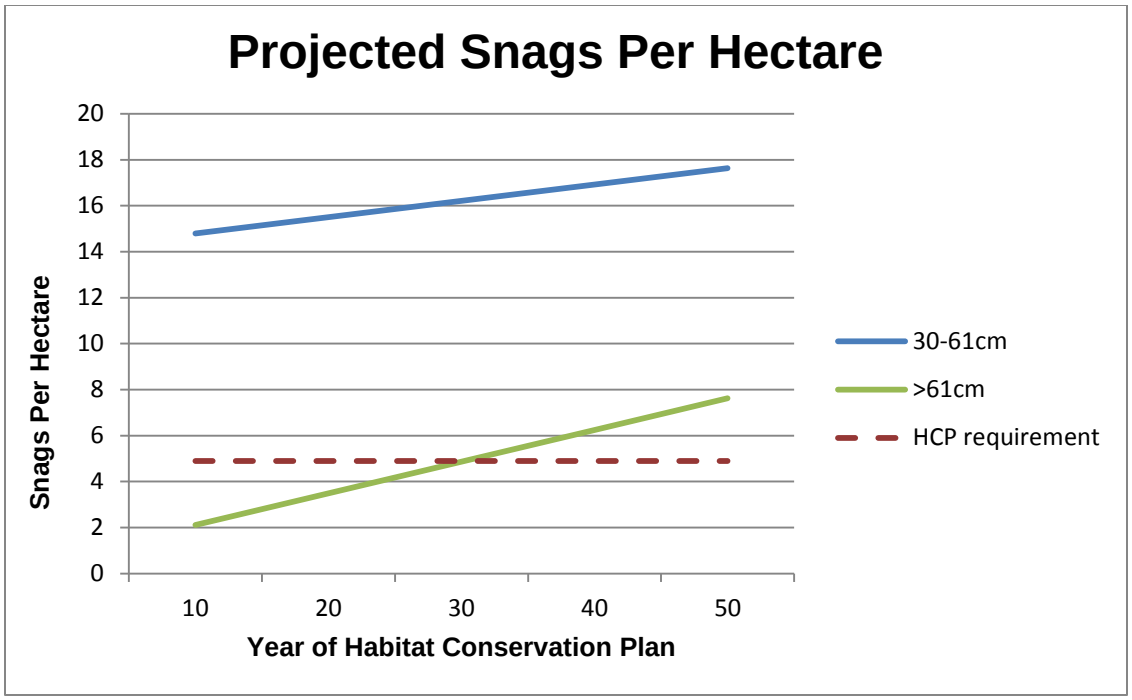

Figure 1.5. Habitat Conservation plan sang retention goal (red) and projected snags per hectare based on current snag recruitment rates. Snag retention goals are being met for small snags (30-61cm) and are projected to be met by year 30 (2031) of the plan. This projection assumes recruitment rates will remain constant.

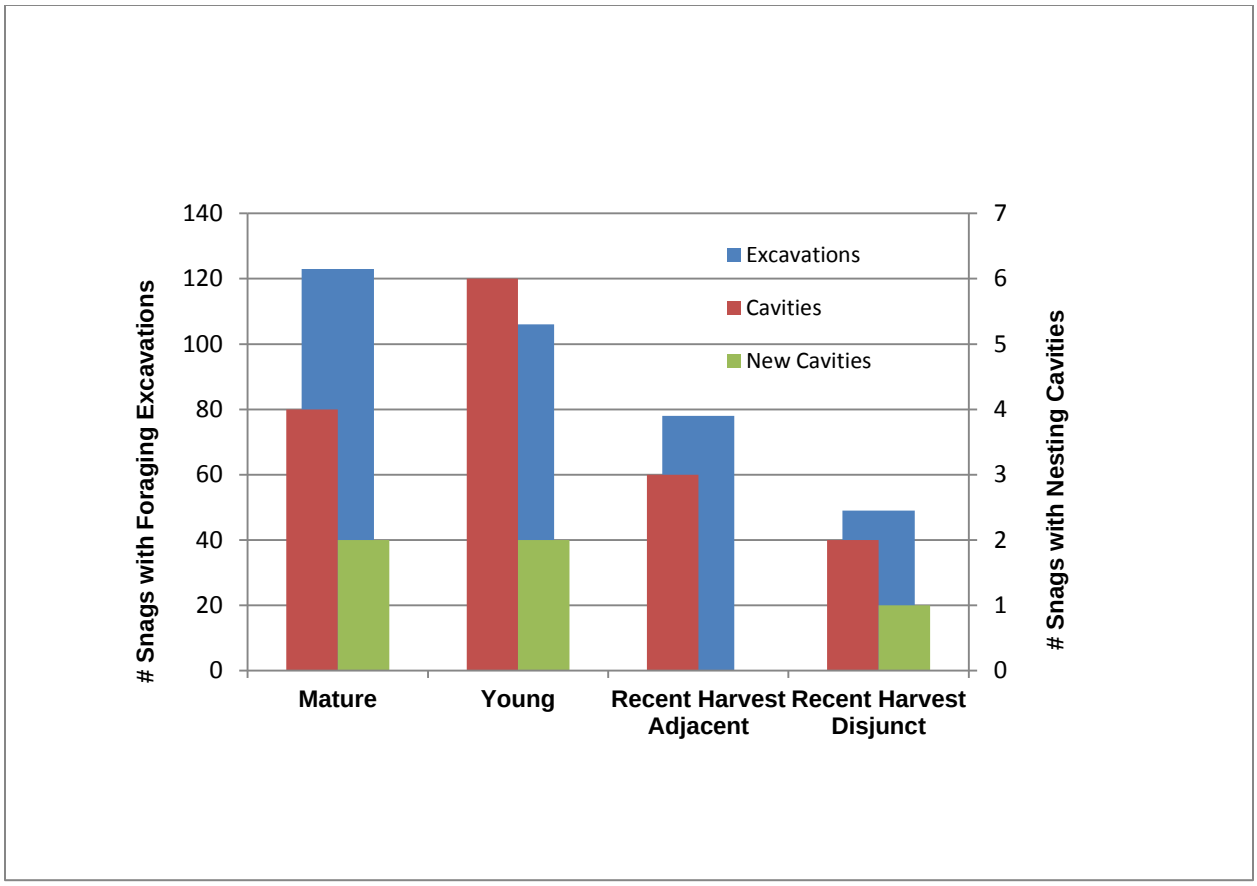

Figure 1.6. Pileated woodpecker response to harvest. Evidence of pileated woodpeckers (foraging or nesting cavities) was present in all four stand categories.

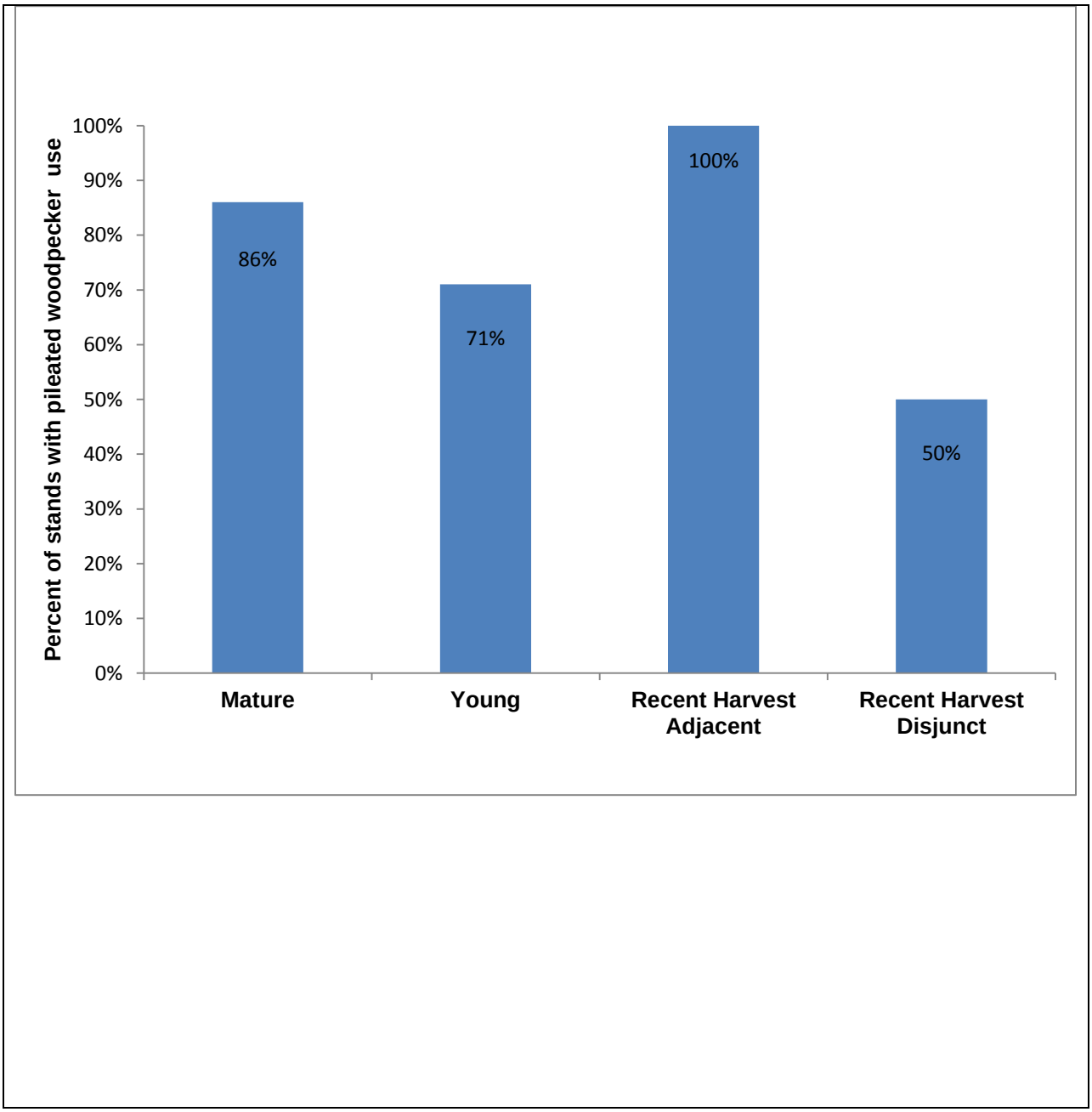

Figure 1.7. Signs of use by stand category: mature forest, mature forest left in plantations >5 years old, mature forest left in areas recently harvested adjacent to mature forest, mature areas left in areas not adjacent to mature forest.

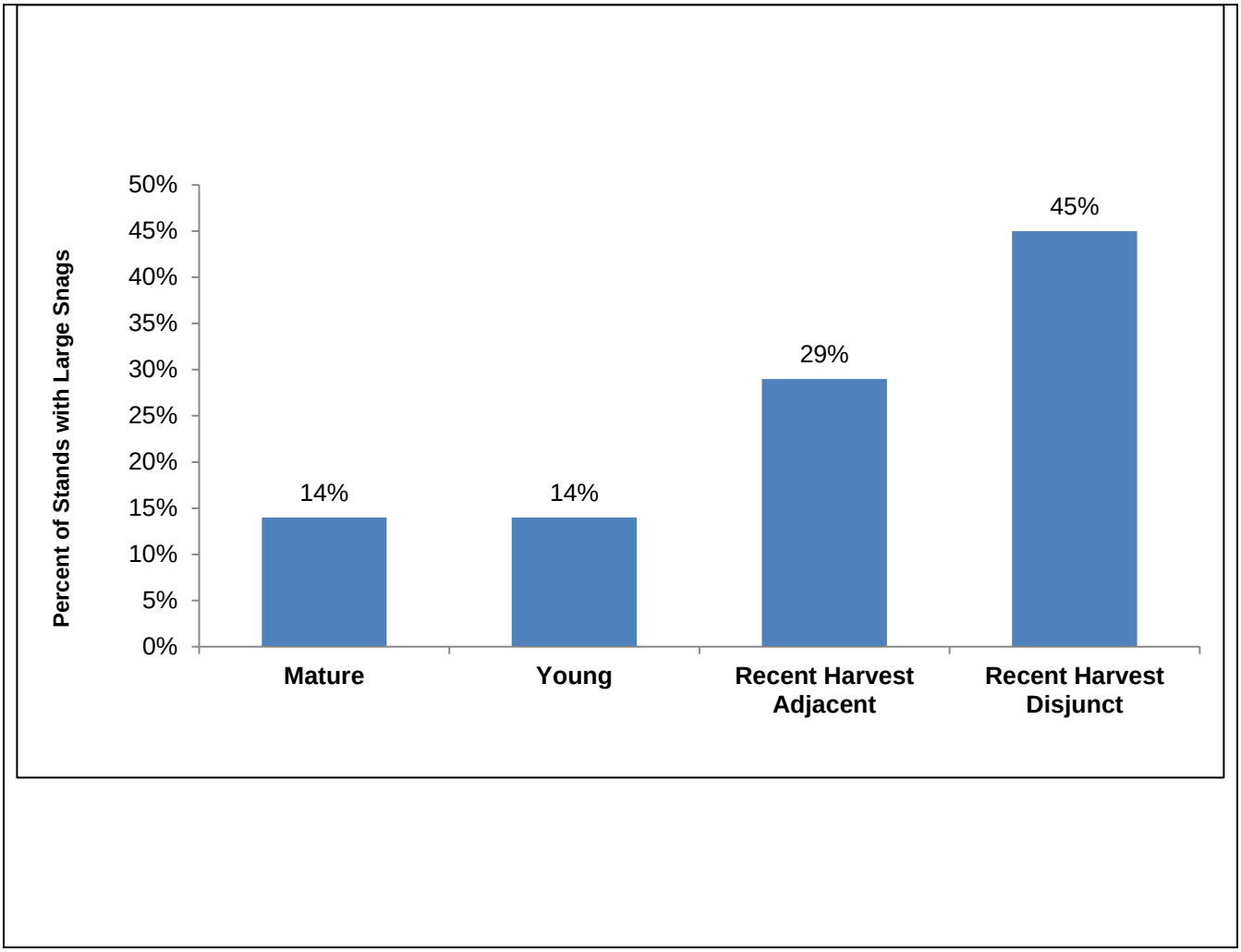

Figure 1.8. Large snag distribution by stand category: mature forest, mature forest left in plantations >5 years old, mature forest left in areas recently harvested adjacent to mature forest, mature areas left in areas not adjacent to mature forest.

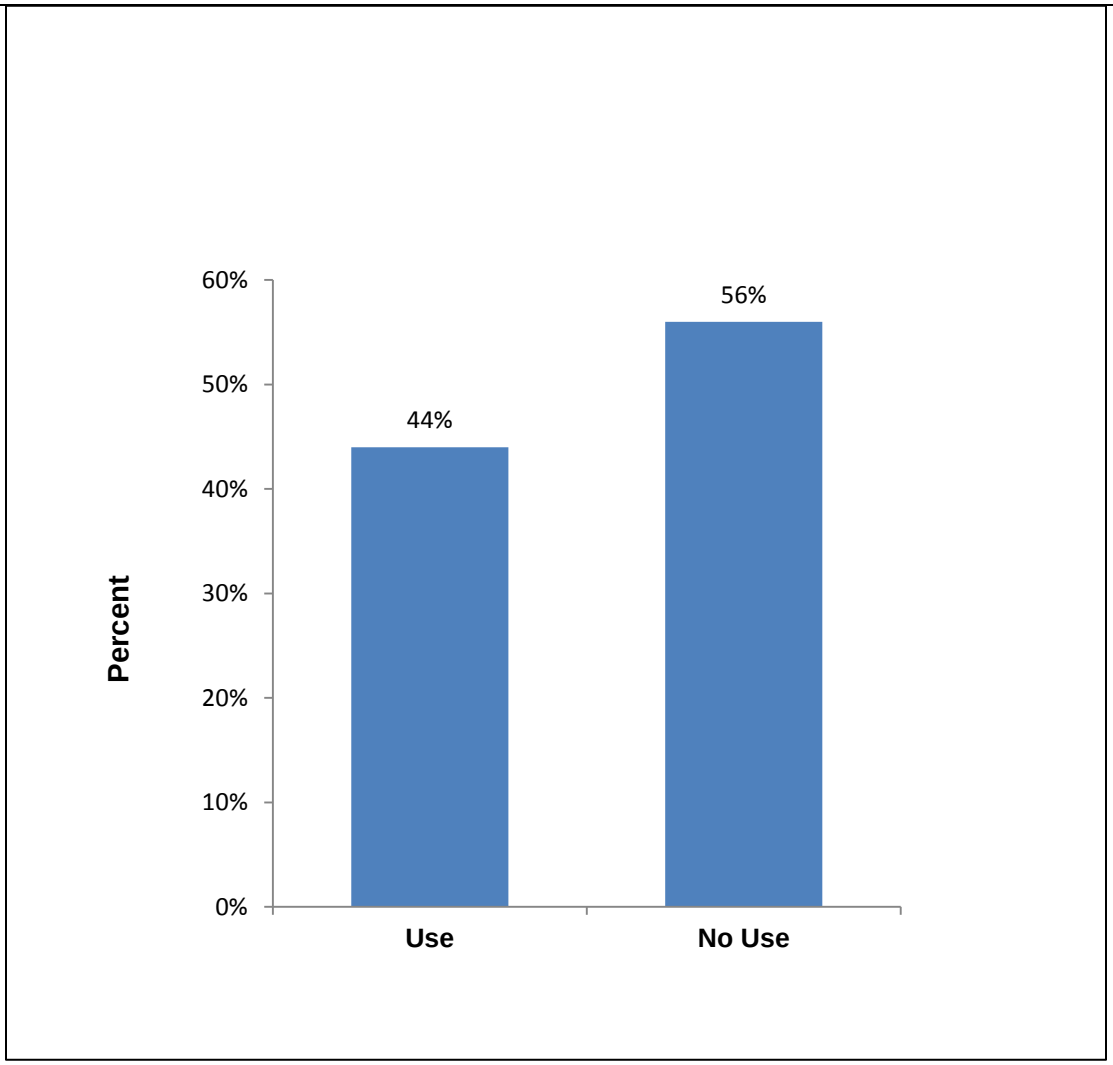

Figure 1.9. Large Snag Use. 44% of stands had signs of use, 56% did not.

Table 1.2. Characteristics of snags with new nesting cavity excavations.

Tree	Species	DBH cm	Snag Class
1	Douglas-fir	32.0	3
2	Douglas-fir	27.9	2
3	Western Hemlock	46.5	3
4	Douglas-fir	20.1	3
5	Douglas-fir	39.6	3

DISCUSSION

To provide adequate management advice for cavity nesting birds, it is important to obtain accurate estimates of habitat available as well as estimates of what will be available in the future. To address this, GDRCo's HCP required snag monitoring start at year ten of the HCP and provide recommendations as to how often these estimates need to be reassessed. It is also necessary to test the assumptions of what makes adequate habitat (see chapter 2). Snags, or standing dead trees, are an important aspect of habitat for cavity nesting birds and other wildlife.

For both small and large snags, net recruitment was positive (i.e. trees are becoming snags more often than snags are falling) over 10 years. In order to see if the large snags will persist throughout the 50 year plan, GDRCo needs to continue monitoring these plots over time. Many of the large snags are old cedar with a decay class of 4 or 5. These may fall in the near future. Less than half of the permanent plots have been sampled; continued sampling will produce more reliable results.

Retention goals established under the GDRCo HCP for small snags are being met. However, surveys indicate that there are fewer than the targeted 4.9 SPH for snags >61cm DBH. However, if large snags continue on the observed positive net recruitment trajectory, the goal will be met by year 30 of the HCP. Large snag retention goals are hard to meet in a managed forest. Moreover, SPH throughout a large tree farm is hard to accurately assess. Snags are difficult to measure because they are rare on repeatedly logged forest land in western Washington (Wilhere 2003, Ganey and Vojta 2005, Wisdom and Bate 2008). Continued assessment of snag rates overtime will be important. Additionally, studies examining larger riparian leave areas, more upland leave areas and longer rotation ages would be valuable because the forest attributes may be as important to cavity nesting birds as snag retention.

I found evidence of pileated woodpeckers throughout GDRCo ownership and excavated cavities occurred in smaller snags than has been reported in literature. The smallest snag I found with a nesting cavity was 20.1cm. I did not confirm the use of these cavities and pileated woodpeckers excavate multiple cavities a year. Rather, the tree characteristics documented as a part of this study were based on the presence of oval shaped excavations and therefore may not represent the trees pileated woodpeckers actually used for nesting. Response to harvest is hard to measure because excavations could have been made before the birds left the area. McClelland and McClelland (1999) reported pileated

woodpeckers remaining in their territory years after it was logged and attributed this behavior to the strong site fidelity reported by Lawrence (1967). Bull et al. (1995) reported the short-term effects of forest management are not informative of long-term effects on pileated woodpeckers.

Continued monitoring of permanent plots for snag recruitment and persistence will be important throughout the life of the 50 year HCP. Since SPH provides limited information, I also decided to study pileated woodpecker occupancy and the habitat variables associated with it (Chapter 2). It may be necessary to include prescriptions for CWD and more mature forest leave areas.

Chapter 2

Habitat Elements Associated with Pileated Woodpecker Occupancy of a Managed Forest

ABSTRACT

Mature forest reserves provide the habitats needed by North America's largest extant cavity excavating bird, the pileated woodpecker (*Dryocopus pileatus*). Mature forest reserves will become increasingly important as intensively managed forests move to a younger rotation age. I surveyed for pileated woodpeckers on Green Diamond Resource Company's (GDRCo) Olympic Tree Farm and then modeled their detection and occupancy using PRESENCE (http://www.mbrpwrc.usgs.gov/software/presenece.html). I estimated that pileated woodpeckers occupied 27.5% of survey locations, which is surprising for a species initially thought to be an obligate of expansive mature forests. The models that performed best included the amount of forest aged 30-45 within 277ha of a survey site, which was negatively correlated with occupancy, and the amount of mature forest within 277ha, which was positively correlated with occupancy. With a one percent increase in forest aged 30-45 within the 277ha home range, I found a 10.25% decrease in the likelihood of a site being occupied. With a one percent increase in mature forest in the 277 ha home range, I found a 3.68% increase in the chance of the site being occupied.

INTRODUCTION

Agriculture, including timber plantations, is a concern for biodiversity worldwide (Maxwell et al. 2016). Globally, the total change in land use is thought to have reduced the number of species on Earth by 8.1% and reduced the abundance of remaining species by 10.1% (Newbold et al. 2015). Agricultural activity is a known threat for 5,407 species in the International Union for Conservation of Nature's Red List; 730 of these species are specifically threatened by the increase in timber plantations world-wide (Maxwell et al. 2016). Timber plantations threaten sensitive forest obligates and especially those that depend on particular forest attributes such as snags, standing dead trees, because these features are often removed out of concern for safety or profit.

Snags and the cavities they provide are an essential part of a forested environment; offering crucial foraging and breeding habitat for a variety of taxa (Thomas 1979, Bull 2002). In the Pacific Northwest, 69 species of vertebrates have been reported to use cavities (Bunnell et al. 2002). For example, fallen snags provide coarse woody debris used by mammals, birds, amphibians and reptiles for shelter, nests, roosts and foraging substrates (Bull 2002). Raptors, such as eagles or owls, may also build nests on top of snags. Snags provide essential habitat for both primary and secondary cavity nesters, which excavate their own cavities and rely on cavities created by other species, respectively (Bull 2002). For example, northern flying squirrels (*Glaucomys sabrinus*) and bats use cavities in snags (Bull 2002, Ormsbee and McComb 1998). The population densities of primary cavity nesting birds, such as woodpeckers, are closely associated with snag density. In fact, a lack of cavity nesting sites limited the abundance of some birds in an intensively managed forest where snags were frequently removed (Angelstam and Mikusinski 1994). In the Sierra Nevada, cavity nesting birds, including excavating woodpeckers, were reported to decline by 52% in a snag removal plot (Raphael and White 1984). In cavity nesting bird populations, species richness, density and diversity increases with snag density (Zarnowitz and Manuwal 1985).

Snag size, height, decay class, hardness and species are important predictors of snag use. Snag size and height are important for woodpeckers nest site selection (Bull 2002). The probability of snags being used has been reported to increase with snag size (Bull 2002, Bevis and Martin 2002). Heart rot decay is critical for nest site selection (Bunnell et al. 2002, Lorenz et al. 2015). Decay stage is essential and may indicate the presence of insects on which woodpeckers feed and conifers are avoided as foraging sites until they reached a specific decay class (Bunnell et al. 2002). Weak cavity excavators prefer snags with a broken top and advance decay (Steeger and Dulisse 2002) Fifteen bird species favor burned areas of forests where snags are plentiful (Bunnell et al. 2002). Weak excavators generally use conifer trees (Bunnell et al. 2002) Hairy woodpeckers (*Picoides villosus*), a primary cavity excavator, prefer western hemlock, while secondary cavity nesters mostly nested in Douglas-fir snags in the Olympic National Forest, Washington (Zarnowitz and Manuwal 1985).

The pileated woodpecker (*Dryocopus pileatus*), the largest extant woodpecker in North America, is reliant on the presence of snags for foraging, roosting and nesting sites. They live in late successional

forests or younger forests where large snags have been retained (Mellen et al. 1992, Renken and Wiggars 1993, Aubrey and Raley 2002b, Hartwig et al. 2002, Bull and Jackson 2011). Although common throughout much of the United States, this large woodpecker is a candidate for listing on the Washington State endangered species list (WDFW 2016).

The ability of managed lands to support viable pileated woodpecker populations has received little attention. In western Washington, the majority of research on pileated woodpeckers has been done on U.S. Forest Service land (but see J. Tomasevic 2016), leading to many of the land management recommendations for this species. For example, Aubrey and Raley (2002b) reported pileated woodpeckers use only snags greater than 65 cm diameter at breast height (DBH) for nesting. Maintaining snags such as these, as well as other residual woody features is a common component of forest management prescriptions (Ganey 1999, Taylor and MacLean 2007), however such recommendations are rarely met, as some snags pose a safety hazard during cutting operations (Ganey 1999, Spiering and Knight 2005). Management strategies for pileated woodpeckers need to be more comprehensive than simply prescribing snag retention goals (Aubry and Raley 2002b) and should be landscape specific (Bull and Jackson 2011). My study aims to provide local strategies informed by actual enumeration of pileated woodpeckers and the forest features that affect their use of the landscape.

In this study, I examined the habitat attributes associated with pileated woodpecker detection and occupancy to assess the hypothesis that woodpecker presence is positively related to the availability of large snags. I also expected pileated woodpecker presence to increase with the amount of mature forest available because mature forest reserves may be an important habitat component (Mellen et al.1992, Bull and Hothausen 1993, Aubry and Raley 2002). I expected pileated woodpecker occupancy to decrease with the amount of recent harvest in within the home range as well as decrease with the amount of younger forest because recent harvest removes mature trees and snags. Thus, young forest isolates mature habitat in a forest landscape where important woody features such as snags and coarse woody debris have not been retained.

METHODS

Survey Methods

I surveyed for woodpeckers in 40 randomly selected forest plots on the Olympic Tree Farm of western Washington, USA (Figure 2.1). These plots came from a pool of 70 plots that were previously surveyed for snag densities (this total pool of 70 plots were also a random sample from 3,672 available forest plots. From September through November 2015, I conducted surveys for pileated woodpeckers using recorded calls, following the approach outlined by Bull (1990) and Bull and Meslow (1988) who found driving forest roads and stopping every 200 meters to play calls provided accurate occupancy results. I chose two to seven survey locations per site, depending on the size of the area of mature trees and feasibility of access because transects had to be located on forest roads within 200 meters of a mature forest patch (Figure 2.1). It would have been ideal to have an equal number of transects at each site, but this goal was not always possible because of the variation of forest plot size and their proximity to forest roads. Conroy and Nichols (1996) suggested standardization of survey methods, while desirable, is unlikely to produce equal detection methods due to unknown and uncontrollable variables. I assumed it was important for detectability for a survey site to be within 200 meters of mature forest because it is unlikely the birds would fly into the middle of a younger plantation.

During each survey point visit, I conducted a five minute survey for pileated woodpecker presence. I played a 10-15 second recorded call every 30 seconds. I alternated between the traditional ascending short call and a long call from the Audubon Birds of North America phone application (National Audubon Society 2016).

When surveying for occupancy, repeat surveys can be conducted in many ways including visiting a site multiple times, having multiple surveyors simultaneously conduct surveys during one visit, conducting surveys in multiple spots if the survey area is large enough, and conducting multiple surveys in a single visit (MacKenzie et al. 2006). In the single visit case the surveys need to be separated by enough time that the surveys are independent. While choosing a survey method it is important to determine which one introduces the least heterogeneity in detection. The likelihood of change in occupancy in the system increases with time and it can be advantageous to complete repeat surveys as

quickly as is reasonable (MacKenzie and Royle 2005). The primary cause of mortality for pileated woodpeckers is predation and this would be the most likely cause for changes between surveys. When surveying for animals, researches are unable to survey the entire home range and must make decisions on sample locations, which should be based on accomplishing the study objectives and sampling in an area the allows for inferences about locations that are not surveyed (Mackenzie et al. 2006). I selected units that had already been sampled for snags because the study's initial objective was to analyze pileated woodpecker use of snags. The surveys were conducted in areas where GDRCo had forest inventory data so that habitat could be examined on a larger scale surrounding the survey locations. Since pileated woodpeckers stay within their territory year round, I assumed that if an area was occupied, the bird would be there at some point in the day. I conducted three surveys on the same day with at least an hour between surveys. My assumptions were that an hour between surveys was enough time for the surveys to be independent, due to the continuous daytime movements by woodpeckers and their ability to fully traverse the territory within that time (J. Tomasevic pers. comm.). Furthermore, I assumed surveying on the same day did not introduce detection heterogeneity. I did not conduct repeat surveys on different days because of the possibility of increasing heterogeneity in detection introduced by weather and multiple observers (repeated visits on multiple days would have required and additional observer).

I assessed pileated woodpecker occupancy and accounted for variable detection using techniques described by MacKenzie et al. (2002). This method assumes that no new sites become occupied, and no sites become abandoned during sampling. This method also assumes species will not be falsely detected. To meet these assumptions, I only counted birds that gave the distinctive pileated woodpecker ascending call and/or were visually confirmed. If a bird responded, the survey was completed and I left in order to not habituate the birds to the recording and affect the likelihood of response for the next survey. Due to the negative effect of rain on detectability of birds in some species (Luginbuhl et al. 2001), I avoided surveying in the rain.

I used ArcGIS 10.1 to collect information on additional variables. I calculated hectares of mature forest at each site for two different home ranges, distance from mature forest for each survey point, and distance from houses from WA orthographic photos (http://gis.apfo.usda.gov/arcgis/services/NAIP/Washington_2015_1m/ImageServer) or Green Diamond's

orthographic flight photos. I used Green Diamond's forest inventory layer to determine forest composition surrounding each survey site for two different home ranges, 277 hectares reported by J. Tomasevic (pers. comm.) and 863 ha reported by Aubry and Raley (1996), which are the two home ranges that have been reported in Washington State (Figure 2.2).

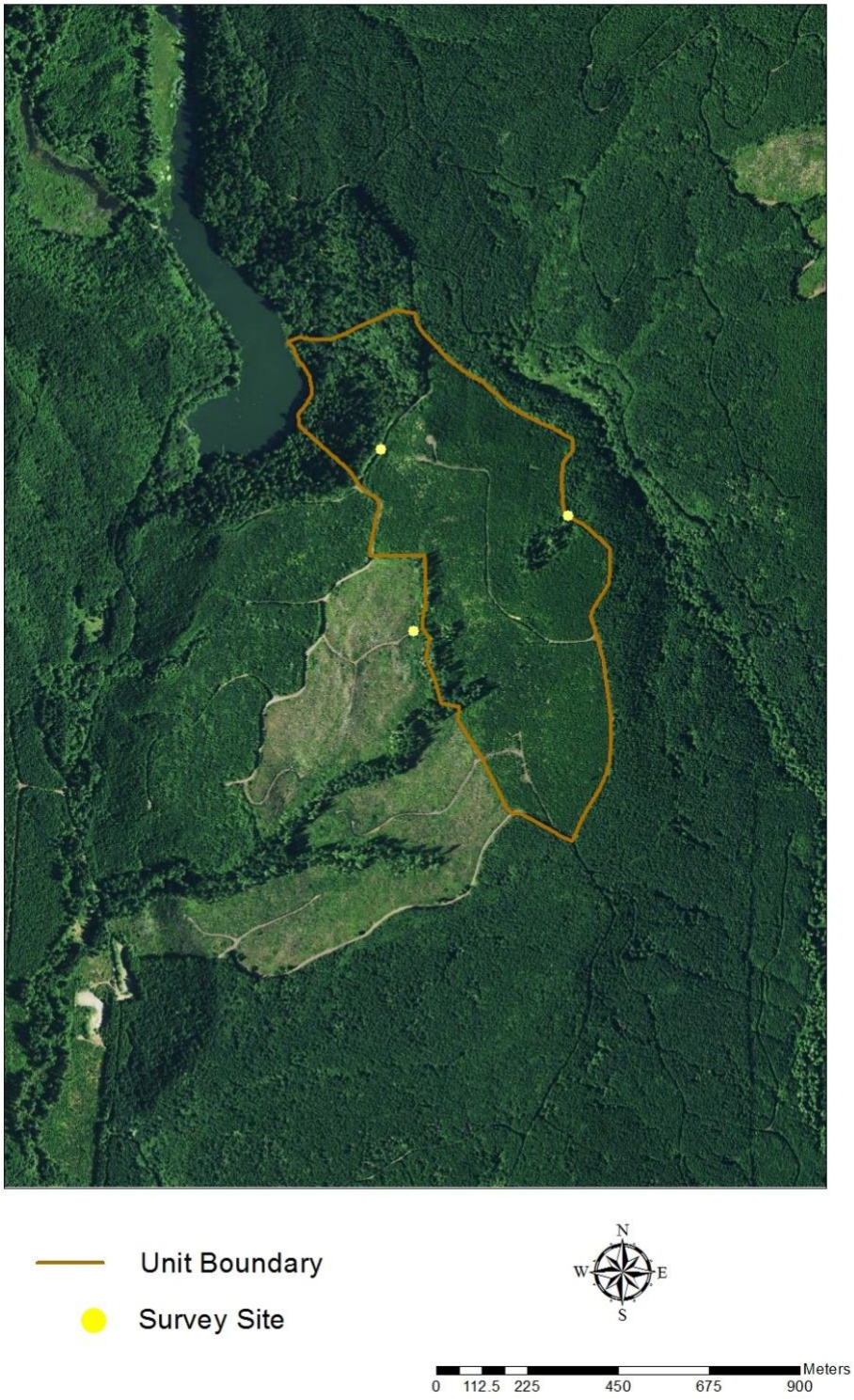

Figure 2.1. Pileated woodpecker survey site locations within a survey unit.

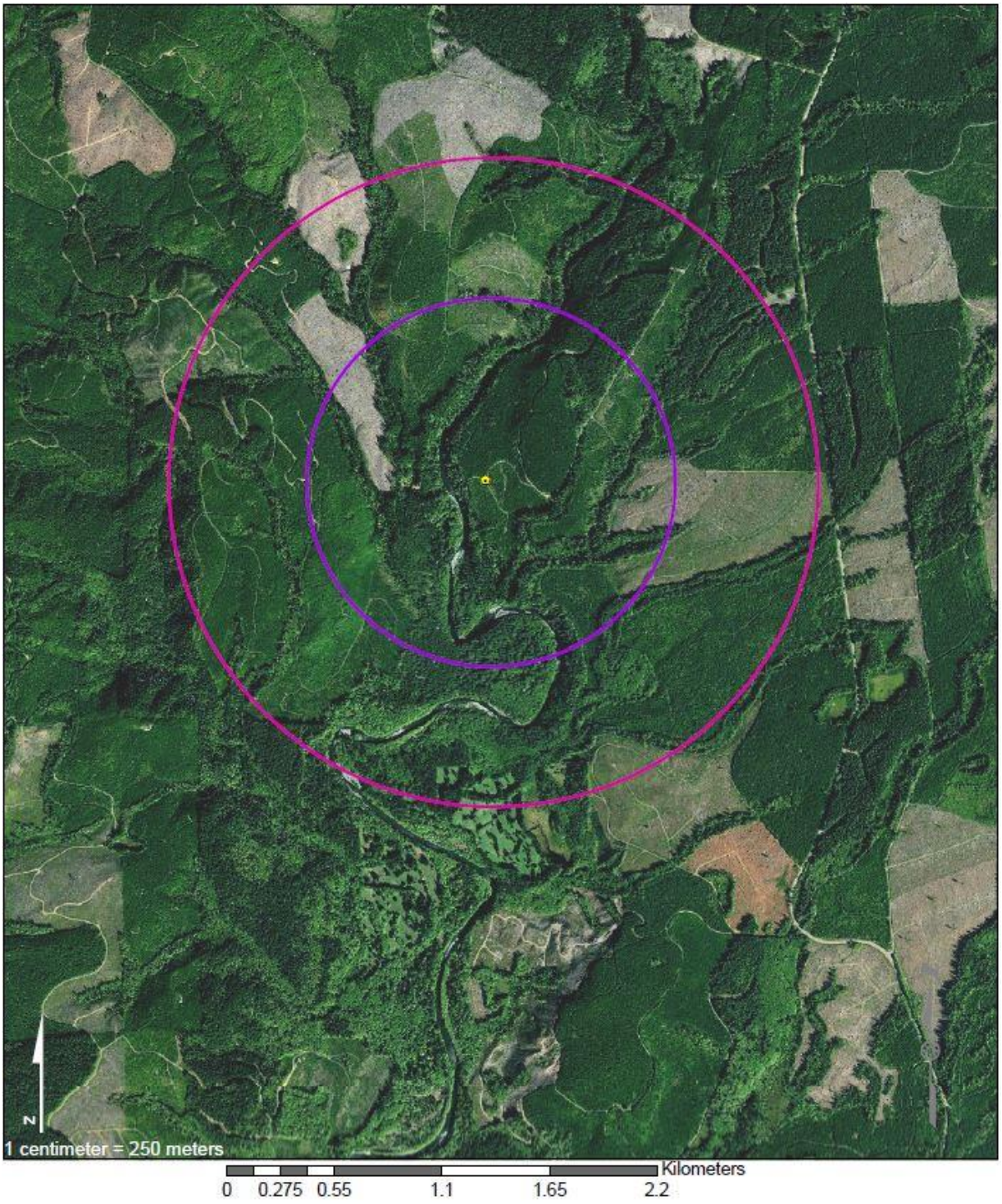

Figure 2.2. GIS analysis of forest composition of two home ranges that have been reported in Washington State, 277 ha (purple) and 863 ha (pink)

PRESENCE Models

To model pileated woodpecker detection and occupancy, I used PRESENCE (http://www.mbr-pwrc.usgs.gov/software/presenece.html). I built models that contained variables I expected to affect detection and occupancy. Specifically, I expected distance from survey point to nearest patch of mature forest, amount of forest obstructing view (acres of trees 20 years or older) and the presence of strong wind to each be negatively associated with detection. I expected years since harvest at site, hectares of mature trees within two different reported home ranges 277ha (J. Tomasevic 2016 pers. comm.) and 863ha (Aubry and Raley 1996) and large (>61 cm) snags per hectare at survey site to be positively associated with occupancy. I expected amount of recent harvest within the home ranges and amount of forest aged 30-45 to be negatively correlated to occupancy. I expected distance from houses to be negatively associated with occupancy.

I used Akaike's Information Criterion adjusted for small sample size (AICc) and model weights (w_i) to identify the best fit model for detectability and occupancy (Akaike 1974). I considered models with a delta AICc less than 2 to be competitive (Burnham and Anderson 2011).

RESULTS

Detection

I detected pileated woodpeckers at 11 out of 40 sites. At four sites, the birds responded for all three surveys, at two sites for two surveys and at four sites for one survey. At one site, I only completed one survey due to onset of rain (accommodated for in PRESENCE). My detection rate was 64% (95% confidence interval 0.44.-0.81). If birds responded, they responded within the first three transects.

Distance, wind and blocking vegetation were all negatively associated with detection (Table 2.1). Distance from mature forest patch and presence of blocking vegetation were both competitive models (AICc <2). However, none of these models ranked higher than the null model and the primary goal of this study was to examine occupancy and habitat covariates. Therefore, I did not include detection variables in the occupancy models. I confirmed that the null detection model was the best fit for each occupancy

model by running each occupancy model with the detection variables, blocking vegetation and distance from nearest mature area (Appendix A). Though the models including detection variables affected the estimates of occupancy (range 29.5%-30.9%), the null detection model provided the most conservative estimate (28.8%) and was weighed the highest model in all cases (Appendix A).

Table 2.1. Model results showing covariates roles in affecting the likelihood of detecting a pileated woodpecker. Detection models occupancy (psi) constant, with one detection model examined at a time, blocking vegetation (p(veg)), distance from mature forest patch (p(distance)), presence of wind during survey (p(wind)).

Detection Models				
Model	AICc	ΔAICc	AICc weight	Number of parameters.
psi(.),p(.)	89.5043243	0.32765766	0.11811719	2
psi(.),p(veg)	91.0166667	1.84	0.05545135	3
psi(.),p(distance)	91.0466667	1.87	0.05462579	3
psi(.),p(wind)	91.4766667	2.3	0.04405796	3

Occupancy

I found a naïve occupancy estimate of 27.5%. Of the eight models evaluated (Table 2.2), those that performed best included amount of forest aged 30-45 within 277ha of the survey site (Tables 2.3 and 2.4) and the amount of mature forest within 277ha of the survey site (Tables 2.3 and 2.4). The only model that was ranked higher than the null model included a reduction in occupancy as the amount of forest aged 30-45 within 277 ha on the survey site increased. Surprisingly, the model including large snags per hectare was not highly ranked and it had a negative coefficient (Tables 2.3 and 2.4). Snags per hectare for all sites ranged from 0-13.8 SPH with an average of 2.5 (95% confidence interval -3.5-8.5). Snags per hectare at occupied sites ranged from 0-6.9 with an average of 2.2 (95% Confidence interval -3.4-7.7). Snags per hectare at non occupied sites ranged from 0-13.8 with an average of 2.6 (95% confidence interval -3.5-8.8). For the occupancy models for both mature forest and third-growth forest, the 277ha home range models ranked higher than the 863ha models. Additionally, I retrospectively ran models at both home range scales that contained both the amount of forest aged 30-45 and the amount of mature forest as predictors of occupancy (Appendix B). These more complex models were not competitive with the simpler, single variable models (Appendix B).

For every one percent increase in mature forest within the 277ha home range, there was a 3.68% increase in the chance of that site being occupied by pileated woodpeckers. With a 1% increase in younger forest, aged 30-45 within 277ha, there was a 10.25% decrease in the chance of a site being occupied. With an increase in one large snag per hectare, there was an associated 0.4% reduction in the likelihood of occupancy.

Table 2.2. Occupancy model results with null detection p(.), examining the role of covariates in pileated woodpecker occupancy. Covariates examined included hectares (ha) of 30-45 year old forest within 277ha of survey site (30-45 277 ha), ha of forest aged greater than 45 within 277ha (Mature 277ha), ha of forest age 30-45 within 863ha (30-45 863ha), ha of forest greater than 45 years old within 863ha (Mature 863ha), amount of snags per hectare in the survey area (SPH), amount of recent harvest within 277 ha (recent harvest 277ha), amount of recent harvest within 863ha (recent harvest 863ha).

Model	AICc	ΔAICc	AICc weight	Number of parameters..
psi(30-45 277ha),p(.)	89.18	0	0.13914354	3
psi(.),p(.)	89.50	0.33	0.11811719	2
psi(Mature 277ha),p(.)	90.46	1.28	0.07336934	3
psi(30-45 863ha),p(.)	90.79	1.61	0.0622094	3
psi(Mature 863ha),p(.)	91.62	2.44	0.04107937	3
psi(SPH),p(.)	91.66	2.48	0.04026594	3
psi(recent harvest 277ha),p(.)	91.75	2.57	0.03849414	3
psi(recent harvest 863ha),p(.)	91.78	2.6	0.03792104	3

Table 2.3 Summary statistics for the top ranked models.

	AICc	ΔAICc	Model weight
Occupancy model including the amount of forest aged 30-45 years within 277 ha of survey site			
Amount of 30-45yr old forest within 277ha	89.18	0.00	0.54
Null model	89.50	0.32	0.46
Occupancy model including the amount of mature forest within 277ha of a survey site			
Null model	89.50	0.00	0.62
Amount of mature forest within 277ha	90.46	0.95	0.38
Occupancy model that includes snags per hectare at the survey site			
Null model	89.50	0.00	0.75
Snags per ha at site	91.66	2.16	0.25

Table 2.4. Parameter estimates, standard errors and 95% confidence intervals for top ranked models

	Estimate	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Occupancy model including the proportion of 30-45 year old forests in 277ha home range of pileated woodpeckers				
Intercept	-0.46	0.45	-1.34	0.42
Amount of 30-45yr old forest within 277ha	-10.81	7.55	-25.61	3.99
Detection	0.64	0.10	.44	0.81
Occupancy model including the amount of mature forest within 277ha of survey site				
Intercept	-1.86	0.94	-3.70	-0.02
Amount of mature forest within 277ha	3.6	3.15	-2.57	9.77
Detection	0.64	0.10	.44	0.81
Occupancy model including the amount of large snags per hectare				
Intercept	-0.78	0.47	-1.70	0.14
Snags per ha at site	-0.13	0.32	-0.76	0.50
Detection	0.64	0.10	0.44	0.81

DISCUSSION

As land use practices continue to evolve, it is crucial that managers evaluate the sensitivity and adaptability of species. Cavity nesting birds, especially primary cavity excavators, are an essential part of a healthy forest ecosystem because they provide nest sites for secondary cavity nesters. Many species have proven adaptable to anthropogenic land use changes. The pileated woodpecker may be one of these species (Bull and Jackson 2011); however, my results suggest that this may not be the case in heavily managed forests. Pileated woodpeckers occupied very few of the mature forest areas I surveyed. Moreover, I found that the amount of mature forest within simulated pileated woodpecker home ranges was positively associated with occupancy and, conversely, that the amount of young-forest (30-45 years old) was negatively associated with occupancy. These results will be important for resource managers to consider as heavily managed forest move to a third-growth rotation because under this scenario, most trees will be harvested before they reach 45 years old. Accordingly, I expect occupancy to decline over time. It will be important to survey future occupancy rates.

Forest management in the Northwest has reduced snag abundance, which in turn has reduced wildlife species dependent on them (Thomas et al. 1979, Neitro et al. 1985). My results demonstrate a naïve occupancy estimate of 27.5%. Ohmann et al.(1994) found that on nonfederal lands in western Washington and Oregon, temperate conifer forests were able to support 40% of maximum potential populations and conifer-hardwood forests were able to support 28%. Large snags in these successional forests were the most important snags for wildlife use, and will be lost over time with current harvest practices (Ohmann et al. 1994).

Contrary to the abundance of literature demonstrating the importance of snags to pileated woodpeckers, I did not find compelling support for presence of large snags being associated with pileated woodpecker occupancy. However, I am unable to dismiss the importance of large snags as a critical component of pileated woodpecker habitat. I found an abundance (14.8 SPH) of smaller snags (30-60 cm), which may help support the woodpeckers I detected. In addition, there are other attributes of snags that need to be measured to assess their value to pileated woodpeckers than just simply estimates of their abundance. In suburban settings pileated woodpeckers nest in snags as small as 34cm DBH (J.

Tomasevic pers. comm.). Future studies should examine smaller snags per hectare as an occupancy variable. Heavily managed forests are understudied, and more studies like this will contribute to the knowledge deficit and inform resource managers on adequate protections for cavity nesting birds.

Studying snags per hectare provides limited information, because not all snags are valuable to pileated woodpeckers. Managers can overestimate habitat valuable to primary cavity excavators by excluding nest site limitations (Lorenz et al. 2015). One unoccupied site in this study had 13.8 SPH, which was the largest SPH of any of the sites. Many of these snags were created by *Phellinus* root rot, which does not decay the core of the snag and is not of high value to woodpeckers. I rarely saw signs of pileated woodpecker use in *Phellinus* root rot patches. The density of trees with heart rot and of snags at the appropriate decay stage may be more important than the DBH of the snags. Studies have reported the importance of heart rot decay for pileated woodpeckers (Conner et al 1976, Harestad and Keisker 1989). Primary cavity excavators have more recently been reported to use nest trees with softer interior and harder exterior wood when compared to random trees (Lorenz et al. 2015). Future studies should examine multiple characteristics of snags, not just snags per hectare.

I found that the amount of mature forest within a pileated woodpecker's home range may additionally be important for occupancy. This is in agreement with previous research (Mellen et al. 1992, Bull and Hothausen 1993, Aubry and Raley 2002). Mature forests support higher densities of pileated woodpeckers (Mannen et al 1980). Bull and Holthausen (1993) recommended management for pileated woodpeckers include leaving 40% forest in mature stands. Forest management often removes trees before they are large enough to harbor pileated woodpecker nests (Bull 1987). Mellen et al. (2002) reported forests younger than 40 years were avoided by pileated woodpeckers. As managed forests move to a third-growth rotation, forest stands may not provide the same quality habitat for pileated woodpeckers that they have in the past and mature areas left after harvest will become increasingly important. Studies examining pileated woodpecker response to larger leave areas, more upland leave areas, uneven-aged management and longer rotation ages would be valuable.

Heavily managed private forests are understudied for pileated woodpecker habitat. This study provided indications that the amount of mature forest and the response to a third-growth rotation are important variables that deserve more scrutiny. Additional studies of habitat features that affect pileated

woodpecker occupancy in managed forests would be valuable for forest management recommendations. I found occupancy and detection surveys and modeling to be the most time and cost effective way to study pileated woodpeckers. Mackenzie (2006) provides recommendations for number of sites versus number of surveys. With my 60% detection rate from the null model and my naïve occupancy of 27.5% (95% CI 17-45), future studies could use two surveys per site and therefore survey more sites than I was able to do.

Continued monitoring of snags should be conducted to evaluate the assumptions that snag recruitment rates are constant. Future snag sampling should include evaluations of wood hardness. Future occupancy studies should use snags >34cm as a habitat variable. CWD should also be measured because lack of foraging sites may be limiting for pileated woodpeckers. Pileated woodpeckers successfully nest and forage in suburban areas (J. Tomasevic pers. comm.). Further studies could inform forest managers on land use decisions to allow pileated woodpeckers to be more successful in managed forests.

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APPENDIX A

Table A.1 Comparison of occupancy estimates with four detection variables: null, distance from mature forest patch, presence of blocking vegetation, distance and vegetation.

OCCUPANCY ESTIMATES	Occupancy estimate	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Psi(.)p(.)	0.288	0.2878	0.1651	0.4523
Psi(.)p(distance)	0.295	0.0777	0.1675	0.4653
Psi(.) p(veg)	0.292	0.0761	0.1666	0.4586
Psi(.)p(veg, distance)	0.309	0.0804	0.1761	0.4833

Table A.2 Parameter estimates, standard errors and 95% confidence intervals for detection models.

	Estimate	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Psi(.)p(veg)				
Intercept	-0.89	0.37	-1.61	-0.17
Intercept	0.74	0.46	-0.17	1.65
Blocking vegetation	-1.14	1.24	-3.57	1.29
P**si(.), p(distance)**				
Intercept	-0.87	0.37	-1.60	-0.14
Intercept	1.02	0.65	-0.26	2.30
Distance	-0.01	0.01	-0.03	0.01
Psi(.), p(veg,distance)				
Intercept	-0.80	0.376508	-1.54	-0.06
Intercept	1.60	0.739266	0.15	3.05
Blocking vegetation	-1.83	1.160282	-4.10	0.44
Distance	-0.02	0.011718	-0.04	0.00

Table A.3 Comparison of occupancy models with detection variables. Null detection model was weighted highest in all cases.

	AICc	ΔAICc	AICc weight	Number of parameters
Occupancy models including amount of forest age 30-45 within 277ha of survey site, with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(30to45)p(.)	89.17667	0	0.486220901	3
psi(30to45),p(distance)	90.90286	1.72619	0.205114388	4
psi(30to45),p(veg)	91.12286	1.94619	0.18374847	4
psi(30-45),p(veg,distance)	91.89471	2.718039	0.124916241	5
Occupancy models including amount of forest age 30-45 within 863ha of survey site, with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(thirdFSHR),p(.)	90.78667	0	0.458906482	3
psi(thirdFSHR),p(veg,distance)	92.97471	2.188039	0.15367298	5
psi(thirdFSHR),p(distance)	92.44286	1.65619	0.200487361	4
psi(thirdFSHR),p(veg)	92.58286	1.79619	0.186933177	4
Occupancy models including amount of mature forest within 277ha of survey site, with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(mature277),p(.)	90.45667	0	0.460159096	3
psi(Mature277),p(veg,distance)	92.66471	2.208039	0.152559195	5
psi(mature277),p(veg)	92.17286	1.71619	0.195093134	4
psi(mature277),p(distance)	92.20286	1.74619	0.192188575	4
Occupancy models including amount of mature forest within 863ha of survey site, with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch				
psi(matureFS),p(.)	91.61667	0	0.435143056	3
psi(matureFS),p(veg,distance)	93.38471	1.768039	0.179765861	5
psi(matureFS),p(veg)	93.20286	1.58619	0.196877085	4
psi(matureFS),p(distance	93.29286	1.67619	0.188213998	4
Occupancy models including amount of recent within 277ha of survey site, with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(harvest277),p(.)	91.74667	0	0.429517503	3
psi(harvest277),p(veg,distance)	93.42471	1.678039	0.185609107	5
psi(harvest277),p(veg)	93.31286	1.56619	0.196284916	4
psi(harvest277),p(distance)	93.39286	1.64619	0.188588474	4

Occupancy models including amount of recent within 863ha of survey site, with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(harvestFS),p(.)	91.77667	0	0.446221231	3
psi(harvestFS),p(veg,distance)	93.74471	1.968039	0.166799961	5
psi(harvestFS),p(distance)	93.44286	1.66619	0.193973126	4
psi(harvestFS),p(veg)	93.45286	1.67619	0.193005681	4

Table A.4 Parameter estimates, standard errors and 95% confidence intervals for occupancy and detection models.

	Estimate	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Occupancy models including amount of forest age 30-45 within 277ha of survey site, with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(30to45)p(.)				
Intercept	-0.46	0.45	-1.34	0.42
Amount of forest 30-45 yrs within 277ha	-10.81	7.55	-25.61	3.99
Detection	0.64	0.10	.44	0.81
psi(30to45),p(distance)				
Intercept	-0.43	0.46	-1.33	0.47
Amount of forest 30-45 yrs within 277ha	-10.92	7.69	-25.99	4.15
Intercept	0.99	0.65	-0.28	2.26
Distance	-0.01	0.01	-0.03	0.01
psi(30to45),p(veg)				
Intercept	-0.48	0.44	-1.34	0.38
Amount of forest 30-45 yrs within 277ha	-10.46	7.60	-25.36	4.44
Intercept	0.73	0.47	-0.19	1.65
Blocking vegetation	-0.84	1.15	-3.09	1.41
psi(30to45),p(veg,distance)				
Intercept	-0.44	0.46	-1.34	0.46
Amount of forest 30-45 yrs within 277ha	-9.83	7.92	-25.35	5.69
Intercept	1.54	0.78	0.01	3.07
Blocking vegetation	-1.59	1.21	-3.96	0.78
Distance	-0.02	0.01	-0.04	0.00
Occupancy models including the amount of forest aged 30-45 within 863ha of survey site with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(30-45 863ha),p(.)				
Intercept	-0.57	0.48	-1.52	0.38
Amount of forest 30-45 yrs within 277ha	-5.9	5.99	-17.63	5.83
Detection	0.6	0.43	-0.24	1.44

psi(30-45 863ha),p(veg,distance)				
Intercept	-0.51	0.50	-1.49	0.47
Amount of forest 30-45 yr 863ha	-5.32	6.15	-17.38	6.74
Intercept	1.59	0.75	0.11	3.07
Blocking vegetation	-1.74	1.17	-4.03	0.55
Distance	-0.02	0.01	-0.04	0.00
psi(thirdFSHR),p(distance)			0.00	0.00
Intercept	-0.53	0.50	-1.50	0.44
Amount forest 30-45yrs 863ha	-6	6.05	-17.86	5.86
Intercept	1.01	0.65	-0.27	2.29
Distance	-0.011	0.01	-0.04	0.01
psi(thirdFSHR),p(veg)			0.00	0.00
Intercept	-0.58	0.48	-1.52	0.36
Amount forest 30-45yrs 863ha	-5.58	6.06	-17.45	6.29
Intercept	0.74	0.47	-0.17	1.65
Blocking vegetation	-0.99	1.21	-3.35	1.37
Occupancy models including the amount of mature forest within 277ha of survey site with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(mature277),p(.)				
Intercept	-1.87	0.09	-2.05	-1.69
Amount of mature forest within 277ha	3.6	3.15	-2.57	9.77
Detection	0.6	0.10	.44	.81
psi(Mature277),p(veg,distance)				
Intercept	-1.7	0.10	-1.89	-1.51
Amount of mature forest within 277ha	3.28	3.15	-2.90	9.46
Intercept	1.57	0.74	0.13	3.01
Blocking vegetation	-1.76	1.18	-4.07	0.55
Distance	-0.02	0.01	-0.04	0.00
psi(mature277),p(veg)				
Intercept	-1.84	0.94	-3.69	0.01
Amount of mature forest within 277ha	3.54	3.15	-2.63	9.71
Intercept	0.74	0.46	-0.17	1.65
Blocking vegetation	-1.08	1.23	-3.48	1.32
psi(mature277),p(distance)				
Intercept	-1.81	0.94	-3.65	0.03
Amount of mature forest within 277ha	3.5	3.11	-2.60	9.60
Intercept	1.02	0.66	-0.27	2.31
Distance	-0.01	0.01	-0.03	0.01

Occupancy models including the amount of mature forest within 863ha of survey site with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
Intercept	-0.53	0.86	-2.21	1.15
Amount of mature forest within 863ha	-1.63	3.43	-8.35	5.09
Detection	0.6	0.43	-0.24	1.44
psi(matureFS),p(veg,distance)			0.00	0.00
Intercept	-0.29	0.91	-2.07	1.49
Amount of mature forest within 863ha	-2.2	3.57	-9.20	4.80
Intercept	1.62	0.74	0.17	3.07
Blocking vegetation	-1.89	1.15	-4.14	0.36
Distance	-0.02	0.01	-0.04	0.00
psi(matureFS),p(veg)			0.00	0.00
Intercept	-0.46	0.88	-2.19	1.27
Amount of mature forest within 863ha	-1.85	3.49	-8.69	4.99
Intercept	0.75	0.46	-0.16	1.66
Blocking vegetation	-1.2	1.25	-3.66	1.26
psi(matureFS),p(distance)			0.00	0.00
Intercept	-0.49	0.87	-2.19	1.21
Amount of mature forest within 863ha	-1.65	3.45	-8.41	5.11
Intercept	1.02	0.65	-0.26	2.30
Distance	-0.01	0.01	-0.03	0.01
Occupancy models including the amount of recent harvest within 277ha of survey site with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(harvest277),p(.)			0.00	0.00
Intercept	-0.77	0.55	-1.86	0.32
Amount of mature forest within 863ha	-1.39	4.50	-10.20	7.42
Detection	0.6	0.43	-0.24	1.44
psi(harvest277),p(veg,distance)				
Intercept	-0.53	0.60	-1.70	0.64
Amount of recent harvest within 277ha	-2.75	4.70	-11.95	6.45
Intercept	1.63	0.74	0.18	3.08
Blocking vegetation	-1.92	1.16	-4.19	0.35
Distance	-0.02	0.01	-0.04	0.00
psi(harvest277),p(veg)			0.00	0.00

Intercept	-0.7	0.58	-1.84	0.44
Amount of recent harvest within 277ha	-1.92	4.64	-11.01	7.17
Intercept	0.75	0.46	-0.16	1.66
Blocking vegetation	-1.22	1.27	-3.71	1.27
psi(harvest277),p(distance)				
Intercept	-0.72	0.57	-1.84	0.40
Amount of recent harvest within 277ha	-1.61	4.53	-10.48	7.26
Intercept	1.03	0.66	-0.26	2.32
Distance	-0.01	0.01	-0.03	0.01
Occupancy models including the amount of recent harvest within 863ha of survey site with four different detection models: null, distance of survey site from closest mature forest patch, presence of blocking vegetation, presence of blocking vegetation and distance from mature forest patch.				
psi(harvestFS),p(.)				
Intercept	-1.02	0.57	-2.14	0.10
Amount of recent harvest within 863ha	1.24	4.74	-8.06	10.54
Detection	0.6	0.43	-0.24	1.44
			0.00	0.00
psi(harvestFS),p(veg,distance)			0.00	0.00
Intercept	-0.89	0.59	-2.04	0.26
Amount of recent harvest within 863ha	0.88	4.84	-8.61	10.37
Intercept	1.6	0.74	0.15	3.05
Blocking Vegetation	-1.82	1.17	-4.10	0.46
Distance	-0.02	0.01	-0.04	0.00
psi(harvestFS),p(distance)			0.00	0.00
Intercept	-1	0.57	-2.13	0.13
Amount of recent harvest within 863ha	1.41	4.76	-7.92	10.74
Intercept	1.03	0.65	-0.25	2.31
Distance	-0.01	0.01	-0.03	0.01
psi(harvestFS),p(veg)			0.00	0.00
Intercept	-0.98	0.59	-2.13	0.17
Amount of recent harvest within 863ha	0.96	4.80	-8.45	10.37
Intercept	0.75	0.46	-0.16	1.66
Blocking vegetation	-1.11	1.24	-3.54	1.32

APPENDIX B

Table B.1 Occupancy models, including amount of mature forest within home range and forest aged 30-45.

psi(>30)	AICc	ΔAICc	Number of parameters
psi(30-45 and mature 277ha)	92.17286	2.99619	4
psi(30-45 and mature 863 ha)	92.39286	3.21619	4

Table B.2 Parameter estimates, standard errors and confidence intervals.

	Estimate	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Psi(30-45 and mature 277ha)p(.)				
Intercept	-1.14	1.10	-3.30	1.02
Amount of mature forest within 277ha	2.3	3.37	-4.31	8.91
Amount of forest 30-45 yrs within 277ha	-9.14	7.66	-24.15	5.87
Detection	0.6	0.43	-0.24	1.44
Psi(30-45 and mature 863ha)p(.)				
Intercept	0.36	1.112424	-1.82	2.54
Mature	-3.43	3.744266	-10.77	3.91
Third	-8.34	6.906410	-21.88	5.20
Detection	0.60	0.430277	-0.24	1.44