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THESIS APPROVAL

The abstract and thesis of Jacqueline I. Fern for the Master of Science in Environmental Sciences and Resources were presented July 18, 2001, and accepted by the thesis committee and the department.

COMMITTEE APPROVALS:

J. Alan Yeakley, Chair

Richard B. Forbes

Yangdong Pan

Michael T. Murphy
Representative of the Office of Graduate Studies

DEPARTMENT APPROVAL

Roy Koch, Director
Program of Environmental Sciences and Resources

ABSTRACT

An abstract of the thesis of Jacqueline I. Fern for the Master of Science in Environmental Sciences and Resources presented July 18, 2001.

Title: Snags in Beaver Ponds and Indications of Use by Primary Cavity-Nesting Birds in the Western Oregon Cascades.

Dead trees, or snags, are used by primary cavity-nesting birds for nesting, foraging, and roosting and are essential habitat for these species. Snags formed in beaver ponds due to flooded conditions are utilized by a variety of woodpecker species. In this study I quantified and compared snag density, size, decay characteristics, and excavations in beaver ponds and in forested riparian sites without beaver influence (reference sites) in the western Oregon Cascades. Beaver ponds were treated as a pooled group ($n=8$) and also categorized into old ($n=5$) and new ($n=3$) classes based on decay indicators. Reference sites ($n=8$) were treated as a pooled group.

Snag density was significantly higher in pooled and new beaver ponds ($P = 0.014$ and $P < 0.001$) compared to reference sites. In general, reference site snags had larger diameters ($P < 0.001$) and were in more advanced decay stages ($P < 0.001$) than beaver pond snags. The proportion of snags excavated was significantly higher in reference sites compared to pooled beaver ponds and new ponds ($P = 0.007$ and $P <$

0.001, respectively). In comparisons between reference sites and old beaver ponds, neither snag density ($P = 0.104$) nor proportion of snags excavated ($P = 0.065$) differed significantly. In new ponds, snag density was high, snags were in early decay stages and utilization by primary cavity-nesting birds was low. As ponds aged, snag density decreased, remaining snags were larger and more decayed, and utilization by primary cavity-nesting birds was higher. In riparian habitat without beaver influence, snag density was low, snags were large and in advanced stages of decay, and utilization was high. These findings suggest that snags in beaver ponds form and reach optimal stages of decay quickly, yet also decompose rapidly. In riparian forests without beaver influence snags form and reach optimal stages of decay more slowly, yet remain on the landscape longer.

SNAGS IN BEAVER PONDS AND
INDICATIONS OF USE BY PRIMARY CAVITY-NESTING BIRDS IN THE
WESTERN OREGON CASCADES

by

JACQUELINE I. FERN

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
ENVIRONMENTAL SCIENCES AND RESOURCES

Portland State University
2001

To the river otters—

whose unexpected appearance

one warm summer day

made this work all the more rewarding.

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Introduction

Purpose

Dead trees, or snags, are an essential habitat component for many forms of wildlife including some small mammals and a wide variety of birds. Cavity-nesting birds, in general, use snags for a variety of life processes including breeding, roosting, perching, and foraging (Neitro et. al. 1985, Swallow et. al. 1986, Bull 1987, Ohmann et. al. 1994, Weikel and Hayes 1999). Primary cavity-nesters including woodpeckers, nuthatches, and chickadees, excavate holes which, when abandoned, become available for use by secondary cavity-nesting birds such as swallows, Buffleheads (*Bucephala albeola*), mergansers, and Wood Ducks (*Aix sponsa*). For cavity-nesting birds, the availability of snags may significantly limit reproduction (Neitro et. al. 1985, Zarnowitz and Manuwal 1985, Ohmann et. al. 1994) and affect population size. Decreased counts of certain species of woodpeckers in North American forests are attributed, at least in part, to the diminishing quantity of suitable snags (Neitro et. al. 1985).

Many factors contribute to snag formation in forested ecosystems, including wildfire, infection, insect damage, lightning strikes, and breakage due to nearby falling trees (Mannan et. al. 1980, Neitro et. al. 1985). In riparian forests, snags can also form due to an increase in saturated conditions from short or long-term flooding (Ives 1942, Loucks 1987). One important agent in creating such flooding and indirectly generating snags is the American beaver (*Castor canadensis*). When beavers construct dams, upstream habitat is flooded and may remain so for long periods. Depending on species, size, and degree of inundation, trees standing in newly formed beaver ponds typically

die within several years (Ives 1942). As snags, these trees continue to benefit wildlife by providing nesting and roosting opportunities, as well as insect prey.

The majority of the literature describing the use of snags by wildlife focuses on terrestrial forested systems. While a number of studies document the importance of snags in riparian systems, few have specifically studied snags in beaver ponds.

Although our knowledge of the impact of beaver pond snags on wildlife is limited, several studies have established that fish, amphibians, reptiles, and many species of birds benefit from beaver activity (Lochmiller 1979, Rendell and Robertson 1989, Snodgrass and Meffe 1998, Edwards and Otis 1999, Russell et. al. 1999).

The purpose of this research was to broaden existing knowledge of the ecological importance of snags formed in beaver ponds. Specifically, I sought to quantify snag production and snag utilization by primary cavity-nesting birds in beaver ponds in western Oregon riparian forests.

Historical Context

Prior to their decimation by European fur trappers and traders, beavers inhabited streams across North America from the arctic to northern Mexico. The beaver population on the continent may have once numbered in the hundreds of millions (Naiman et. al. 1988, Outwater 1996), influencing waterways in habitats as diverse as tundra, boreal forest, and desert. The demand for pelts, driven primarily by fashion trends, led to the near extirpation of beavers in Europe by the 1600s. With North American beavers still largely unexploited, trading posts in New York, Maine, Connecticut and Massachusetts were soon established. However, by 1700, the beaver

population on the east coast of America collapsed due to overtrapping and by 1900, beavers were extirpated from many western watersheds as well (Outwater 1996). The beaver population in North America in the past 100 years has begun to recover, largely due to more restrictive hunting regulations and the scarcity of the beaver's key predator, the grey wolf (*Canis lupus*). However, the current estimated population, between 6 and 12 million (Naiman et. al. 1988), is still just a small fraction of the number before European impact.

The history of beaver in Oregon reveals a repetitive cycle of widespread trapping followed by periods of conservation measures ranging from regulations on harvest levels to recolonization of overexploited areas. There were no legal restrictions on beaver trapping prior to 1893, but in 1899, trapping was prohibited statewide (Verts and Carraway 1998) due presumably to overexploitation. Approximately twenty years later, trapping was again allowed in specific areas with little restriction (primarily in the northwest portion of the state). In 1932, a relocation program was initiated to move nuisance beavers to areas where they had been historically overharvested. Nevertheless, by the mid 1940's, as described by Verts and Carraway (1998), "the emphasis shifted from transplanting to killing nuisance beavers" and increased harvest levels ensued. The increased harvest levels in the 1940's were followed by a significant decline in the 1950s when new regulations limited the number of tags trappers could purchase to kill beavers. Since that time, harvest levels have remained within the range of 4,000 to 12,000 beavers killed per year in Oregon. Based on harvest records from 1969 to 1992, the current density of beaver populations is likely

greatest in the northwestern portion of the state, particularly in Clatsop, Columbia and Benton Counties where an annual average of more than 40 beavers were killed per 1,000 hectares during the reported period (Verts and Carraway 1998).

Ecological Effects of Beaver Activity

Beavers have the capacity to alter the landscape in a way unlike any other mammal, affecting both abiotic and biotic factors in an ecosystem. Dam building and foraging alter physical characteristics including hydrology (Naiman et. al. 1988, Butler 1989, Woo and Waddington 1990), nitrogen and carbon inputs (Francis et. al. 1985, Naiman et. al. 1988) and even solar influx (Johnston and Naiman 1990). In combination, these changes result in increased habitat heterogeneity in forested ecosystems, a resultant shift in biotic community composition, and an overall increase in biodiversity within the area of influence (McDowell and Naiman 1986, Johnston and Naiman 1990, Edwards and Otis 1999).

The major hydrologic effects that follow beaver dam construction consist of upstream flooding, pond formation, and a local rise in the water table. Above the dam physical conditions shift from lotic to lentic—streamflow velocity decreases while upstream saturated surface area and sediment deposition increase. Soil oxygen becomes depleted in flooded areas upstream of beaver dams. The limited availability of oxygen causes the death of vegetation and trees that are intolerant of newly saturated conditions (Loucks 1987, Kozlowski et. al. 1991). In addition, trees may become weakened and die when their roots become buried in sediment in ponded areas (Kozlowski et. al. 1991).

The presence of slower-moving waters above beaver dams causes a corresponding shift in upstream invertebrate communities (McDowell and Naiman 1986, Clifford et. al. 1993) while maintaining lotic system invertebrates at the dam (Clifford et. al. 1993). The ability of dams to slow the movement of water also reduces the magnitude of peak flow events, reduces sediment transport to downstream locations, and decreases the erosive powers of streamwater (Naiman et. al. 1986, Naiman et. al. 1988, Butler 1989, Woo and Waddington 1990). These ecosystem alterations can help reduce flooding and stream erosion to such a degree that beavers have recently been successfully introduced by watershed managers to improve in-stream and bank conditions (Olson and Hubert 1994, McKinstry et. al. 2000).

Sediment trapping and woody debris inputs in beaver ponds enhance the availability of biotically important elements such as nitrogen and carbon. The increased sediment trapped above dams acts as a substrate for nitrogen fixing organisms, primarily microbes (Francis et. al. 1985, Naiman et. al. 1988). Naiman and Melillo (1984) found that nitrogen in beaver pond sediments was retained for long periods of time and was likely unavailable to higher trophic levels until ponds were abandoned and dry. The retention of nitrogen and slow downstream release in beaver-influenced watersheds decreases nutrient spiraling and thus enhances nitrogen processing in upstream locations (Naiman and Melillo 1984). The increased concentration of nitrogen in the vicinity of beaver ponds has a direct positive effect on primary productivity, particularly in ecosystems where nitrogen was previously a limiting factor (Naiman and Melillo 1984). Beavers add significant quantities of

organic carbon to the stream system (Naiman et. al. 1986) in the form of woody debris from food caches, dead and dying trees, shrubs, and vegetation. Woody debris entering the stream system as a result of beaver dam construction and foraging enhances habitat for invertebrates (McDowell and Naiman 1986), reptiles and amphibians (Russell et. al. 1999) and provides resting and hiding areas for coho salmon (*Oncorhynchus kisutch*) (Leidholt-Bruner et. al. 1992, Nickelson et. al. 1992, Hammerson 1994). The increase in carbon inputs also increases available dissolved organic carbon (DOC) and particulate organic matter (POM). Availability of DOC drives microbial activity and POM is utilized as a key food source by a wide range of aquatic invertebrates including shredders, grazers, suspension feeders, crustaceans and snails (Allan 1995). Carbon inputs have slow turnover rates in beaver ponds compared to lotic systems, which enhances the degree to which organic material is utilized and transformed in the ecosystem (Naiman et. al. 1988).

Solar influx is another physical characteristic altered by beaver activity. The felling of trees for dam building and foraging creates canopy openings that allow greater solar penetration and warmer water temperatures. This likely benefits a host of wildlife including amphibians, riparian and wetland birds, reptiles, and mammals. The increase in solar influx combined with quiescent upstream conditions, results in a shift in plant communities and an increase in vegetative complexity (Naiman et. al. 1988, Johnston and Naiman 1990). Furthermore, the increase in sunlight from canopy openings appears to promote the growth of the beaver's preferred forage species, including willow (*Salix spp.*), trembling aspen (*Populus tremuloides*), and alder (*Alnus*

spp.) (Johnston and Naiman 1990).

The formation of a pond provides beavers easier access to sources of food and dam building materials, and offers protection from predators. Ponds also enhance biodiversity and species richness of plants and wildlife (McDowell and Naiman 1986, Johnston and Naiman 1990, Medin and Clary 1990, Hammerson 1994, Brown et. al. 1996, Snodgrass and Meffe 1998, Russell et. al. 1999) by contributing to overall wetland acreage and increasing habitat patchiness. Flooded conditions result in increased biomass of wetland and aquatic plants that are tolerant of saturated soils. In addition, trees such as aspen, willow, and cottonwood (*Populus spp.*) that are better able to withstand saturated soils, may replace less tolerant coniferous species (Ives 1942). In general, disturbance caused by beavers can significantly alter vegetative succession (Naiman et. al. 1988) and increase habitat heterogeneity. This provides opportunities for unique assemblages of organisms, including amphibians, reptiles, mammals, fish, and birds.

Overall, beaver ponds likely enhance an ecosystem's resilience and ability to withstand disturbances such as flooding and drought (Naiman et. al. 1988). Over time as beaver ponds are abandoned and dams are left unmaintained, these wetlands gradually change to fertile meadows, emergent marsh, or bogs that can be stable for centuries (Naiman et. al. 1986). The cycle of beaver occupation, dam building and eventual abandonment likely led to the formation of much of the rich soil and meadow-marsh complexes in western drainages (Ives 1942). The dramatic reduction in the beaver population in North America during the 1700s and 1800s directly led to a loss

of wildlife habitat as well as a loss of natural flooding and erosion control, and reduced stability of aquatic ecosystems. Riparian landscapes, particularly in arid parts of the western U.S., are likely very different from what they once were when beavers were a more prominent influence (Naiman et. al. 1988).

Effects of Beaver Activity on Bird Species Richness and Diversity

A variety of studies conducted in diverse locations report an increase in species richness and diversity of ducks and other wetland birds in beaver ponds (Medin and Clary 1990, Brown et. al. 1996, Edwards and Otis 1999). In many cases, these population dynamics correlate to specific habitat characteristics including an increase in available shoreline, stable water levels, denser cover from shrub and grass vegetation, and an increased abundance of insect prey (Renouf 1972, Reese and Hair 1976, Medin and Clary 1990, Brown et. al. 1996, Edwards and Otis 1999).

Brown et. al. (1996) studied the use by of beaver ponds by birds in the Laramie Range in Wyoming to determine important habitat characteristics for migration and breeding. Thirteen species of birds were observed including ducks, riparian birds, shorebirds, and piscivorous birds. They found that piscivorous birds including Belted Kingfishers (*Ceryle alcyon*) and Great Blue Herons (*Ardea herodias*), benefited from the increased water depth and wetted surface area in beaver ponds. In addition, Brown et. al. (1996) found species richness to be highest in beaver ponds with larger areas of shallow water and available shoreline. Renouf (1972) studied waterfowl use of active and inactive beaver ponds in New Brunswick, Canada. Fifty-three percent of active beaver ponds contained broods compared to 27% of inactive ponds. He attributed this

significant difference to the seasonal decreases in water levels in ponds not maintained by beaver. Medin and Clary (1990) found bird density, diversity, and species richness in an Idaho beaver pond to be significantly higher than in an adjacent undammed site. They attributed these findings to the more developed vegetation and reliable source of water found in the beaver pond.

A few studies also included information on beaver pond habitat characteristics associated with an abundance of cavity-nesting birds. In a study of the seasonal shifts in bird communities associated with beaver ponds in the Piedmont region of South Carolina, Reese and Hair (1976) found high avian biodiversity to be associated with habitat complexity, including forest openings, the localized occurrence of plants in varying stages of succession, and the abundance of aquatic insects. They also noted that an abundance of cavity-nesting species, including wood ducks, nuthatches, chickadees, and several species of woodpeckers, was attributed to the presence of snags. Edwards and Otis (1999) studied bird use of six ponds in the Piedmont region of South Carolina to determine seasonal variations in the biotic community and to assess important characteristics of habitat that correlate to species richness and abundance. They concluded that greater habitat patchiness contributed to waterfowl and aquatic bird species richness, and the presence of snags contributed to woodpecker abundance.

The Importance of Snags for Primary Cavity-Nesting Birds

Wildlife and forest managers stress the importance of maintaining adequate sizes and densities of snags in heavily managed forests such as those in the Pacific

Northwest. A large body of research has clearly established the significance of snags, particularly those with large diameter and sufficient height, for maintaining stable populations of both primary and secondary cavity-nesting bird species (Mannan et. al. 1980, Neitro et. al. 1985, Zarnowitz and Manuwal 1985, Schreiber and deCalesta 1992, Ohmann et. al. 1994). Past research includes detailed studies of snag characteristics, snag use and preference by cavity-nesting birds, and recommendations for snag management in geographically and biologically diverse forests (Mannan et. al. 1980, Stauffer and Best 1982, Raphael and White 1984, Neitro et. al. 1985, Swallow et. al. 1986, Bull 1987, Lundquist and Mariani 1991, MacDonald 1992, Bull et. al. 1997).

Research indicates that cavity-nesting birds tend to forage and nest in snags rather than live trees (Raphael and White 1984, Lundquist and Mariani 1991) and that these snags tend to have larger diameters (Scott et. al. 1978, Mannan et. al. 1980, Zarnowitz and Manuwal 1985, Swallow et. al. 1986, Bull et. al. 1997, Weikel and Hayes 1999). This preference is likely because large diameter snags have greater amounts of insects such as carpenter ants, beetles and termites (Cline et. al. 1980, Bull 1987, Weikel and Hayes 1999). Scott et. al. (1978) found that cavity-nesting birds in British Columbia chose nest snags that had broken tops and were greater than 30 centimeters (cm) in diameter. In western Oregon, Mannan et. al. (1980) found that cavity-nesting birds tended to forage and nest in Douglas-fir snags that were greater than 60 cm in diameter and greater than 15 meters (m) tall. Lundquist and Mariani (1991) found cavity-nesters to use snags with a mean diameter of 76 cm for nesting in the southern Washington Cascades. In a study conducted in the Olympic National

Forest in Washington State, Zarnowitz and Manuwal (1985) found that cavity-nesting birds, including Hairy Woodpeckers (*Picoides villosus*), Pileated Woodpeckers (*Dryocopus pileatus*), Northern Flickers (*Colaptes auratus*), Red-breasted Nuthatches (*Sitta canadensis*), Brown Creeper (*Certhia americana*), Vaux's Swift (*Chaetura vauxi*) and Tree Swallows (*Tachycineta bicolor*), selected nest trees with significantly higher diameter than average for all snags measured. In Schreiber and deCalesta's (1992) research in central Oregon coast range clear-cuts, cavity-nesting birds selected snags between 78 and 102 cm in diameter. In another study in the Oregon coast range, Weikel and Hayes (1999) found that a variety of cavity-nesting birds, including the Chestnut-backed Chickadee (*Poecile rufescens*), Red-breasted Nuthatch, Brown Creeper and Hairy Woodpecker selected larger diameter trees for foraging.

Presence of a broken top, snag hardness, or other signs of decay appear to play a role in cavity-nesting bird preferences for nesting and foraging, though some findings from separate studies are conflicting. Scott et. al. (1978) found that snags used most frequently for nesting in the Fraser Experimental Forest in British Columbia had broken tops. Weikel and Hayes (1999) found that hairy woodpeckers in the coast range of Oregon selected heavily decayed standing and downed wood for foraging. Neitro et. al. (1985) found that downy and hairy woodpeckers tended to use softer snags for nesting, though hairy woodpeckers also selected less decayed trees as nest sites. Pileated woodpeckers typically selected harder snags for nesting. In coniferous forests of Washington, Lundquist and Mariani (1991) found that cavity-nesting birds, including hairy woodpeckers, selected mostly large, hard snags as nest sites. In a study

of primary cavity-nesting bird utilization of quaking aspen trees, Schepps et. al. (1999) found that four species of woodpeckers selected quaking aspen nest trees that were softer than surrounding available nest sites. Also, the nest tree was more decayed at the site of the nest cavity than elsewhere on the tree.

Studies show that the density of available snags is positively correlated with the density of cavity nesting birds (Raphael and White 1984, Zarnowitz and Manuwal, 1985). There also appears to be a positive correlation between cavity-nesting bird density and forest maturity (Mannan et. al. 1980, Lundquist and Mariani 1991). Snags are likely a limiting factor in reproduction of cavity-nesting birds (Zarnowitz and Manuwal 1985) and there is concern that once existing remnant snags are gone, they will not be replaced easily due to current forest management practices (Neitro et. al. 1985, Ohmann et. al. 1994).

Previous Research on the Use of Snags in Beaver Ponds by Cavity-Nesting Birds

Surprisingly, there has been little research exploring the presence and use of snags by cavity-nesting birds in beaver ponds. Rendell and Robertson (1989) studied the characteristics of snags utilized by tree swallows (secondary cavity-nesters) in two deciduous woodland beaver ponds in Ontario, Canada. They also collected snag and nest cavity data for unoccupied nest snags and snags utilized by other species. Key measurements included snag height, cavity height, snag circumference at the base and at the nest cavity, cavity dimensions, proximity to nearest swallow nest, and distance from shore. Most nest snags had circumferences of 60 to 90 cm at the base and 41 to 105 cm at the cavity entrance. Rendell and Robertson found greater reproductive

success in nests with higher cavities and larger cavity floors, but the proximity of nest snags to shore or to other nests did not influence reproductive success. This research did not include any measurements of snag decay indicators such as decay classification, amount of bark remaining, presence of conks, or whether a snag had a broken top. The study did not address the use of beaver ponds by primary cavity-nesting birds in any way.

Lochmiller (1979) studied wintertime use by woodpeckers of a beaver pond in the Oconee National Forest of Georgia. This research focused on two sites at different locations on a single pond, and a control site without beaver influence. Seven woodpecker species were observed including Pileated, Hairy, Red-headed (*Melanerpes erythrocephalus*), Red-bellied (*Melanerpes carolinus*), and Downy Woodpeckers, Yellow-bellied Sapsucker (*Sphyrapicus varius*), and Northern Flicker. Behavior was classified as foraging or non-foraging. Birds were also classified by percentage of time spent in each area. Measurements were made of total basal area of standing trees in the three sites as well as the basal area of snags. Snags comprised 87% and 66% of total basal area in the two areas of the beaver pond compared to 4% in the control site. Lochmiller found that Pileated Woodpeckers spent a disproportionately large amount of time in one of the beaver pond sites and concluded that this higher incidence of woodpecker use was attributable to higher concentrations of insects in dying trees. Habitat characteristic data was limited to snag basal area, site size and site location. No assessment was made of past foraging activity. Neither Lochmiller (1979) nor Rendell and Robertson (1989) specifically addressed the issue of snag generation and degree of

utilization in beaver ponds.

Hypotheses

The key research objectives of this study were: 1) to quantify the production of snags that would be suitable for primary cavity-nesting birds in forested riparian habitats in the western Oregon Cascades; and 2) to quantify the degree to which suitable snags have been excavated by primary cavity-nesting birds. Additional hypotheses addressed differences in snag characteristics between excavated and unexcavated snags, and between beaver ponds and undammed riparian habitat.

Key Hypotheses

HA₁: There are significantly more snags in beaver ponds in forested riparian habitat in the western Oregon Cascades than in unponded forested stream areas with comparable slope, soil, vegetation, and elevation.

HA₂: Significantly more snags are excavated by primary cavity-nesting birds in beaver ponds in the western Oregon Cascades than in unponded forested stream areas with comparable slope, soil, vegetation, and elevation.

HA₃: Snags in beaver ponds differ in size and degree of decay from snags in unponded forested stream areas.

HA₄: Excavated snags in beaver ponds differ in size and degree of decay from excavated snags in unponded forested stream areas.

Methodology

Experimental Design

To test these hypotheses I compared snag characteristics and utilization by primary cavity-nesting birds in eight beaver ponds and eight forested riparian reference sites that lacked any visible hydrologic or biotic influence from beaver activity. Study sites were in or adjacent to Mount Hood National Forest (Figure 1). All ponds and reference sites were located in the Upper Clackamas River drainage area, approximately 97 kilometers (km) southeast of Portland, Oregon (Figures 2a, b, and c). The study area extended from USGS Township 4S Range 6E to Township 6S Range 6E within the U.S. Forest Service's Clackamas Ranger District. Selecting study sites within the same geographic area ensured that sites would be similar in terms of vegetation, geologic influences and hydrology, thus minimizing site variability. This area was also chosen due to the known presence of beaver and due to the ability to locate ponds that were relatively undisturbed by human development.

I defined reference sites as randomly selected plots that were ≤ 1 hectare in area. This size criterion was based on average sizes of beaver pond study sites and on findings that the majority of beaver foraging occurs within approximately 21 meters of the stream (McGinley and Whitham 1985).

Within each study site, I assessed specific characteristics that provided an indication of degree of decay and suitability as habitat for woodpeckers. I also assessed snags for the presence of forage and/or nest holes and classified them into one of three categories of excavating species: 1) Pileated Woodpecker, 2) Hairy/Downy/Northern

Flicker, or 3) Red-breasted Sapsucker. The analysis of utilization by primary-cavity nesting birds focused on the Pileated Woodpecker, Hairy Woodpecker, Downy Woodpecker, Northern Flicker and Red-breasted Sapsucker since these species are known to use western Oregon forests and are year-round residents in the region. Habitat characteristics that might affect primary cavity-nesting bird utilization were also recorded.

The research focused on snags that were at least 20 cm in diameter at breast height (diameter at 137 cm from the ground) and at least 2 m high. These minimum values were based on snag characteristics preferred by primary cavity-nesting birds (Mannan et. al. 1980, Raphael and White 1984, Neitro et. al. 1985, Bull 1987). In studies of snag use by birds in western Oregon, Mannan et. al. (1980) found that woodpeckers foraged mostly on snags with diameters ≥ 20 cm (mean diameters of snags used by foraging Pileated Woodpeckers, Northern Flickers, and Hairy Woodpeckers were 103 cm, 95 cm, and 62 cm, respectively). Forage and nest snags in Mannan et. al.'s study were all above 20 m in height. In an extensive compilation of research on the use of snags by wildlife, Neitro et. al. (1985) defined a snag as ≥ 10 inches (approximately 25.6 cm) in diameter and ≥ 6 feet (approximately 1.85m) tall.

I conducted exploratory research during winter and spring 2000 to survey beaver pond habitat characteristics and confirm the feasibility of the study. Locations of three preliminary study sites with potential beaver activity were provided by the U.S. Forest Service district office for the Upper Clackamas River drainage area of Mount Hood National Forest. I collected preliminary data to determine the range of variables

to measure to adequately address the hypotheses proposed.

Beaver Pond Study Site Selection and Site Descriptions

The eight beaver ponds that I studied were located using information provided by the U.S. Forest Service Estacada Ranger Station, the Oregon Department of Fish and Wildlife, Portland General Electric (PGE), and Timber Lake Job Corps Center, as well as from my own exploration of the area. I narrowed my search using specific criteria for gradient and habitat type. Beavers tend to build dams on small meandering streams in relatively flat, broad valleys with riparian vegetation (Olson and Hubert 1994, Verts and Carraway 1998). Typical streams occupied by beavers have a gradient $\leq 15\%$ and do not have rocky bottoms. While not limited by elevation, beavers require deciduous vegetation for dam building and foraging. Preferred species include poplar, willow, alder and maple (*Acer spp.*) (Verts and Carraway 1998). Through use of topographic maps and site reconnaissance, I excluded areas with steep terrain and higher elevation subalpine forests where preferred food species were less likely to grow. Criteria used to select beaver pond study sites included the following:

- All beaver ponds occurred in forested riparian habitat.
- Beaver dams were present at all sites with evidence of flooded trees from upstream ponding.
- All sites had flowing water, even if the source of the water appeared to be subsurface.
- All sites were at least 0.1 hectares to sufficiently capture the effects of

beaver on the landscape and to minimize variability in habitat characteristics among ponds.

- All sites were ≤ 0.5 km from a road or trail to ensure ease of access for multiple site visits.

Table 1 summarizes the eight beaver pond sites. More detailed descriptions are provided in the sections that follow.

Ponds 1 and 2: PGE Sewage Lagoon Area

Ponds 1 and 2 were located in the northern portion of Township 4S, Range 5E, Section 18 (USGS 7.5" Bedford Point Quadrangle) on the northern side of Highway 224 in the vicinity of PGE's Promontory Park (Figure 2a). This land, owned by PGE, was approximately 2 km northwest of the Mount Hood National Forest boundary and was bordered mostly by Bureau of Land Management (BLM) land. The area was approximately 0.5 km northeast of the Upper Clackamas River and 2 km southeast of the North Fork Reservoir on the Upper Clackamas River. At the time of the study, PGE maintained sewage lagoons and a gravel site within 0.5 km of Pond 1, but these uses were separated from the pond site by mature red alder (*Alnus rubra*) and shrub vegetation. Land directly adjacent to the ponds was gently sloping, but slope increased further to the north and south.

Pond 1 was a narrow, elongated body of water (Figure 3), approximately 0.3 hectares in area and was located at an elevation of approximately 253 m. Habitat in the immediate vicinity of the pond to the north and east was dominated by red alder, however there was minimal canopy cover at the pond. Surrounding habitat consisted of

a mixture of red alder and Douglas-fir (*Pseudotsuga menziesii*), with Douglas-fir dominant. The habitat surrounding the pond to the south was significantly disturbed by human activity. This area was cleared sometime in the past and contained gravel, deep ruts from past vehicular use, and non-native grasses.

Pond 2 was located approximately 0.1 km upstream of Pond 1 at an elevation of approximately 274 m. This pond was 0.1 hectares in area (Figure 4) and appeared to be significantly older than Pond 1 as evidenced by decay stages of snags and size of live trees. While still close to the cleared areas to the south that border Pond 1, Pond 2 was immediately surrounded by a dense cover of mixed alder, bigleaf maple (*Acer macrophyllum*) and Douglas-fir habitat.

The upstream source for Ponds 1 and 2 appeared to be intermittent and/or subsurface flow originating from a tributary of the North Fork of the Clackamas River. Beavers had constructed two lodges on Pond 1, both of which appeared to be active. Beavers were heard but not seen on the site. There was sign of active foraging in habitat near both ponds, including recently stripped limbs and gnawed tree trunks.

Pond 3: Sandstone Creek Area

Pond 3 was located within Mount Hood National Forest between Township 5S, Range 6E, Section 33 and Township 6S, Range 6E, Section 33 (USGS 7.5" Fish Creek Mountain Quadrangle), on the west side of Forest Service Road 4620 (Figure 2b). The pond was approximately 1 km west of the Clackamas River on moderately sloped, relatively undisturbed land at an estimated elevation of 494 m. Habitat in the immediate vicinity of the pond was dominated by red alder with some Douglas-fir,

western hemlock (*Tsuga heterophylla*) and bigleaf maple. Upslope and surrounding forested areas were dominated by Douglas-fir.

Pond 3 was approximately 0.4 hectares in area (Figure 5). The upstream source appeared to be water from an offshoot of Sandstone Creek that rejoined the creek downstream of the dam. Downstream flow from the pond dropped in elevation below the dam to a culvert that guided water under Forest Service Road 4620 where it then flowed through steeper, rockier terrain. Beavers actively maintained a lodge at Pond 3 and there was sign of recent foraging activity.

Pond 4: Ripplebrook Residential Area

Pond 4 was located within Mount Hood National Forest in Township 6S, Range 6E, Section 2 (USGS 7.5" Fish Creek Mountain Quadrangle) on the west side of Forest Service Road 4631 across from the residential area of Ripplebrook (Figure 2c). The site was 0.5 km north northwest of the Oak Grove Fork of the Upper Clackamas River at an estimated elevation of 476 m.

Pond 4 was approximately 1.4 hectares in area and was a relatively older pond with numerous large standing snags (Figure 6). Habitat in the immediate vicinity of the pond was dominated by a mix of red alder and Douglas-fir with alder prevalent in more open areas. Surrounding habitat was dominated by Douglas-fir to the east and west, alder to the north, and a mix of red alder and Douglas-fir to the south. The southern edge of the pond was in close proximity to the road and downstream flow from the dam was culverted under the road. There was little to no canopy cover over the pond except around forested edges.

The upstream source for Pond 4 appeared to be subsurface flow associated with Bull and/or Pint Creeks. The area was located 1.5 km due south of Frog Lake and an aqueduct, thus, waterways in the vicinity of the pond were likely altered from their natural state. Other human influence included two nest boxes placed on larger snags, presumably to encourage duck breeding, and use of the west side of the pond as a hiking trail. Beavers actively maintained a lodge at Pond 4 and were heard periodically in the lodge and seen on a few occasions in the pond. There was sign of active foraging including fresh gnawings and wood chips.

Pond 5: Ripplebrook Campground Vicinity

Pond 5 was located approximately 1 km northeast of Pond 4 within Mount Hood National Forest in Township 6S, Range 6E, Section 2 (USGS 7.5" Fish Creek Mountain Quadrangle). Pond 5 was 1.35 hectares in area and was situated in moderately sloped terrain at an elevation of roughly 494 m (Figures 2c and 7). While the pond itself was open, it was surrounded by a dense canopy of mostly coniferous trees, dominated by Douglas-fir. Tall conifers on surrounding slopes contributed to considerable shade all year at this site. Occasional bigleaf maples and red alders were found in close proximity to the pond, particularly in the vicinity of a decommissioned Forest Service road near the southeast portion of the pond.

Surrounding habitat appeared to be relatively undisturbed. The pond was located 1 km south-southeast of Frog Lake and a Forest Service road was just northwest of the pond. In addition, Ripplebrook Campground was located 0.5 km to the south. Like Pond 4, the upstream source of water to this pond appeared to be

subsurface flow originating at Bull and/or Pint Creeks, and historical flow may have been altered due to Frog Lake and the construction of an aqueduct.

Pond 6: Half Pint Creek Area

Pond 6 was located within Mount Hood National Forest in Township 5S, Range 6E, Section 36 (USGS 7.5" Fish Creek Mountain Quadrangle), approximately 1.5 km east of Frog Lake and 1 km northeast of the Oak Grove Work Center (Figure 2c). The pond had an estimated area of 0.13 hectares and was located at an approximate elevation of 658 m on relatively flat terrain (Figure 8).

Habitat in the immediate vicinity of the pond was dominated by mature bigleaf maples and red alder. Bigleaf maple snags in Pond 6 had intact boles, limbs, and twigs but significant bark loss. Surrounding land was dominated by Douglas-fir forest. The canopy in the immediate area surrounding the pond was open, which allowed for significant year-round solar input. The area was relatively undisturbed except for proximity to developed sites such as the Oak Grove Work Center. The upstream source to the pond was Half-Pint Creek. Beavers were seen and heard at the site and the lodge, as well as surrounding trees, showed signs of active use.

Ponds 7 and 8: Highway 224 in Vicinity of Ripplebrook Guard Station

Ponds 7 and 8 were both located within Mount Hood National Forest in Township 6S, Range 6E, Section 2 (USGS 7.5" Fish Creek Mountain Quadrangle) on moderately sloped terrain at an elevation of 451 m (Figure 2c). The ponds were located directly north of Highway 224 and were bordered by Forest Service Road 4631 to the

west and Forest Service Road 260 to the east.

Pond 7 was located directly off of Highway 224 and had an estimated area of 0.98 hectares (Figure 9). This pond appeared to be older as evidenced by the decay stages of standing snags and the diameter and height of surrounding trees. The habitat was dominated by mixed alder and bigleaf maple in open areas to the north and west of the pond. Further away from saturated areas, Douglas-fir dominated. Downstream flow from the dam was culverted under Highway 224. The site was significantly disturbed by human activity, particularly on the side of the pond adjacent to Forest Service Road 260. Pond 8 was located upstream from Pond 7 and extended through a narrow portion of land bordered on the west by Forest Service Road 4631 and on the east by Forest Service Road 260. This site consisted of multiple dammed areas in close proximity to one another that formed a contiguous long, narrow pond with an estimated area of 0.63 hectares (Figure 10). Dominant trees in the immediate vicinity of Pond 8 were red alder and bigleaf maple. However, further from the areas of saturation, the tree layer was dominated by Douglas-fir. The land surrounding the northeast portion of Pond 8 and upslope from the site was disturbed due to ongoing human activity including construction equipment and gravel piles.

The upstream source to both Ponds 7 and 8 appeared to be subsurface flow. However, it was difficult to accurately identify the source because of considerable disturbance to the landscape in surrounding areas. Beavers maintained an active lodge on Pond 7 and there were signs of recent foraging in the vicinity of both Ponds 7 and 8.

Reference Site Selection and Site Descriptions

All reference sites were randomly selected within the Upper Clackamas River drainage area of Mount Hood National Forest. The following are specific site selection criteria established to ensure that reference sites had characteristics reflective of pond sites prior to beaver influence:

- Sites showed no evidence of beaver activity.
- Sites were within ± 152 m (500 feet) of mean elevation of eight ponds to minimize variability in habitat characteristics between beaver ponds and reference sites.
- Slope was less than 20% to control for the typical gradient of areas influenced by beavers. Using an upper boundary of 20% slope instead of 15% reported in the literature provided required flexibility for finding enough suitable reference sites.
- Sites were within forested riparian habitat with similar vegetation to beaver ponds.
- Sites were ≤ 0.5 km from an access trail or road to ensure ease of access for multiple site visits.

To identify potential reference sites, a circle with a radius of 5 km was drawn around each pond on a USGS 7.5 minute map (USGS Fish Creek Mountain (1985) and Bedford Point (1986) 7.5" Quadrangle Maps). A two-dimensional grid was then superimposed on the USGS 7.5" quadrangle map with each cell representing an area

equivalent to 4 hectares (200 m by 200 m). Using a random number generator function in MS Excel[®], pairs of random numbers were obtained that represented the x and y coordinates of overlay grid cells. If the selected grid cell or any areas within 200 m of the selected cell met the established criteria, the grid cell was marked as a reference site for field exploration. If a selected reference site did not meet all the established criteria, as evidenced by closer examination of the USGS map or upon field reconnaissance, a new set of random coordinates was generated to locate additional potential reference site locations. Two of the eight ponds (Ponds 1 and 2 described above) were located approximately 15 km to the west of the other 6, just outside the boundary of Mount Hood National Forest. All eight reference sites were located within Mount Hood National Forest within 5 to 7 km of the Ripplebrook area (Figures 2b and 2c). No acceptable reference sites were identified within 5 km of Ponds 1 and 2 due to the steep terrain and limited access to Forest Service roads in the vicinity of Fish Creek Mountain. Table 2 provides a summary of reference site characteristics. Detailed descriptions are provided below.

Reference Site 1: Bull Creek

The Bull Creek reference site was located within Mount Hood National Forest in Township 5S, Range 6E, Section 34 (USGS 7.5" Fish Creek Mountain Quadrangle) less than 1 kilometer northeast of Timber Lake Job Corps Center in Mount Hood National Forest (Figure 2c). The plot was on moderately sloped terrain at an elevation of approximately 503 m. Bull Creek originated approximately 3 km east of the reference site location and flowed into Timber Lake. The 0.67 hectare reference site

was located approximately 200 m from an old logging road. Bull Creek at this location was a meandering stream, approximately 4 meters wide. The site was dominated by Douglas-fir with red alder found within the near-stream portion of the habitat and under canopy openings further away from the stream. Canopy cover was significant at the site. The reference site was in relatively undisturbed habitat but was adjacent to what appeared to be a decommissioned, overgrown logging road and replanted clear-cut area.

Reference Site 2: Big Creek

The Big Creek reference site was located in Township 6S, Range 6E, Section 9 (USGS 7.5" Fish Creek Mountain Quadrangle), approximately 0.5 km from Forest Service Road 4521 in Mount Hood National Forest at an elevation of 567 m (Figure 2b). The 0.51 hectare plot was located on terrain that was gently sloping on the north side and more steeply sloped on the south side. Big Creek originated from several headwater sources near Fish Creek Mountain. Three km downstream from the reference site, the creek emptied into the Upper Clackamas River. There was evidence of historic clear-cuts directly adjacent to the stream bank on the south side of the site. These cleared areas had either not been replanted or were replanted without success. Big Creek at this location was approximately 9 meters wide. The site showed signs of recent disturbance from storm events in the form of large downed wood. The dominant species in the immediate vicinity of the stream was red alder with some bigleaf maple and a partial canopy cover. The surrounding forested areas were dominated by Douglas-fir. The reference site was in relatively undisturbed habitat except for past

logging.

Reference Site 3: John Creek

The John Creek reference site was located within Mount Hood National Forest in Township 6S, Range 6E, Section 1 (USGS 7.5" Fish Creek Mountain Quadrangle), approximately 1 kilometer southeast of the confluence of John Creek and the Oak Grove Fork of the Upper Clackamas River (Figure 2c). John Creek at this location was on moderately sloping terrain at an elevation of approximately 622 m. The reference site was the smallest of the eight sites (0.26 hectares) due to the increase in elevation from the stream to upland areas. The center of the reference site plot was located approximately 200 m from Forest Service Road 120 off of Highway 57 that heads east from the Ripplebrook area. John Creek at this location was approximately 3 meters wide. Habitat immediately surrounding the stream was dominated by Douglas-fir and red alder with Douglas-fir dominating further away from the near-stream area. The site had significant canopy cover from mature conifers. The area was relatively undisturbed habitat other than past logging activities. Closer to Forest Service Road 120 red alder was dominant, due to what appeared to be a decommissioned logging road that created openings in the Douglas-fir canopy.

Reference Site 4: Tag Creek

The Tag Creek reference site was located in Township 6S, Range 6E, Section 11 (USGS 7.5" Fish Creek Mountain Quadrangle), near Austin Meadow and approximately 0.2 km west of Highway 46, south of the Ripplebrook area in Mount

Hood National Forest (Figure 2c). Tag Creek originated approximately 3 km upstream from the reference site and flowed into the Upper Clackamas River approximately 0.3 km downstream from the site.

Tag Creek at the reference site was approximately 3 meters wide. The site was 0.68 hectares in area and was located on moderately sloping terrain at an approximate elevation of 442 m. The habitat immediately surrounding the stream was dominated by red alder. However, in upland areas, the dominant species was Douglas-fir. The area was relatively undisturbed though it was within close proximity of the Riverside Trail and Highway 47.

Reference Site 5: Mag Creek

The Mag Creek reference site was located in Mount Hood National Forest in Township 6S, Range 6E, Section 13 (USGS 7.5" Fish Creek Mountain Quadrangle), on moderately sloping terrain at an elevation of 579 m in Mount Hood National Forest (Figure 2c). The creek originated approximately 1.5 km southeast of the reference site and emptied into Tag Creek near the confluence of Tag and the Upper Clackamas River approximately 2 km downstream from the reference site.

The center of the 0.79 hectare plot was located an estimated 200 m from a logging road. Mag Creek at this location was approximately 2 meters wide. Habitat in the near-stream area was dominated by red alder and in upland areas the tree layer was mixed Douglas-fir and red alder. There were many openings in the canopy allowing considerable influx of sunlight. The habitat appeared to be undisturbed except for past logging activity.

Reference Site 6: Station Creek

The Station Creek reference site was located in Mount Hood National Forest in Section 36 of 5N, Range 6E (USGS 7.5" Fish Creek Mountain Quadrangle), approximately 0.5 km southwest of the Oak Grove Work Center in Mount Hood National Forest (Figure 2c). The site was on fairly level terrain at an elevation of 564 m. At the center of the 0.57 hectare reference site, Station Creek was an estimated 4 meters wide.

Habitat in the near-stream area was dominated by red alder and Douglas-fir with some bigleaf maple. The tree layer in upland areas was dominated by Douglas-fir. There were numerous canopy openings allowing for solar input. The habitat was surrounded on the north by a Forest Service road and on the south by a logging road and an extensive clear-cut area.

Reference Site 7: Pint Creek

The Pint Creek reference site was located in Township 5S, Range 6E, Section 35 (USGS 7.5" Fish Creek Mountain Quadrangle) near Forest Service Road 4631 and 1.5 km southeast of Frog Lake in Mount Hood National Forest (Figure 2c). The reference site was located on gently sloping terrain at an elevation of 530 m.

At the center of this 0.97 hectare plot, Pint Creek was approximately 2 to 3 meters wide. Pint Creek originated approximately 0.5 km upstream from the reference site. One kilometer downstream, Pint Creek emptied into the Oak Grove Fork of the Upper Clackamas River. The habitat was dominated by bigleaf maple in the near-stream area and Douglas-fir in upland habitat further from the plot center. A portion of

this reference site was adjacent to Forest Service Road 4631, but otherwise it was relatively undisturbed. The canopy was open in the vicinity of the stream and was partially closed in upland areas.

Reference Site 8: Half Pint Creek

The Half-Pint Creek reference site was located in Township 5S, Range 6E, Section 36 (USGS 7.5" Fish Creek Mountain Quadrangle) within Mount Hood National Forest, approximately 1.5 km east of Frog Lake and 1 kilometer northwest of Oak Grove Work Center (Figure 2c). The site was on gently sloping terrain at an estimated elevation of 610 m.

The reference site was 0.97 hectares in area and Half-Pint Creek at the plot center was approximately 3 meters wide. Half-Pint Creek originated approximately 1.5 km north-northeast of the reference site plot in higher elevation terrain. Approximately 0.5 km downstream of the reference plot Half-Pint merged with Pint Creek, which then emptied into the Oak Grove Fork of the Upper Clackamas River.

The near-stream habitat was dominated by bigleaf maple and red alder with more Douglas-fir in upland areas. The site was adjacent to a clear-cut and a roadway with grasses dominant at the edge of the clear-cut. The canopy was relatively open throughout. Except from past logging activity, the area appeared to be relatively undisturbed.

Measurement of Snag Characteristics in Beaver Ponds

At each pond, observation points that afforded good visibility of the top and

base of each snag were established and flagged. To delineate each pond for mapping purposes, a Brunton pocket transit was used to obtain a compass reading every 10 to 15 meters around the pond perimeter. The perimeter of the pond was defined as the outer extent of saturation. The saturation line rather than the water line was used to define the pond boundary to more accurately estimate the area of land influenced by hydrologic alteration due to beaver activity that may have contributed to snag formation. Although a complete wetland delineation as defined by the Wetland Training Institute (1995) was not performed for each pond, criteria commonly used in the delineation process were applied to determine pond boundaries. Criteria used to indicate saturation included presence of wetland vegetation and hydrologic indicators such as water marks, sediment deposits on leaves, and drainage patterns (Wetland Training Institute 1995). No soil samples were collected.

Preliminary site maps of each beaver pond, depicting the location of snags and the pond's boundary, were produced on graph paper. A protractor was used to replicate azimuth data collected in the field combined with distance data from point to point around the pond perimeter. Resulting drawings had a margin of error for perimeter length of ± 5 m. Pond areas were derived by counting the squares and portions of squares within the drawn boundary. These initial maps were scanned and replicated using Adobe Illustrator[®] software to produce final sketches. Pond maps (Figures 3 through 10) include the location of observation points and the snags recorded at each observation point based on distance and azimuth data collected. From each pond observation point the following characteristics were recorded for all snags ≥ 20 cm

diameter and ≥ 2 m in height:

- Identification number.
- Degrees from true north.
- Diameter (cm).
- Distance from observation point to snag.
- Snag height.
- Depth of pond at snag (average of 4 measurements around snag using a meter stick).
- Whether snag was deciduous or coniferous.
- Species of snag (if possible to determine).
- % bark remaining (20 classes in 5% increments).
- Whether snag had a broken top.
- Decay class (based on five classes shown in Table 3).
- Number of large limbs remaining.
- Other descriptive notes (e.g. percent of leaning, number of trunks, presence of conks).

A Brunton[®] pocket transit was used to measure degrees from true north from the designated observation point to each snag. Standard diameter tape was used to measure snag diameter in cm. Distance from the observation point to the snag was obtained by using meter tape (distance “x” in Figure 11). For a small number of snags that were not accessible due to pond depth, I used a rangefinder with an accuracy of

0.16 m for distances of 20 m to estimate distance from the observation point to the snag. The angle from the observation point to the top of the snag (θ_1 in Figure 11) and to the base of the snag (θ_2 in Figure 11) were determined using a Brunton[®] clinometer. Snag height (H) was then determined based on the following trigonometric relation: $H = (x * \tan \theta_1) + (x * \tan \theta_2)$ (Figure 11). Note that all observation points were located above the base of the snag for these measurements.

The depth of the pond at each snag was obtained by measuring water depth from the pond bottom to the pond surface at four locations around the snag using a 3 meter pole and then averaging the data. The pond bottom was defined as the point at which the meter stick met resistance with the sediment. Available field guides (Bull et. al. 1997, Parks et. al. 1997) and evidence of bark, limbs, and growth pattern were used to assess whether the snag was deciduous or coniferous and, where possible, to determine species. The percent of bark remaining was determined by examination of the snag from top to base. Any bark present, even if loose, was included in the total percentage. Decay class was assigned based on a five class system (Table 3) for Douglas-fir forests (Cline 1977, Cline et. al. 1980). Note for deciduous snags, the color of sapwood and heartwood can be markedly different from that of Douglas-fir; therefore, only applicable indicators from Cline's system, such as state of the bole and presence of limbs, branches and bark, were used.

Measurement of Snag Characteristics in Reference Sites

Using a USGS 7.5" quadrangle map and a Global Positioning System (GPS) unit, I located the stream occurring within the randomly selected reference site and

designated the center of the stream channel as the center of a circle plot. Using a compass and 100 meter tape, 16 radial transects were walked from the center of the plot at intervals of 22.5 degrees (Figure 12). The length of each transect was ≤ 56.4 m. A transect length of 56.4 m was designated as the maximum distance because it is equivalent to the radius of a circle plot with an area of 1 hectare. However, actual transect length was less than 56.4 m in cases where the elevation from the center of the plot extending along the transect increased by 2 m or more. In these instances I assumed, based on my personal observations and the literature (Olson and Hubert 1994) that flooding in beaver-influenced habitat would likely not exceed 2 meters in depth. Thus, the end of the transect was designated as the point reflecting no more than 2 meters in elevation change from the center of the plot, measured using a clinometer.

Along each transect the following data were recorded for snags ≥ 20 cm diameter and ≥ 2 m height:

- Distance along the transect.
- Distance and direction from transect line.
- Species.
- Diameter in cm.
- Height (see Figure 11 for description of snag height calculation).
- Decay stage.
- Whether snag had a broken top.
- Percent bark remaining.
- Number of large limbs remaining.

Species, diameter, height, decay stage, percent bark remaining, and characteristics of excavations by primary cavity-nesting birds were assessed using the identical protocol used for snags in beaver ponds. The distance along the transect was determined by recording the distance along the 100 meter tape where the lateral location of the snag occurred. The distance of the snag from the transect line was determined by running meter tape perpendicularly from the transect to the snag and measuring total distance. In addition, the side of the transect on which the snag occurred was recorded.

To calculate the area of each reference site plot, the end of each transect was treated as the mid-point of one plot sector (the entire plot consisted of 16 sectors at intervals of 22.5 degrees from the center of the plot) (Figure 12). These mid-points were then connected to form the perimeter of the reference plot. The area for each plot sector was calculated trigonometrically by determining the areas of right triangles comprising each sector given the known transect length, theta (22.5 degrees) and the location of 90 degree angles. The sum of the areas of plot sectors equaled the total area for each reference site.

Size of Beaver Ponds versus Size of Reference Sites

Beaver ponds and reference sites were comparable in size with no statistically significant differences in median areas (Mann-Whitney Rank Sum Test: $P = 0.798$) (Figure 13). Median values for beaver ponds and reference sites were 0.490 and 0.675 hectares, respectively.

Characterization of Primary Cavity-Nesting Bird Excavations

In addition to measuring snag characteristics in beaver ponds and reference sites, I surveyed snags ≥ 20 cm diameter and ≥ 2 m in height for signs of excavation (presence of nest cavities or forage holes). For each snag with excavations, the following information was recorded:

- Type of excavation (nesting or foraging).
- Excavating species.
- Number of excavations.
- Portion of snag excavated.
- Distance from excavated snag to nearest available cover.
- Any other applicable notes to describe cavities (e.g. shape of opening, interesting location).

Distinctions between nesting and foraging excavations were based on size, shape and smoothness of excavation, and where they occurred on the snag. As noted earlier, excavations were classified as one of three categories: Pileated, Hairy/Downy/Northern Flicker, or Red-breasted Sapsucker. This classification was possible for forage holes because each group excavates in a unique fashion and creates distinctive forage holes. Pileated Woodpeckers tend to forage deeply and in softer wood their excavations are often extensive, elongated sections. Northern Flickers forage primarily on the ground, but during the winter months they have been observed foraging on standing trees (Moore 1995). Because of a longer bill than Hairy or Downy woodpeckers, forage holes made by Northern Flickers in trees are larger, but generally not as extensive or deep as Pileated Woodpecker holes. Hairy and Downy

woodpeckers have smaller bills and tend to create shallow, round holes, particularly in sounder wood. Comparatively, Hairy Woodpeckers have longer bills than Downy Woodpeckers and are able to make a wider, deeper hole. Sapsuckers tend to forage in a horizontal fashion, leaving behind multiple rows of small holes.

My observations of avian activity during site visits included species, number of individuals, age (juvenile or adult), sex (if possible to discern), activity, and location (particularly if near a specific snag or live tree). Birds heard in proximity to the pond, but not observed, were also recorded but identified as “heard only.” These observations, while not performed according to a standard protocol, provided confirmation of pond use by the species in question.

Data Analysis

General Approach

The study unit in this research was an individual snag. In statistical tests, snag data were treated as groups to enable comparisons between beaver ponds and reference sites for specific characteristics. Key characteristics for which statistical analyses were performed included density, diameter, height, percent bark remaining, and decay class of all available snags and all excavated snags. The majority of data collected was not normally distributed, and in many cases, data distributions were significantly skewed. For non-normal distributions, the literature recommends nonparametric statistical tests for assessing differences in central tendency. These tests typically use the median as a measure of central tendency and do not make any assumptions about data distribution (Sokal and Rohlf 1995, Zar 1999).

The nonparametric tests I used to analyze data collected were Kruskal-Wallis and Mann-Whitney Rank Sum, both of which use ranked data rather than raw data values to test for significant differences in medians between populations ($P < 0.05$). Kruskal-Wallis generates an H statistic, which, for larger sample sizes as in this study, can be approximated by a Chi-Square test with $k - 1$ degrees of freedom (df), where k equals the number of populations compared (Sokal and Rohlf 1995, Zar 1999). For both the Kruskal-Wallis and Mann-Whitney Rank Sum tests, a significant difference in population medians occurs when the statistic generated by the test is greater than the critical value at a significance level of 0.05. The Kruskal-Wallis and Mann-Whitney Rank Sum tests also generate upper (75th percentile) and lower (25th percentile) quartile values, which I used to interpret statistical results. In addition to nonparametric methods, I performed t -tests, Chi-Square, Log Likelihood Ratio and correlation analyses where applicable.

Classification of Old Versus New Beaver Ponds

During field observations, I noted qualitative differences among the eight beaver pond sites that appeared to be attributable to habitat succession. To address the issue of beaver pond habitat variability, I used the Kruskal-Wallis test in a preliminary analysis to explore pond age as a possible contributing factor. With Kruskal-Wallis I compared snags in the eight beaver pond populations for each of the following four characteristics: diameter, height, decay class and percent bark remaining. I assumed that higher decay class values and lower percent bark remaining values were indicative of an older pond. Two tests were run for each snag characteristic: one to compare

excavated snags and another to compare all available snags. In addition, I ran Dunn's pairwise comparison tests to better understand the specific ponds contributing to statistically significant differences in medians. The Dunn's test is a commonly used post-test for nonparametric data that calculates a P value for all permutations of populations compared in the Kruskal-Wallis test (Zar 1999). A P value of less than 0.05 indicated that there was a statistically significant difference in the median values for a specific snag characteristic between two particular ponds.

For pooled beaver pond snags, there were significant differences in the median values for diameter ($H = 59.05$, $P < 0.001$, $df = 7$), decay stage ($H = 70.21$, $P < 0.001$, $df = 7$), height ($H = 35.76$, $P < 0.001$, $df = 7$), and percent bark remaining ($H = 50.29$, $P < 0.001$, $df = 7$) using Kruskal-Wallis tests. Dunn's pairwise comparisons revealed numerous pairs of ponds for which there were statistically significant differences in median values for one or more of the four characteristics (Table 4). These results confirmed the differences among ponds shown by the Kruskal-Wallis tests.

Based on significant differences in median values for snag decay stage and percent bark remaining, I divided the eight beaver ponds into two age groups. Ponds 2, 4, 5, 7, and 8 were classified as old ponds and ponds 1, 3, and 6 were classified as new ponds. I then ran Kruskal-Wallis and Dunn's tests again to assess differences in snags in the beaver pond populations comprising the newly created groups.

Follow-up Kruskal-Wallis and Dunn's tests of the differences in old and new beaver pond categories for specific snag characteristics revealed a significant decrease in variability compared to pooled ponds (Table 5). In old ponds there were still

differences in median values for diameter ($H = 26.65$, $P \leq 0.001$, $df = 4$), height ($H = 21.67$, $P \leq 0.001$, $df = 4$), decay stage ($H = 24.91$, $P \leq 0.001$, $df = 4$), and percent bark remaining ($H = 50.29$, $P \leq 0.001$, $df = 4$) for several ponds using Kruskal-Wallis tests. New ponds had very few significant differences except for percent bark remaining ($H = 20.22$, $P \leq 0.001$, $df = 2$). This confirmed that the division into the two age groups had addressed, at least in part, variability among beaver ponds. These age classifications were used in all subsequent statistical tests.

Differences Among Reference Sites

In preliminary statistics, I also used Kruskal-Wallis and Dunn's tests to compare snags in the eight reference site populations for each of the four key characteristics (diameter, height, decay class, and percent bark remaining). The Kruskal-Wallis test showed significant differences in median diameter ($H = 23.98$, $P = 0.001$, $df = 7$), decay stage ($H = 16.03$, $P < 0.025$, $df = 7$), height ($H = 18.72$, $P = 0.009$, $df = 7$), and percent bark remaining ($H = 17.71$, $P < 0.013$, $df = 7$). Results from Dunn's pairwise multiple comparisons revealed that in many cases, significant differences among reference sites were not associated with specific snag characteristics and were attributed to only one or two pairs of sites (Table 6). Therefore, it was not necessary to divide reference sites into subgroups for further statistical tests. In all subsequent statistical tests to compare beaver pond snags to reference site snags, reference sites were treated as a pooled population (all sites treated as a single population) and compared to the three distinct beaver pond groups: new, old, and pooled.

Assessing Differences in Snag Density and Snag Characteristics

I used the nonparametric Mann-Whitney Rank Sum test to determine if there was a statistically significant difference between snags in pooled reference sites and snags in each specific group of beaver ponds (new, old, and pooled) for particular characteristics. Through Mann-Whitney unpaired comparisons, I was able to statistically isolate and assess how snags in each beaver pond group differed from snags in pooled reference sites without beaver influence. These specific results were necessary to adequately address the hypotheses central to my research.

I ran separate Mann-Whitney Rank Sum tests to compare snags in each of the three beaver pond groups to snags in pooled reference sites for the following five characteristics: snag density, diameter, height, percent bark remaining, and decay class. Two tests were run for each snag characteristic: one to compare excavated snags in beaver ponds versus reference sites and another to compare all available snags in beaver ponds versus reference sites. Also, I used Mann-Whitney Rank Sum tests to assess differences between pooled reference sites and individual beaver ponds for the characteristics listed above. The results of these tests provided additional information on the degree to which beaver pond groups and reference sites differed for specific characteristics. In addition, I used Mann-Whitney tests to compare median site size of pooled reference sites versus pooled beaver ponds. In cases where data could be successfully log transformed to yield a normal distribution, I ran *t*-tests to determine whether there was a statistically significant difference between the mean values for snag characteristics in reference sites versus beaver ponds. All percentage data used in

t-tests was arcsine transformed (Zar 1999), rather than log transformed.

Independence of Individual Parameters

I used Chi-Square contingency tables and Log Likelihood Ratio tests to assess independence of specific parameters. These statistical measures were used to help interpret research results and better understand inter-relationships of habitat variables measured. Of particular interest was any correlation between diameter, height, percent bark remaining, and decay class and whether a snag had been excavated or not. The Chi-Square and Log Likelihood Ratio are similar tests, often yielding comparable results (Zar 1999), however, the power of some of the Chi-Square tests was significantly lower in some cases than recommended by the statistical software. For these instances, only log likelihood results were reported.

Table 1. Summary of beaver pond sites. Site characteristics shown include elevation, location, size, dominant vegetation, degree of canopy cover and level of human disturbance. Canopy cover reflects the degree of solar influx based on qualitative habitat assessments during summer months. Human disturbance is based on observations of past or current human activities that could influence wildlife utilization or ecosystem processes at the site. Beaver ponds 2, 4, 5, 7, and 8 were classified as old ponds and beaver ponds 1, 3, and 6 were classified as new ponds.

Beaver Pond	Elevation (m)	USGS Location in Mount Hood National Forest			Area (Ha)	Dominant Tree Species	Canopy Cover (H, M, or L)	Degree of Disturbance (H, M, or L)
1	253	T4S	R5E	S18	0.31	Red alder	L	H
2	274	T4S	R5E	S18	0.11	Red alder	M	M to H
3	494	T5S	R6E	S33	0.35	Red alder	H	L
4	476	T6S	R6E	S2	1.35	Red alder and Douglas-fir	L	L to M
5	494	T6S	R6E	S2	1.45	Douglas-fir	L to M	L
6	658	T5S	R6E	S36	0.13	Bigleaf maple	L	L
7	451	T6S	R6E	S2	0.98	Red alder and Bigleaf maple	L	M to H
8	451	T6S	R6E	S2	0.68	Red alder and Bigleaf maple	L to M	M to H

H = High; M = Medium; L = Low; T = Township; R = Range; S = Section; N = North; E = East

Table 2. Summary of reference sites. Site characteristics shown include elevation, location, size, dominant vegetation, degree of canopy cover and level of human disturbance. Canopy cover reflects the degree of solar influx based on qualitative habitat assessments during summer months. Human disturbance is based on observations of past or current human activities that could influence wildlife utilization or ecosystem processes at the site.

Ref. Site	Elevation (m)	USGS Location in Mount Hood National Forest			Area (Ha)	Dominant Tree Species	Canopy Cover (H, M, or L)	Degree of Disturbance (H, M, or L)
1	503	T5S	R6E	S34	0.67	Douglas-fir	H	M
2	567	T6S	R6E	S9	0.51	Red alder	L to M	M
3	622	T6S	R6E	S1	0.26	Douglas-fir	H	L
4	442	T6S	R6E	S11	0.68	Red alder	M	L
5	579	T6S	R6E	S13	0.79	Red alder	M	L
6	564	T5S	R6E	S36	0.57	Red alder and Douglas-fir	M to H	M
7	530	T5S	R6E	S35	0.97	Bigleaf maple	M	L to M
8	610	T5S	R6E	S36	0.97	Bigleaf maple and Red alder	M	M

H = High; M = Medium; L = Low; T = Township; R = Range; S = Section; N = North; E = East

Table 3. Decay Class Designations Used in Snag Surveys. This table was adapted from a table developed by Cline (1977) to describe decay classes of Douglas-fir snags. For deciduous snags, indicators of decay also included condition of bole, limbs and bark.

Snag Characteristic	Decay Class 1	Decay Class 2	Decay Class 3	Decay Class 4	Decay Class 5
Limbs and Branches	All Present	Few limbs, no fine branches	Limb stubs only	Few or no stubs	None
Top	Bole intact	Bole broken	Bole broken	N/A	N/A
% Bark Remaining	100	Variable	Variable	Variable	< 20
Sapwood Condition	Sapwood intact, sound, incipient decay, hard, original color	Sapwood sloughing; advanced decay, fibrous, firm to soft, light brown	Sapwood sloughing, fibrous, soft, light to reddish brown	Sapwood sloughing; cubical, soft, reddish to dark brown	Sapwood gone
Heartwood Condition	Sound, hard, original color	Sound at base, incipient decay in outer edge of upper bole, hard, light to reddish brown	Incipient decay at base, advanced decay throughout upper bole, fibrous, hard to firm, reddish brown	Advanced decay at base, sloughing from upper bole, fibrous to cubical, soft, dark reddish brown	Sloughing, cubical, soft, dark brown, OR fibrous, very soft, dark reddish brown, encased in hardened shell

Table 4. Assessment of variability in beaver ponds. Variability was assessed for pooled beaver ponds using Kruskal-Wallis and Dunn's pairwise multiple comparison. Results from the Dunn's test showed considerable differences between multiple ponds for multiple characteristics.

Snag Characteristic	Kruskal-Wallis Test			Dunn's Pairwise Multiple Comparison: Ponds with Statistically Significant Differences ($P < 0.05$)
	H	df	P	
Diameter	59.05	7	$P < 0.001$	Pond 5 vs. Pond 8 Pond 5 vs. Pond 7 Pond 5 vs. Pond 3 Pond 4 vs. Pond 8 Pond 4 vs. Pond 8 Pond 4 vs. Pond 3
Height	35.76	7	$P < 0.001$	Pond 2 vs. Pond 7 Pond 1 vs. Pond 7 Pond 5 vs. Pond 7 Pond 6 vs. Pond 7
Decay Stage	70.21	7	$P < 0.001$	Pond 8 vs. Pond 6 Pond 8 vs. Pond 3 Pond 8 vs. Pond 1 Pond 8 vs. Pond 5 Pond 7 vs. Pond 6 Pond 7 vs. Pond 3 Pond 2 vs. Pond 6 Pond 4 vs. Pond 6
Percent Bark Remaining	50.29	7	$P < 0.001$	Pond 5 vs. Pond 8 Pond 5 vs. Pond 6 Pond 5 vs. Pond 7 Pond 3 vs. Pond 8 Pond 3 vs. Pond 6 Pond 1 vs. Pond 6

Table 5. Assessment of variability in old and new pond categories. Variability was assessed using Kruskal-Wallis and Dunn's pairwise multiple comparisons. Results from the Dunn's test showed significantly fewer ponds contributing to differences in medians compared to Dunn's test results for pooled beaver ponds (Table 4).

Snag Characteristic	OLD BEAVER PONDS (<i>df</i> = 4)			NEW BEAVER PONDS (<i>df</i> = 2)		
	Kruskal-Wallis Test		Dunn's Pairwise Multiple Comparison: Ponds with Statistically Significant Differences (<i>P</i> < 0.05)	Kruskal-Wallis Test		Dunn's Pairwise Multiple Comparison: Ponds with Statistically Significant Differences (<i>P</i> < 0.05)
	H	<i>P</i>		H	<i>P</i>	
Diameter	26.65	<i>P</i> ≤ 0.001	Pond 5 vs. Pond 8 Pond 4 vs. Pond 8	3.69	<i>P</i> = 0.158	None
Height	21.67	<i>P</i> ≤ 0.001	Pond 2 vs. Pond 7 Pond 5 vs. Pond 7	5.55	<i>P</i> = 0.062	None
Decay Stage	24.91	<i>P</i> ≤ 0.001	Pond 8 vs. Pond 5 Pond 8 vs. Pond 4 Pond 7 vs. Pond 5	4.18	<i>P</i> = 0.124	None
% Bark Remaining	50.29	<i>P</i> < 0.001	Pond 5 vs. Pond 7 Pond 5 vs. Pond 8 Pond 5 vs. Pond 4	20.22	<i>P</i> ≤ 0.001	Pond 3 vs. Pond 6 Pond 1 vs. Pond 6

Table 5. Assessment of variability in old and new pond categories. Variability was assessed using Kruskal-Wallis and Dunn's pairwise multiple comparisons. Results from the Dunn's test showed significantly fewer ponds contributing to differences in medians compared to Dunn's test results for pooled beaver ponds (Table 4).

Snag Characteristic	OLD BEAVER PONDS (<i>df</i> = 4)			NEW BEAVER PONDS (<i>df</i> = 2)		
	Kruskal-Wallis Test	Dunn's Pairwise Multiple Comparison: Ponds with Statistically Significant Differences (<i>P</i> < 0.05)	Kruskal-Wallis Test	Dunn's Pairwise Multiple Comparison: Ponds with Statistically Significant Differences (<i>P</i> < 0.05)		
Diameter	H 26.65 P ≤ 0.001	Pond 5 vs. Pond 8 Pond 4 vs. Pond 8	H 3.69 P = 0.158	None		
Height	H 21.67 P ≤ 0.001	Pond 2 vs. Pond 7 Pond 5 vs. Pond 7	H 5.55 P = 0.062	None		
Decay Stage	H 24.91 P ≤ 0.001	Pond 8 vs. Pond 5 Pond 8 vs. Pond 4 Pond 7 vs. Pond 5	H 4.18 P = 0.124	None		
% Bark Remaining	H 50.29 P < 0.001	Pond 5 vs. Pond 7 Pond 5 vs. Pond 8 Pond 5 vs. Pond 4	H 20.22 P ≤ 0.001	Pond 3 vs. Pond 6 Pond 1 vs. Pond 6		

Table 6. Assessment of variability for pooled reference sites. Variability was assessed using Kruskal-Wallis and Dunn's pairwise multiple comparison. Results from the Dunn's test showed that relatively few reference sites contributed to differences in median values for diameter, height, and decay stage.

	Kruskal-Wallis Test		Dunn's Pairwise Multiple Comparison: Ponds with Statistically Significant Differences ($P < 0.05$)
	H	P	
Diameter	23.98	$P = 0.001$	Site 4 vs. Site 6
Height	18.72	$P = 0.009$	Site 4 vs. Site 1
Decay Stage	16.03	$P < 0.025$	Site 2 vs. Site 4 Site 5 vs. Site 4
Percent Bark Remaining	17.71	$P < 0.013$	None

Figure 1. Location of Study Area in Mount Hood National Forest.

Figure 2a. Beaver Ponds in Vicinity of PGE Promontory Park Near Mount Hood National Forest Boundary

Figure 2b. Beaver Pond and Reference Site in Vicinity of Sandstone Creek Near Indian Henry Campground

Figure 2c. Beaver Ponds and Reference Sites in Ripplebrook Area and Surrounding Locations

Figure 3. Beaver Pond 1 in Vicinity of PGE Sewage Lagoon

Figure 4. Beaver Pond 2 in Vicinity of PGE Sewage Lagoon

Figure 5. Beaver Pond 3 at Sandstone Creek

Figure 6. Beaver Pond 4 in Vicinity of Ripplebrook Residential Area

Figure 7. Beaver Pond 5 in Vicinity of Ripplebrook Campground

Figure 8. Beaver Pond 6 in Vicinity of Half-Pint Creek

Figure 9. Beaver Pond 7 -- Lower Pond Near Highway 224

Figure 10. Beaver Pond 8 -- Upper Pond System Near Highway 224

Figure 11. Trigonometric Calculation of Snag Height. Snag height was calculated using the formula $\text{Height} = (x * \tan \theta_1) + (x * \tan \theta_2)$ by obtaining the angle to the top and base of the snag from an established observation point and measuring the distance (x) to the snag from the observation point.

Figure 12: Reference Area Plot Sketch. Plots consisted of 16 transects with lengths of less than or equal to 56.4 meters.

Figure 13: Comparison of Beaver Pond and Reference Site Size. Graph compares areas of beaver ponds and reference sites in ascending order.

Results

Snag Density

Density of All Available Snags

There were significantly more snags per hectare (excavated and unexcavated combined) in pooled beaver ponds than in reference sites (Mann-Whitney Rank Sum Test: $P = 0.038$; t -test: $t = 2.812$, $P = 0.014$) (Figure 14). The mean numbers of snags per hectare for pooled beaver ponds and pooled reference sites were 79.0 and 23.3, respectively. The median numbers of snags per hectare for pooled beaver ponds and pooled reference sites were 89.3 and 19.2, respectively. There were also significantly more snags per hectare in new ponds compared to reference sites (Mann-Whitney Rank Sum Test: $P < 0.001$). However, there was no significant difference in snag density between old ponds and reference sites (Mann-Whitney Rank Sum Test: $P = 0.104$).

Density of Excavated Snags

The number of excavated snags per hectare did not differ significantly between beaver ponds and reference sites (t -test: $t = 1.257$, $P = 0.229$; Mann-Whitney Rank Sum test: $P = 0.279$) (Figure 15). However, the proportion of reference site snags with excavations was significantly higher than in pooled beaver ponds (t -test: $t = 3.795$, $P = 0.002$; Mann-Whitney Rank Sum test: $P = 0.007$) and in new beaver ponds (Mann-Whitney Rank Sum Test: $P < 0.001$) (Figure 16). There was no difference in the proportion of snags excavated between old ponds and reference sites (Mann-Whitney Rank Sum Test: $P = 0.065$).

Snag Characteristics

Diameter

Reference site snags (excavated and unexcavated combined) had significantly larger diameters than beaver pond snags in all categories (Mann-Whitney Rank Sum Test: $P \leq 0.001$) (Figure 17). The median diameter values for reference site snags and pooled beaver pond snags were 47.2 cm and 32.9 cm, respectively. Excavated reference snags had significantly larger diameters than excavated snags in all beaver pond categories (Mann-Whitney Rank Sum Test: $P < 0.001$ for comparison with pooled beaver ponds; $P \leq 0.001$ for new beaver ponds; $P = 0.003$ for old ponds) (Figure 18). Median diameter values for reference sites and pooled beaver ponds were 52.9 cm and 38.5 cm, respectively.

Height

Beaver pond snags in all categories (excavated and unexcavated combined) were significantly taller than reference site snags (Mann-Whitney Rank Sum Test: $P \leq 0.001$). Medians for pooled pond snags and reference snags were 13.5 m and 6.7 m, respectively (Figure 19). Excavated beaver pond snags were also significantly taller than excavated reference site snags (Mann-Whitney Rank Sum Test: $P \leq 0.001$ for all pond categories). Median values for excavated beaver pond snags and excavated reference site snags were 12.6 m and 6.3 m, respectively (Figure 20).

Percent Bark Remaining

There was no significant difference in the percentage of bark remaining on

pooled beaver pond snags compared to reference site snags ($P = 0.120$ with Mann-Whitney Rank Sum Test) (Figure 21). However, new ponds had significantly more bark remaining ($P = 0.023$) than pooled reference sites. There was no significant difference in the percentage of bark remaining on excavated snags in any of the beaver pond categories and reference sites (Mann-Whitney Rank Sum Test: $P = 0.116$ for comparison with pooled beaver ponds; $P = 0.488$ for new ponds; $P = 0.138$ for old ponds) (Figure 22).

Decay Stage

Reference site snags were significantly more decayed than beaver pond snags (Mann-Whitney Rank Sum Test: $P < 0.001$) for all pond categories (Figure 23). Median values for reference site and beaver pond snag decay classes were 3 and 2, respectively, and for new ponds the median decay class was 1. Excavated reference site snags were also significantly more decayed than excavated beaver pond snags in all pond categories (Mann-Whitney Rank Sum Test: $p \leq 0.001$) with 3 as the median value for reference sites and 2 as the median value for all beaver pond categories (Figure 24).

Relationships Between Snag Characteristics and Presence of Excavations

Diameter and Excavation

In beaver ponds, there was a significant relationship between a snag's diameter and whether it had been excavated ($\chi^2_{0.05,8} = 40.215$, $P < 0.001$; Log likelihood ratio: $P < 0.001$) (Figure 25). In general, the larger the diameter, the greater the percentage of snags excavated. A similar relationship between diameter and excavation was found

for reference sites (Log likelihood ratio: $P < 0.001$) (Figure 26). Note that only log likelihood data were reported for reference site data because the power of the χ^2 test was 0.394, well below the power of 0.80 recommended by the statistical software.

Height and Excavation

In beaver ponds, there was a significant relationship between a snag's height and whether it had been excavated (Log Likelihood Ratio: $P < 0.05$) (Figure 27). Note that no significant relationship was found using Chi-Square ($\chi^2_{0.05,4} = 9.415$, $P = 0.052$), however, the power of the test was below the level of 0.80 recommended by the statistical software. In reference sites, there was no significant relationship between the two parameters (Log Likelihood Ratio test: $P < 0.50$). The power of the Chi-Square test in this case was well below the level recommended by the statistical software and was not reported.

Decay Class and Excavation

In beaver ponds, there was a positive correlation between a snag's decay class and whether it had been excavated ($\chi^2_{0.05,4} = 41.792$, $p < 0.001$) (Figure 28). In reference sites, there was also a positive correlation between the two parameters ($\chi^2_{0.05,4} = 11.676$, $P = 0.020$).

Percent Bark Remaining and Excavation

In beaver ponds, there was no significant relationship between the percent bark remaining on a snag and whether the snag had been excavated (Log Likelihood Ratio

test: $P < 0.250$). However, in reference sites the two variables were related (Log Likelihood Ratio test: $P < 0.025$).

Observational Data and Classification of Excavations

Direct observations of bird activity and classification of forage and nest holes by excavating species were not statistically analyzed because the data did not specifically address the hypotheses in this study. In addition, significant differences in the amounts of observation time spent at each site may have contributed to inaccurate statistical conclusions. However, the data provided a qualitative assessment of current habitat utilization and resource partitioning among species. Direct observation data were only tabulated for beaver ponds (Table 7) as bird species were more easily identified in beaver ponds than in reference sites due to better light and visibility.

Observations of Primary Cavity-Nesting Bird Use of Beaver Ponds

Primary cavity-nesting species observed in beaver ponds included Pileated Woodpecker, Hairy Woodpecker, Downy Woodpecker, Northern Flicker, Red-breasted Sapsucker, and Red-breasted Nuthatch. Secondary cavity-nesters I observed included Buffleheads, Wood Ducks, Common Mergansers (*Mergus merganser*), Hooded Mergansers (*Lophodytes cucullatus*), and tree swallows. Ponds 4 and 5 had the highest number of bird species, overall, and also the highest number of primary and secondary cavity-nesters (Table 7).

Primary cavity-nesting species observed in reference sites included Pileated Woodpecker, Hairy Woodpecker, Northern Flicker, and Red-breasted Nuthatch. I did

not observe any secondary cavity-nesting species in reference sites.

Forage and Nest Hole Excavations by Primary Cavity-Nesting Birds

Based on presence of excavation holes, a higher proportion of snags in reference site snags were foraged by Pileated Woodpeckers and the Hairy/Downy/Northern Flicker group of woodpeckers compared to beaver ponds. In addition, all woodpeckers foraged in a greater proportion of old beaver pond snags than new beaver ponds (Table 8).

In beaver ponds, 24.3% of all available snags were foraged by Pileated Woodpeckers, 40.4% by the Hairy/Downy/Northern Flicker woodpeckers, and 5.1% by sapsuckers. In addition, 4.8% (n=13) of all available snags had nest holes, the majority of which appeared to be excavated by *Picoides* species based on shape and size. A greater proportion of snags in old ponds had nest holes (n=9, 5.0%) compared to new ponds (n=4, 4.3%).

In reference sites, 62.8% of all available snags were foraged by Pileated Woodpeckers, 60.0% by the Hairy/Downy/Northern Flicker woodpeckers, and 5.0% by sapsuckers. Only 2.5% (n=3) of available snags had nest holes.

Results Summary

In general, reference site snags, both excavated and unexcavated, had larger diameters and were in more advanced decay stages than were beaver pond snags in all categories. Beaver pond snags, regardless of age, were taller than reference site snags. Snags in older beaver ponds had significantly less bark than snags in reference sites,

whereas snags in new ponds had more bark than snags in reference sites. The presence of excavations in both beaver pond and reference site snags increased as snag decay class and diameter increased. In ponds, the presence of excavations increased as snag height increased. Percent bark remaining was positively correlated with presence of excavations in reference sites, but not in beaver ponds. Both excavated and unexcavated snags in reference sites had less bark remaining than in beaver ponds. In general, old beaver ponds had less bark, higher decay classes, larger diameters, and lower snag densities. New beaver ponds had more bark remaining, lower decay classes, somewhat smaller diameters, and lower snag densities.

Table 7. List of Bird Species Observed During Field Work (March 2000 through April 2001). Ponds 2, 4, 5, 7, and 8 were classified as old ponds and ponds 1, 3, and 6 were classified as new ponds.

Species Observed	Beaver Pond(s) in Which Species Was Observed							
	1	2	3	4	5	6	7	8
Great Blue Heron (<i>Ardea herodias</i>)	x			x				
Turkey Vulture (<i>Cathartes aura</i>)				x				
Wood Duck (<i>Aix sponsa</i>)				x			x	
Mallard (<i>Anas platyrhynchos</i>)	x		x	x	x		x	x
Cinnamon Teal (<i>Anas cyanoptera</i>)							x	
Bufflehead (<i>Bucephala albeola</i>)				x	x		x	
Hooded Merganser (<i>Lophodytes cucullatus</i>)				x				
Common Merganser (<i>Mergus merganser</i>)							x	
Red-tailed Hawk (<i>Buteo jamaicensis</i>)				x				
Ruffed Grouse (<i>Bonasa umbellus</i>)		ho				ho		
Spotted Sandpiper (<i>Actitis macularia</i>)			x	x				
Common Snipe (<i>Gallinago gallinago</i>)				ho				
Owl sp. (unidentified species)	x							
Belted Kingfisher (<i>Ceryle alcyon</i>)	x		x	x	x			
Red-breasted Sapsucker (<i>Sphyrapicus ruber</i>)				x				
Downy Woodpecker (<i>Picoides pubescens</i>)				x	ho			
Hairy Woodpecker (<i>Picoides villosus</i>)			x	x	x			ho
Northern Flicker (<i>Colaptes auratus</i>)			x	x	ho			
Pileated Woodpecker (<i>Dryocopus pileatus</i>)			ho	x	x		ho	
Western Wood-Pewee (<i>Contopus sordidulus</i>)			ho	x				ho
Flycatcher sp. (<i>Empidonax</i> sp.)				x				
Steller's Jay (<i>Cyanocitta stelleri</i>)		x	x	x	x			
American Crow (<i>Corvus brachyrhynchos</i>)	x			x			x	
Tree Swallow (<i>Tachycineta bicolor</i>)	x			x				
Red-breasted Nuthatch (<i>Sitta canadensis</i>)			x	ho	ho			ho
Brown Creeper (<i>Certhia americana</i>)				x				
Winter Wren (<i>Troglodytes troglodytes</i>)		ho	ho			ho		ho
American Dipper (<i>Cinclus mexicanus</i>)	x		x					
Ruby-crowned Kinglet (<i>Regulus calendula</i>)				x		ho		
American Robin (<i>Turdus migratorius</i>)	x			x		x	x	
Cedar Waxwing (<i>Bombycilla cedrorum</i>)				x				
Yellow Warbler (<i>Dendroica petechia</i>)				x				
Western Tanager (<i>Piranga ludoviciana</i>)				x				
Song Sparrow (<i>Melospiza melodia</i>)	x			x		ho		
Red-winged Blackbird (<i>Agelaius phoeniceus</i>)	x			x				
Evening Grosbeak (<i>Coccothraustes vespertinus</i>)						x		

ho = heard only

Table 8. Summary of Species Utilization of Snags. Data include forage excavations in beaver ponds and reference sites.

Site	Pileated Woodpecker		Hairy/Downy/ Northern Flicker		Sapsuckers	
	n	Proportion Foraged	n	Proportion Foraged	n	Proportion Foraged
All Beaver Pond Snags (n = 272)	66	24.3%	110	40.4%	14	5.1%
New Pond Snags (n = 92)	12	13.0%	14	15.2%	1	1.1%
Old Pond Snags (n = 180)	54	30.0%	96	53.3%	13	7.2%
Reference Site Snags (n = 121)	76	62.8%	75	62.0%	6	5.0%

Figure 14: Median Snag Density. Values shown are median, upper and lower quartiles for beaver ponds and reference sites.

Figure 15: Median Excavated Snag Density. Values shown include median, upper and lower quartiles for beaver ponds and reference sites.

Figure 16: Median Proportion of Snags Excavated. Values shown include median, upper and lower quartiles for beaver ponds and reference sites

Figure 17: Median Diameter of Snags. Values shown include median, upper and lower quartiles for beaver ponds and reference sites.

Figure 18: Median Diameter of Excavated Snags. Values shown include median, upper and lower quartiles for excavated snags in beaver ponds and reference sites.

Figure 19: Median Snag Height. Values shown include median, upper and lower quartiles for all snags in beaver ponds and reference sites.

Figure 20: Median Excavated Snag Height. Values shown include median, upper and lower quartiles for excavated snags in beaver ponds and reference sites.

Figure 21: Median Percent Bark Remaining. Values shown include median, upper and lower quartiles for all snags in beaver ponds and reference sites.

Figure 22: Median Percent Bark Remaining on Excavated Snags. Values shown include median, upper and lower quartiles for excavated snags in beaver ponds and reference sites.

Figure 23: Median Snag Decay Class. Values shown include median, upper and lower quartiles for all snags in beaver ponds and reference sites.

Figure 24: Median Excavated Snag Decay Class. Values shown include median, upper and lower quartiles for excavated snags in beaver ponds and reference sites.

Figure 25: Diameters of Excavated Snags in Beaver Ponds. Graph shows numbers of excavated and unexcavated beaver pond snags in each of five size classes.

Figure 26: Diameters of Excavated Snags in Pooled Reference Sites. Graph shows numbers of excavated and unexcavated reference site snags in each of five size classes.

Figure 27: Height Classes of Excavated Snags. Graph shows number of excavated beaver pond and reference site snags in each of five height classes.

Figure 28: Relationship Between Decay Class and Excavation. Graph shows percentage of snags excavated of total number of snags in each of five decay classes.

Discussion

Density of Beaver Pond Snags

Flooded conditions from impounded water are known to cause the rapid death of many tree species common to western Oregon riparian forests, including red alder, Douglas-fir, and western hemlock (Kozlowski et. al. 1991). Because of this effect, I hypothesized that beaver ponds would have a higher density of snags suitable for primary cavity-nesting birds compared to reference sites. In general, the findings supported this prediction, however, older ponds and reference sites had similarly low snag densities.

These results may be a reflection of natural succession in beaver ponds. Newer ponds likely have higher snag density since flooding above the beaver dam would kill all trees within the area of influence. As ponds age, the likelihood for snags to weaken, decay and topple would increase, particularly for snags with smaller diameters (Neitro et. al. 1985). This process would lead to a decrease in snag density over time, as was indicated by the differences found between new and old beaver ponds in this study. In riparian forests without beaver ponds, snags likely form more slowly. Except in the case of severe disturbances such as windstorms, fire, or widespread disease, snag density would be low, with more similarity to old beaver ponds than new beaver ponds.

Decay and Bark Loss in Beaver Pond Snags

I expected beaver ponds snags to have a higher degree of decay and a greater loss of bark than reference site snags due to continually moist conditions. However,

results showed that beaver pond snags were significantly less decayed and had bark loss similar to reference site snags. These unexpected findings may be attributed to a more rapid loss of older, decayed snags in beaver ponds compared to reference sites. Moist conditions typically accelerate the decomposition of organic matter (Kozlowski et. al. 1991). Therefore, snags in beaver ponds would be expected to decompose relatively quickly and older snags, with presumably less bark, would be limited in occurrence. In contrast, in reference sites the decay process would likely be slower due to drier conditions and snags in advanced stages of decay with significant bark loss would remain on the landscape for longer periods of time.

Size Differences

The larger diameters of reference site snags compared to beaver pond snags is likely attributed to differences in tree mortality in the two habitat types. In beaver ponds, flooding that occurs following dam formation kills all trees within the zone of influence regardless of size or condition. Snags may, therefore, range widely in diameter depending on the structural diversity of the forest prior to flooding. In undammed riparian forests, trees likely have more opportunity to mature to large diameters before declining and dying, barring large-scale disturbance events such as fire and windstorms.

Reference site snags may have been shorter than beaver pond snags because they were more decayed and, therefore, more prone to breakage and toppling (Cline et. al. 1980). It is also plausible that shorter snags in beaver ponds experienced higher rates of decomposition because a greater percentage of the snag's mass was exposed to

moisture. Further study with a larger sample size of snags in both habitat types would be necessary to fully understand the differences in height observed.

Characteristics of Snags Excavated by Primary Cavity-Nesting Birds

A significantly higher percentage of reference snags was excavated compared to pooled and new beaver pond snags (Figure 16), even though there were more snags available per hectare in beaver ponds. There are a number of possible explanations for this result. First, the decay condition of the snag may have influenced selection for excavation by primary cavity-nesting birds. Reference site snags were significantly more decayed than beaver pond snags, making them preferable for foraging. Snags in more advanced stages of decay are believed to have a greater abundance of insect prey (Neitro et. al. 1985, Weikel and Hayes 1999) and decayed snags may be easier to excavate due to softer wood (Neitro et. al. 1985). Snag conditions change in complex ways during the decay process due to microbes, insects, and environmental influences (Cline et. al. 1980). Rot conditions must be appropriate for selection by cavity-nesting birds (Zarnowitz and Manuwal 1985). Thus, it is possible that although there were more available snags in beaver ponds, snag conditions were less optimal than in reference sites for unknown reasons.

Secondly, it is possible that primary cavity-nesting birds utilized reference site snags more extensively than beaver pond snags due to differences in snag decomposition rates. Because they decay more slowly, reference site snags were likely available for excavation by primary cavity-nesting birds for longer periods of time than snags in beaver ponds. Utilization may have been insignificant at first, but increased

over time as the snag approached optimal decay conditions. Though beaver pond snags form quickly, they also decay quickly. Thus, while a snag may serve as high quality habitat for primary cavity-nesting birds shortly following formation, snag longevity would be reduced due to accelerated decay rates. This indicates that the degree of utilization would be most similar between snags in reference sites and large, slowly decaying snags in old beaver ponds, as was found in this study.

Snag size may also have influenced utilization in the two habitat types. Reference site snags were larger in diameter than beaver pond snags. Primary cavity-nesting birds prefer larger snags for foraging and nesting (Mannan et. al. 1980, Zarnowitz and Manuwal 1985, Neitro et. al. 1985, Lundquist and Mariani 1991, Bull et. al. 1997) due, in part, to a greater abundance of insects (Weikel and Hayes 1999). Larger snags also decay more slowly (Cline et. al. 1980) which may provide greater stability for nest and roost cavities.

The denser cover from vegetation and trees may also explain why primary cavity-nesting birds excavated reference site snags more than beaver pond snags. Degree of cover is known to be a factor in providing camouflage and refuge for most wildlife species and the availability of cover is a commonly measured habitat characteristic when assessing bird species abundance (Reese and Hair 1976, Medin and Clary 1990, Brown et. al. 1996, Edwards and Otis 1999). While there may be greater biomass of shrubs and grass species in ponds compared to unimpounded sites (Medin and Clary 1990), I found that beaver ponds, in general, were more open with less canopy cover. Aquatic birds likely benefit from dense vegetation surrounding ponds

and warm water temperatures due to an open canopy (Reese and Hair 1976, Medin and Clary 1990). However, species such as woodpeckers may prefer greater canopy cover for protection from predators. Interestingly, older ponds did not differ from reference sites in the percentage of snags excavated. This pond category had more cover from trees, similar to reference site conditions.

Several studies have found primary cavity-nesting bird populations to be positively correlated with the density of available snags (Raphael and White 1984, Zarnowitz and Manuwal 1985). However, resource utilization may be affected by territoriality and inter-specific competition, particularly for nest sites (von Haartman 1957, Short 1979, Dobkin et. al. 1995), and likely for forage sites, too. Based on qualitative field observations, snags in beaver ponds were generally distributed in a clumped fashion compared to reference sites where snags were more evenly distributed. Thus, depending on the degree of territoriality or competition, the higher density of beaver pond snags compared to reference site snags may have actually reduced a snag's suitability as a forage or nest site resulting in fewer excavations.

Finally, the proportion of snags that were coniferous versus deciduous may have also played a role in selection by primary cavity-nesting birds. Reference sites had significantly more coniferous snags than beaver ponds (82% versus 52%), however, this distinction was not accounted for in statistical tests. Differences between coniferous and deciduous snags that could affect selection by primary cavity-nesting birds might include decay rates, available insect species, and wood hardness.

Differences in Snag Selection Among Primary Cavity-Nesting Birds

There were more nest holes in beaver pond snags than in reference site snags, however, the total number of samples ($n=16$) was too small to draw any substantive conclusions. Factors that might affect nest site selection include warmth from solar radiation, presence of perch sites, snag stability, ease of excavation, and abundance of forage opportunities. An adequate assessment of nest-site selection would require confirmation of nest hole excavation and use during the breeding season. In addition, it would be useful to determine correlations between nest hole presence and specific characteristics of the snag and habitat.

Pileated Woodpeckers and the Hairy/Downy/Northern Flicker group of woodpeckers foraged in a higher proportion of reference site snags than beaver pond snags, whereas, sapsuckers foraged in a higher proportion of old beaver pond snags (Table 8). The differences I observed in species' selection of snags for foraging may have largely been due to decay conditions of the snag, foraging strategies, presence of food resources, territoriality, or vulnerability to predation. However, several unknowns complicate the interpretation of data. For example, it is unknown when the holes were excavated. Also, it is unknown whether primary cavity-nesting birds were successful in acquiring food from the excavation. Observations of bird activity in this study confirmed the use of beaver pond snags by resident woodpeckers and a number of secondary cavity-nesting birds. A comprehensive study of bird use in these habitats would yield useful information on current utilization of snags for nesting and foraging.

Temporal Factors in Snag Generation and Forest Succession in Beaver Ponds

The results of this study suggest some important effects of beaver activity on the dynamics of snag formation and forest succession. In riparian forest habitat without beaver influence, snags form due to small-scale disturbances such as insect pests and wind breakage, as well as to large-scale disturbances such as wildfires (Spies and Franklin 1989). The formation of snags, along with other events such as blow down and clear-cuts, create gaps in the canopy that interrupt forest succession to varying degrees, depending on the gap size. Within gaps of 0.20 hectares or more, the microclimate is altered, initiating changes in the biotic community and creating edge effects. Over time, the crowns of neighboring trees expand and begin to close the canopy opening, returning conditions to what they were before the gap was created (Oliver and Larson 1990).

In beaver-influenced habitat, tree felling and flooding create gaps in the canopy that alter forest succession in a unique way. Unlike other types of forest gaps, beaver pond openings likely remain part of the riparian landscape for extended periods since flooded conditions impede or prevent the growth of new trees and other woody plants (Kozlowski et. al. 1991). As a pond ages, the gap likely enlarges due to toppling snags within the pond and vulnerability of live trees around the edge of the pond to wind throw (Oliver and Larson 1990). Reforestation can only begin when the pond drains or fills with sediment, which may not occur for many decades. Therefore, depending on the extent of the flooded area, beaver ponds could have a significant effect on slowing forest succession and changing species composition in localized areas.

Management Implications

Snag availability is a concern to natural resource managers particularly for small cavity-nesting mammals and cavity-nesting birds that live in the heavily managed forests of the Pacific Northwest (Cline et. al. 1980, Mannan et. al. 1980, Neitro et. al. 1985, Zarnowitz and Manuwal 1985, Ohmann et. al. 1994). Forest and wildlife managers have expressed concern that the USDA Forest Service guidelines for retaining snags of minimal diameters in managed forests are not being implemented appropriately. These scientists call for more innovative techniques to ensure sufficient snag resources (Cline et. al. 1980, Neitro et. al. 1985, Zarnowitz and Manuwal 1985, Morrison et. al. 1986).

Biologists have already tested a number of creative ways to artificially generate snag habitat for cavity-dependent species, including the use of explosives and chainsaws to produce broken tops and the inoculation of trees with fungi that cause decay (Bull et. al. 1997, Chambers et. al. 1997). However, no strategy will single-handedly resolve snag shortages. Forest managers need a variety of approaches that are tailored to the specific habitats in which snag-dependent species reside. This study suggests that beavers could fulfill an important role in generating snags in riparian forests.

Beavers are known as a keystone species due to their ability to transform their habitat in lasting ways by modifying hydrology, creating wetlands, and increasing local biodiversity. The effectiveness of this mammal to enhance the ecological function of riparian systems has prompted some biologists to reintroduce beavers to areas within

their former range, specifically to improve stream conditions, reduce bank erosion and generate wetland habitat (Olson and Hubert 1994, McKinstry et. al. 2000). Based on findings from this research, beavers are also capable of producing high quality snag habitat for primary cavity-nesting birds within relatively brief periods of time. Therefore, the well-planned reintroduction of beavers into riparian forest locations where populations are below historic levels could prove effective in simultaneously increasing wetland acreage and generating essential snag habitat. Overall, a multifaceted solution consisting of improvements in forest management policy and creative approaches that can be implemented locally may be the best long-term strategy for ensuring adequate snag resources.

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