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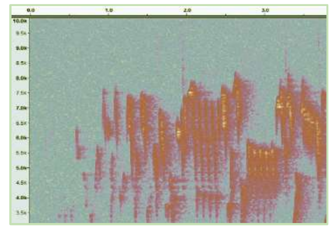

Using Passive Acoustic Monitoring to Evaluate the Sustainability of Forest Management

Study Plan

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES

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1.0	Final draft for peer review	Teodora Minkova, Lauren Kuehne, Daniel Donato	Kathryn Irvine (US Geological Survey) Mathew Betts (Oregon State University)	02/06/2020
2.0	Revision to address peer review comments and refinement of habitat survey protocol	Teodora Minkova	Lauren Kuehne, Daniel Donato	02/09/2021

Acronyms and Abbreviations

ARU – Autonomous Recording Unit

DBH – Diameter at Breast Height

GIS – Geographic Information System

GPS – Global Positioning System

HCP – Habitat Conservation Plan

LiDAR – Light Detection and Ranging

OESF – Olympic Experimental State Forest

PAM – Passive Acoustic Monitoring

WADNR – Washington Department of Natural Resources

Executive Summary

This study uses passive acoustic monitoring paired with forest habitat surveys to measure the responses of birds to habitat change caused by forest management. It is part of a broader management experiment whose overall goal is to find silvicultural practices and watershed management approaches that increase environmental and economic outcomes on state lands in Washington. The management experiment takes place on state trust lands in the Olympic Experimental State Forest (OESF) managed by Washington Department of Natural Resources (WADNR) on the western Olympic Peninsula in the temperate rainforest zone of the Pacific Coastal Ecoregion.

The study's goal is to evaluate bird use as an indicator of habitat function in forest stands at different seral stages and subject to different regeneration practices. First, we will estimate occupancy (presence-absence) of 10 indicator bird species among the four most prevalent forest developmental stages in the OESF: stand initiation, stem exclusion, mature/old forest, and commercially thinned stands. After harvest in the competitive exclusion stands, we will compare bird occupancy between traditional forest regeneration and novel regeneration practices aimed at creating complex early-seral habitat.

Multiple autonomous recording units (sound recorders) will be installed in forest stands representing the four forest developmental stages for a total of 210-217 monitoring stations. Field surveys at each monitoring station will measure habitat that could be manipulated by silviculture treatments including live trees, standing and down dead wood, and understory vegetation. Landscape-level habitat characteristics, which are known to influence habitat use by the 10 indicator species, will be derived from remote sensing data.

Ten songbird species are selected for monitoring based on their abundance in the area, seasonal vocalization activity, associations with particular habitat, and home range size. Hypotheses about their responses to two primary gradients resulting from harvest practices—early-seral to late-seral forest, and contiguous to patchy forest—will be tested using occupancy modeling (MacKenize et. al 2002). The presence/absence data for each indicator species will be derived from the acoustic recordings at each sampling station. Audio files representing individual surveys will be processed for detection of species by matching audio survey data with a template of birds' typical calls and songs. Because of the large number of indicator species and sites to be evaluated, we will rely heavily on automated template recognition to detect presences and will manually validate a subset of surveys.

Using data on bird occupancy, probability of detection, and habitat data at stand and landscape scales, we will generate a set of statistical models for each of the 10 indicator species and rank them to indicate the best-fitting model. Using this analytical approach, we will compare bird occupancy across different seral stages and forest regeneration techniques, to evaluate which techniques and associated vegetation structure result in higher or lower habitat function.

The study results will be used in tradeoff analyses of ecological values (e.g. habitat function) and economics (e.g. future timber revenue). Beyond the scope of the study, these analyses are intended to inform WADNR and other land managers about the effectiveness of current and alternative forest management practices.

Using passive acoustic monitoring, we will also document and report the presence of 11 additional bird species, selected because of their conservation status or their influence on protected species.

The study is a collaboration between WADNR, Omfishient Consulting, and University of Washington Olympic Natural Resources Center, and is partially funded by a grant from Earthwatch.

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Introduction

This study uses passive acoustic monitoring (PAM) paired with forest habitat surveys to measure ecological diversity and responses of biota to habitat change caused by forest management. The study is part of a broader management experiment whose overall goal is to find silvicultural practices and watershed management approaches that maximize environmental and economic outcomes on state lands in Washington. The management experiment takes place in the Olympic Experimental State Forest (OESF) on the western Olympic Peninsula in Washington State, and includes riparian forest manipulations with assessment of stream habitat and biotic responses (detailed elsewhere), as well as upland forest manipulations with assessment of stand and upland biotic responses (this study).

Bird community composition in the Pacific Northwest varies with seral stage, with differences being most pronounced between very early open canopy (grass-forb-shrub-seedlings) and closed canopy stages (Johnson and O'Neil 2001). In the past 25 years, forest management practices in the region, and particularly on public lands, have changed to combine timber production objectives with ecological objectives such as provision of habitat. There are still many unknowns regarding how wildlife responds to both past and novel management practices. Many species that reach highest abundance in older forest will use early-seral stages as long as key structural elements are present such as snags left in the recently harvested units (Chamber et al. 1999, Linden and Roloff, 2013, Schieck and Song, 2006). The responses of bird species to thinnings are variable depending on their habitat associations and time passed since the thinning (Cahall et al. 2013, Hagar et al. 2004).

Forest bird species are appropriate indicators to test the effectiveness of ecological forestry[1] because they occupy a broad range of forest habitat types and food sources, are responsive to the types of changes in forest conditions caused by forest management, vocally defend breeding territories, can be cost-effectively and unobtrusively monitored, and are a high conservation priority and responsibility for resource managers (Rempel et al. 2016)

PAM is a flexible, cost-effective monitoring strategy that has been used to evaluate presence or abundance of species, measure biodiversity, or even assess ecosystem services such as pollinator activity (Acevedo and Villanueva-Rivera 2006, Blumstein et al 2011, Miller-Struttmann et al. 2017, Shonfield and Bayne 2017, Turner et al. 2018). Several factors contributed to choosing this monitoring approach in our study: it allows sampling large areas; is non-invasive, creates a permanent data record that can be repurposed, and is an accessible technology that is rapidly developing and expanding its applications. Although PAM has been used previously to evaluate occupancy (presence-absence) of indicator species in relation to forest habitat extent and condition (review in Shonfield and Bayne, 2017), to our knowledge this study will be among the first to apply this approach in a large-scale experimental framework to compare changes in response to different forest management techniques.

In this study, we will compare bird occupancy across different seral stages (resulting from past management) and forest regeneration techniques (novel treatments), to evaluate which techniques and associated vegetation structure result in higher or lower bird occupancy and diversity.

[1] Forest management alternative to tree plantations, combining ecological values and commodity production based on the principles of environmental disturbances and stand development processes (Palik et al. 2021).

Study Goal, Objectives and Research Questions

Goal

The study aims to evaluate bird use as an indicator of habitat function in forest stands at different seral stages and subject to different regeneration practices.

We define habitat function as the capability of habitat features, such as vegetation structure, forest age, and species composition, to sustain an array of bird species. The habitat associations of these species are mostly known. What is not well known, is their response to habitat created through forest management. We developed hypotheses about the responses of several indicator bird species and will use their occupancy (presence-absence) to test these hypothesized responses to forest stand seral stage and alternative regeneration practices. We will also evaluate how the responses may vary across the landscape, considering differences in elevation, topography, and other large-scale habitat features.

This study goal is directly related to uncertainties (knowledge gaps) identified by the Washington Department of Natural Resources (WADNR) in managing state lands. WADNR manages state trust lands under a Habitat Conservation Plan (WADNR 1997), which includes conservation strategies for multiple upland and stream-associated species. A central assumption in these strategies is that it is possible to integrate commodity production and conservation. One of the underlying hypotheses is that it is possible to produce quality commercial timber and provide and protect habitat in a managed forest by maintaining an array of forest stand structures on the landscape (HCP p. IV.83, WADNR 1997). The study results will be used to evaluate the degree to which the WADNR approach of managing toward a diversity of seral stages and forest structures will support diverse ecological communities.

An optional study goal is to explore what integrative indices of biotic diversity, derived from the acoustic data sets, are useful to characterize habitat function.

Objectives

1. Compare the occupancy (presence-absence) of 10 indicator bird species among the four most prevalent forest developmental stages in the OESF:
   - Stand initiation (regeneration) - stand age 0-15 yr;
   - Stem exclusion (competitive exclusion) - 25-80 yr; most abundant on landscape and most likely to be manipulated;
   - Mature/old forest - 100+ yr ; stands with large trees and/or late-seral structure (includes “1921 Blow” windstorm-origin stands and old-growth stands)
   - Forest stands thinned in the past 25 yr; with distinct understory and management relevance

   Note: The canopy closure stage (age 15-25) is almost absent from the study area and therefore excluded as a stratum in this study.

2. Assess how the occupancy of the 10 indicator bird species differs among stands subject to different regeneration techniques. These treated stands are a subset of the stands listed in #1 above – namely, the competitive exclusion stands will be subject to new harvest/regeneration treatments after the first round of habitat and bird sampling. This before-after component of the study will

compare responses to traditional regeneration harvests and novel harvests aimed at creating complex early-seral habitat (in brief: greater numbers of leave trees, less (if any) tree planting, and no herbicide control of broadleaf vegetation).

3. Optional: Explore the use of acoustic indices to summarize the acoustic heterogeneity, evenness, dissimilarity, etc., and their ability to characterize and compare biotic diversity across forest developmental stages as well as before and after forest treatments.

Research Questions

1. What are the differences in forest composition and stand structure among the four most prevalent stand developmental stages?
2. What are the differences in forest composition and stand structure before and after treatment in the subset of newly treated stands?
3. What are the differences in habitat function (as determined by occupancy rates of indicator bird species) among the four stand developmental stages?
4. What are the differences in habitat function (as determined by occupancy rates of indicator bird species) before and after treatment in each of the new treatments?
5. What are the outcomes and tradeoffs for timber production and economic outputs under novel silvicultural treatments such as early-seral habitat creation and variable density thinning.

Study Area

The study will be conducted in sixteen watersheds in the Olympic Experimental State Forest (OESF) managed by WADNR (Figure 1). These state lands are located on the western Olympic Peninsula in the temperate rainforest zone of the Pacific Coastal Ecoregion. The 16 watersheds were designated earlier for a landscape-level management experiment to evaluate the effects of four land management strategies (Bormann and Minkova 2016). The experiment uses a randomized block design with 4 strategies, one per watershed, replicated across 4 blocks. The watershed-level management strategies include no-management control, traditional management, and two alternative management approaches. The watersheds are large enough (2.2 - 10.8 km^2) to encompass diverse landscape features such as forest patches at different developmental stages, stream types, and slopes of variable steepness and aspect. Each of the four management strategies is a combination of riparian and upland silvicultural treatments. Our acoustic monitoring study, which focuses on bird responses to stand-level silvicultural treatments in uplands is nested in that broader-scale design.

The elevation of the study area ranges from 60 to 1,155 m. The maritime climate receives heavy precipitation ranging from 203 to 355 cm per year, with the majority falling as rain during the winter. The Sitka spruce (*Picea sitchensis*) vegetation zone dominates along the coast (Franklin and Dyrness 1973). Inland, the western hemlock (*Tsuga heterophylla*) zone comprises a majority of the forest with western redcedar (*Thuja plicata*) in areas with wetter soils. Major seral components of vegetation are Douglas-fir (*Pseudotsuga menziesii*) in all zones, and red alder (*Alnus rubra*) at lower elevations and near waterways. The Pacific Silver Fir (*Abies amabilis*) zone, at higher elevation, comprises a minor portion of the OESF.

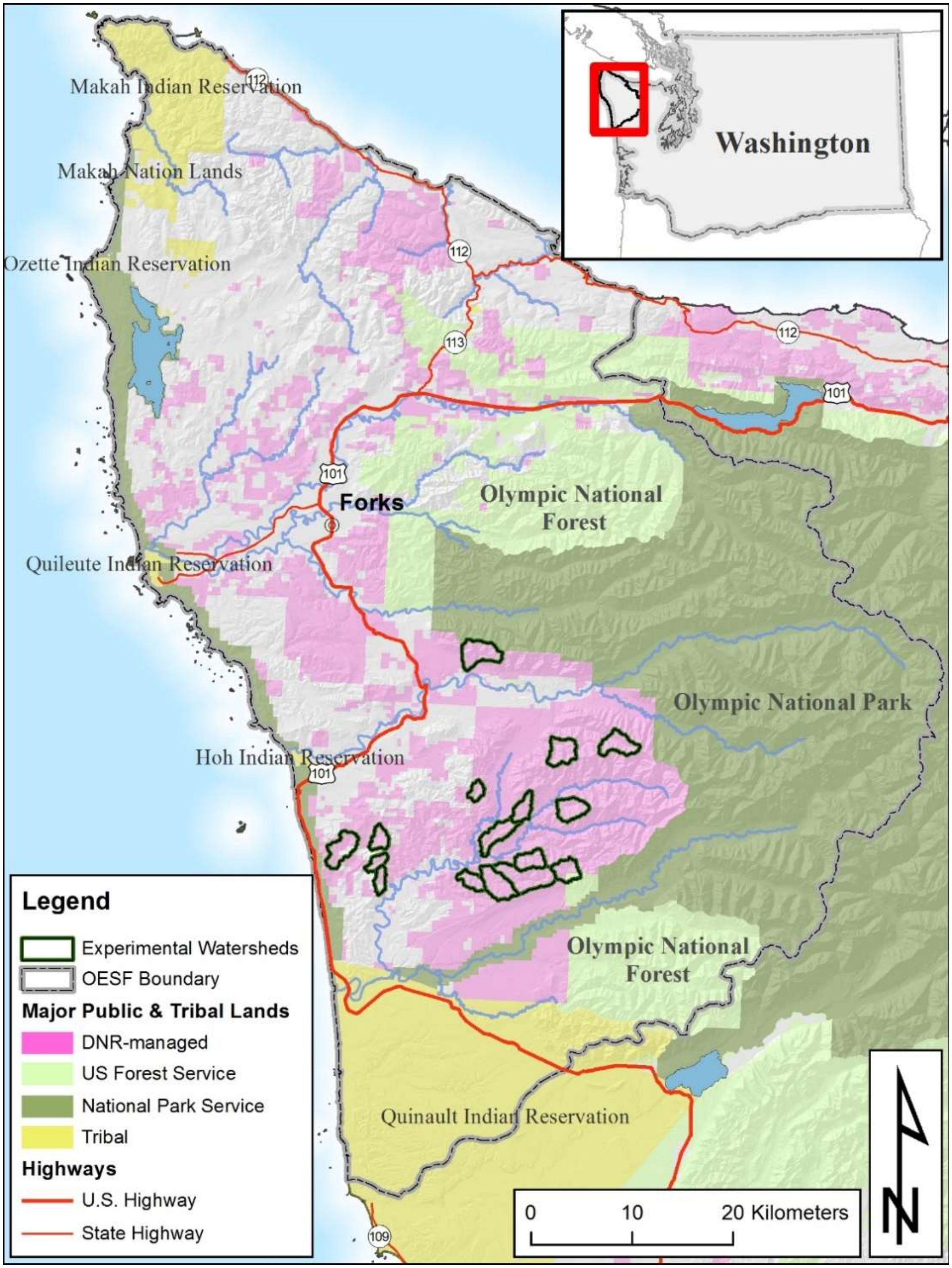

Figure 1. *Study area.*

Abundant moisture and a long growing season result in high tree growth rates. Old-growth forests that once dominated the landscape still exist on about 11 percent of the OESF, distributed among multiple patches within and across the 16 watersheds (Figure 2). Around 50 percent of the OESF consists of younger stands resulting from extensive logging since the 1970s and 1980s (WADNR 2016); this age class is predominant in the 16 watersheds (Figure 2).

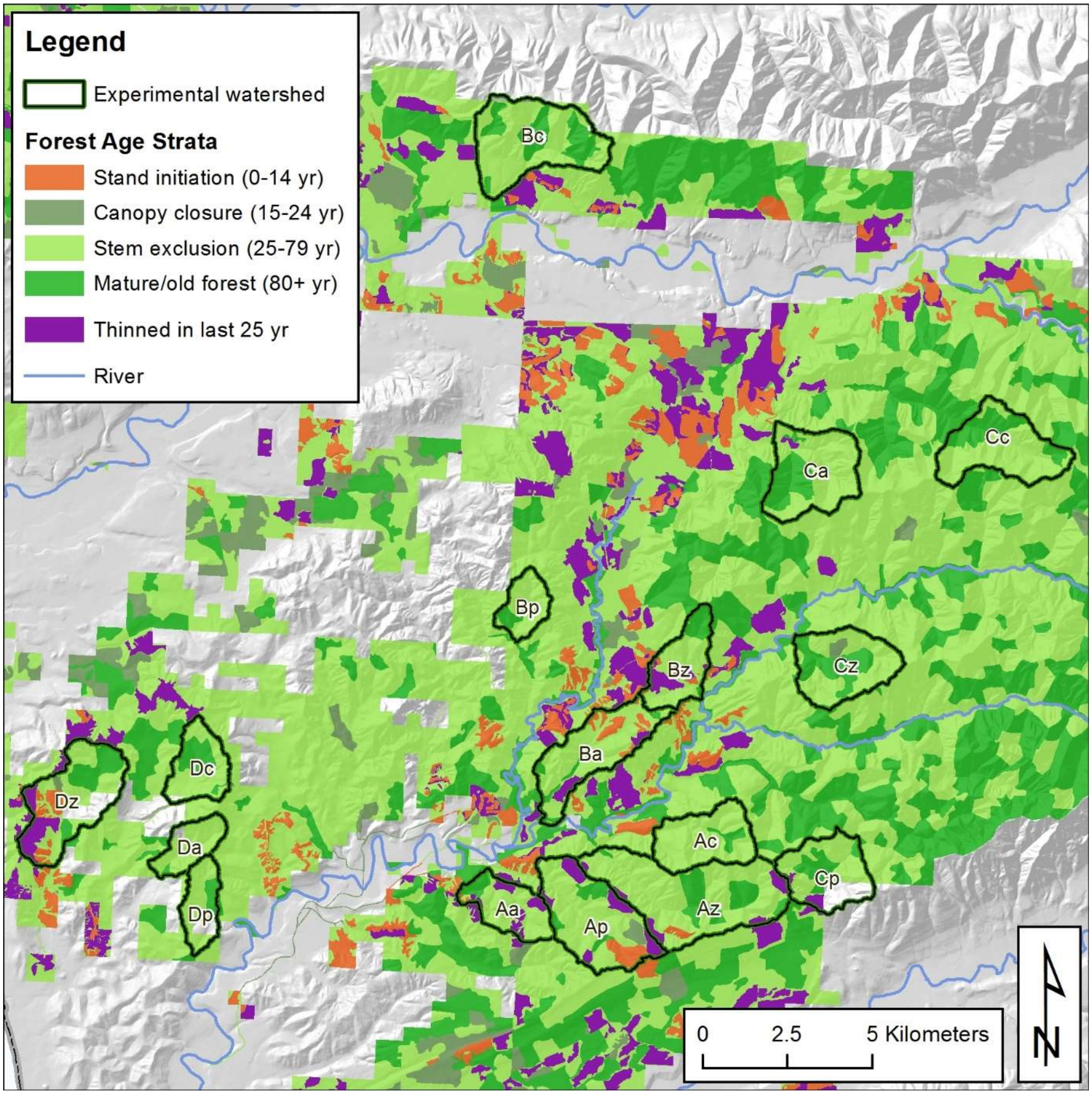

Figure 2. *Distribution of forest developmental stages in the study area.*

The OESF is a working forest with a timber volume deliverable set every decade. Under the current sustainable harvest level for the period 2015-2024 (WADNR 2019), about 1% of the forested land in the OESF is harvested annually through a combination of regeneration harvest and thinning. The harvested area varies greatly per watershed and about half of the state lands in the OESF are temporarily or permanently deferred from harvest (WADNR 2016). The deferrals protect wildlife habitat, riparian forests, old-growth forests, wetlands, unstable slopes, and other ecologically significant features.

Our study will sample in various forest developmental stages (Figure 2) across all 16 watersheds (detailed sample design is presented in the next section). Some of the sampled forest stands will be harvested starting in year 2021 and completed within 2-3 years. Since the location and exact boundaries of the timber harvest units are yet to be determined, here we show all areas currently available for harvest in the 12 treatment watersheds (excluding the 4 watersheds designated as control) (Figure 3). On average, about 20 percent of the watershed area is available for harvest. About 13 percent of the uplands in each watershed is expected be harvested as part of the broader landscape-level management experiment. The experimental treatments will be implemented through the WADNR timber sale program.-The descriptions of the silviculture experimental treatments, including manipulation specifications and monitoring plans are under development.

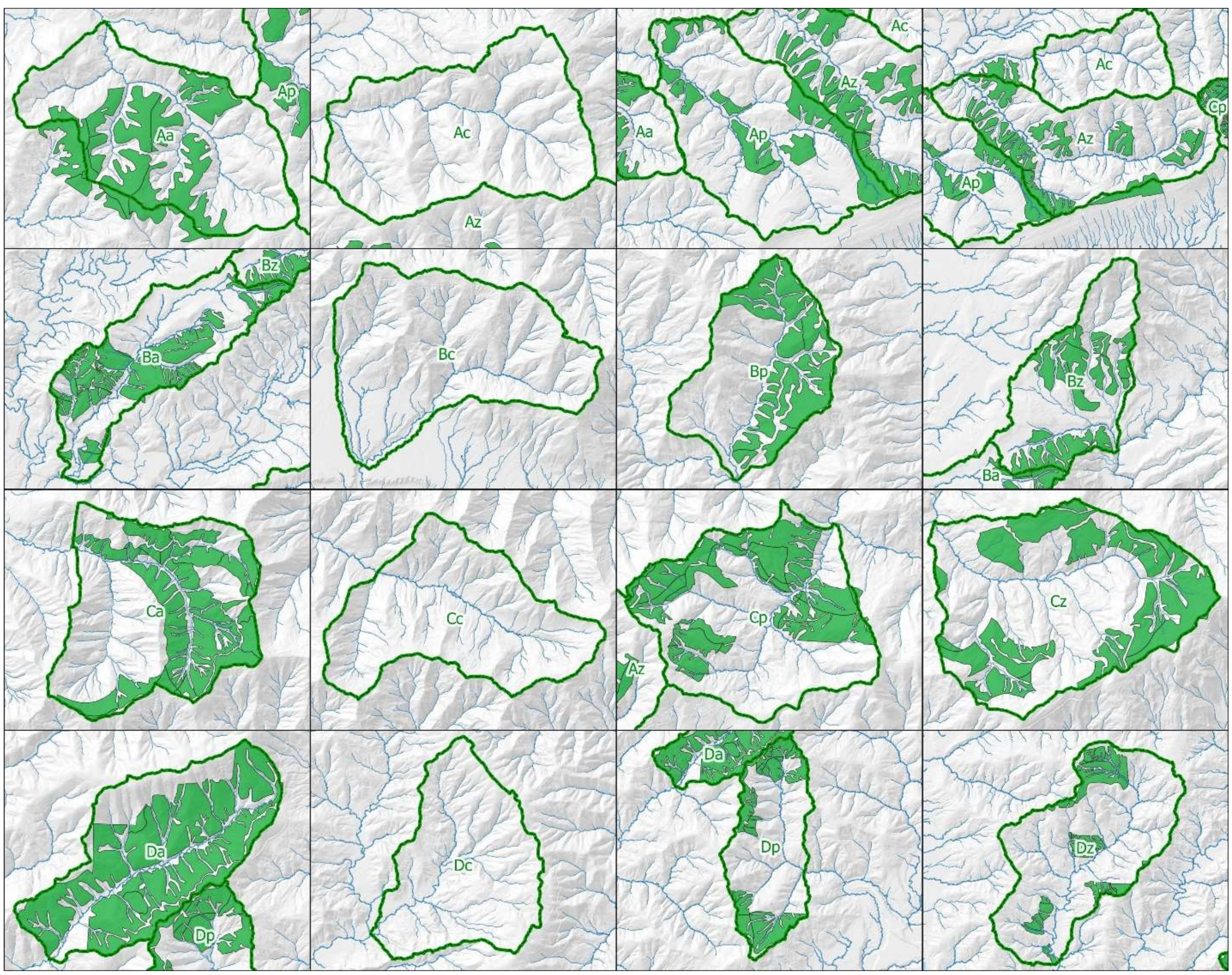

Figure 3. *Operable areas (areas currently available for timber harvest), depicted in green, within the experimental watersheds where timber harvest units will be delineated.*

Sampling Design

Our study approach is to 1) stratify the 16 experimental watersheds according to four stand developmental stages (habitat types) and sample each stratum for two years before any treatments are implemented; 2) compare occupancy of the 10 indicator species among stand development stages; 3) compare the occupancy for each indicator species before and after treatments that will be implemented in the stem-exclusion-stage stands .4) track changes in bird occupancy in treated stands over time.

The sampling design for the acoustic surveys and audio processing are described in detail below. The habitat surveys, which are conducted around autonomous recording units (ARU), are described briefly at the end of the section. Refer to Appendix 1 for a detailed field protocol for habitat surveys.

Number of sample units

Generally, increasing the number of sample sites and the number of sampling occasions (repeat surveys) increases both the accuracy and precision of the occupancy estimates (MacKenzie et. al 2002). This is balanced against needing to collect acoustic data sufficient for replicate surveys for all sites within the sampling season (in our case, the birds' breeding season), with a limited number of recording units. Our sampling unit (sample site) is a circular plot of 100-m radius centered on a sampling station (usually a tree) where an ARU is installed.

As mentioned earlier, we nest our study within the broader management experiment. The 16 experimental watersheds are stratified into four forest developmental stages or strata (Figure 4). Within each watershed, we will sample 4 forest stands of each stratum. Ideally, this would result in a total of 256 sample stations across all watersheds. However, since not all watersheds have all 4 seral stages (or, large enough patches to accommodate four sample units), based on the first year of sampling, the total number of sample stations meeting study plan criteria for placement of an ARU is 210-217 stations.

The forest patches are of variable size and distribution (Figure 4), therefore the 4 sample units (100-m radius plots) for one strata within a watershed may be spread across one or more patches. Regardless of the clustering pattern, the sampling stations will always be spaced ≥250 m apart. This minimum spacing is based on pre-survey detection range testing of the ARUs in varying forest conditions (Kuehne et al. 2019). The range at which a call can be detected is a complex interplay of many factors including source sound level (i.e., how loud the call is) and frequency, topography, habitat, and environmental conditions (Darras et al. 2017, MacLaren et al. 2018, Yip et al. 2017). Our testing showed that the effective detection range of our recording units (Songmeter SM4 and Songmeter Mini, Wildlife Acoustics Inc., Massachusetts) in these conditions is 100 m and is unlikely to exceed 125 m for most of the indicator species. This is particularly true given that our audio processing protocols depend largely on automated detection, which reduces the effective detection range of the ARU (Kuehne et al. 2019).

Placement of sampling stations

Sampling stations (i.e., the ARU location) will be positioned within patches (i.e. polygons) of a given habitat stratum (forest developmental stage) within watersheds. Patches have been previously buffered to maintain minimum distances from the influence of stand edges (100 m), paved roads (100 m), and streams (60 m) (Figure 4). We have the flexibility to distribute stations within or among patches of a given stratum within a watershed. This approach is acceptable because inference is being made to a) stations, and b) overall strata - not the intermediate spatial level of individual patches.

Stations will be spaced at a minimum distance of 250 m apart (see above), and will be randomly established within a patch subject to the constraints of safety, accessibility, and ability to "fit" an ARU detection radius in a given patch.

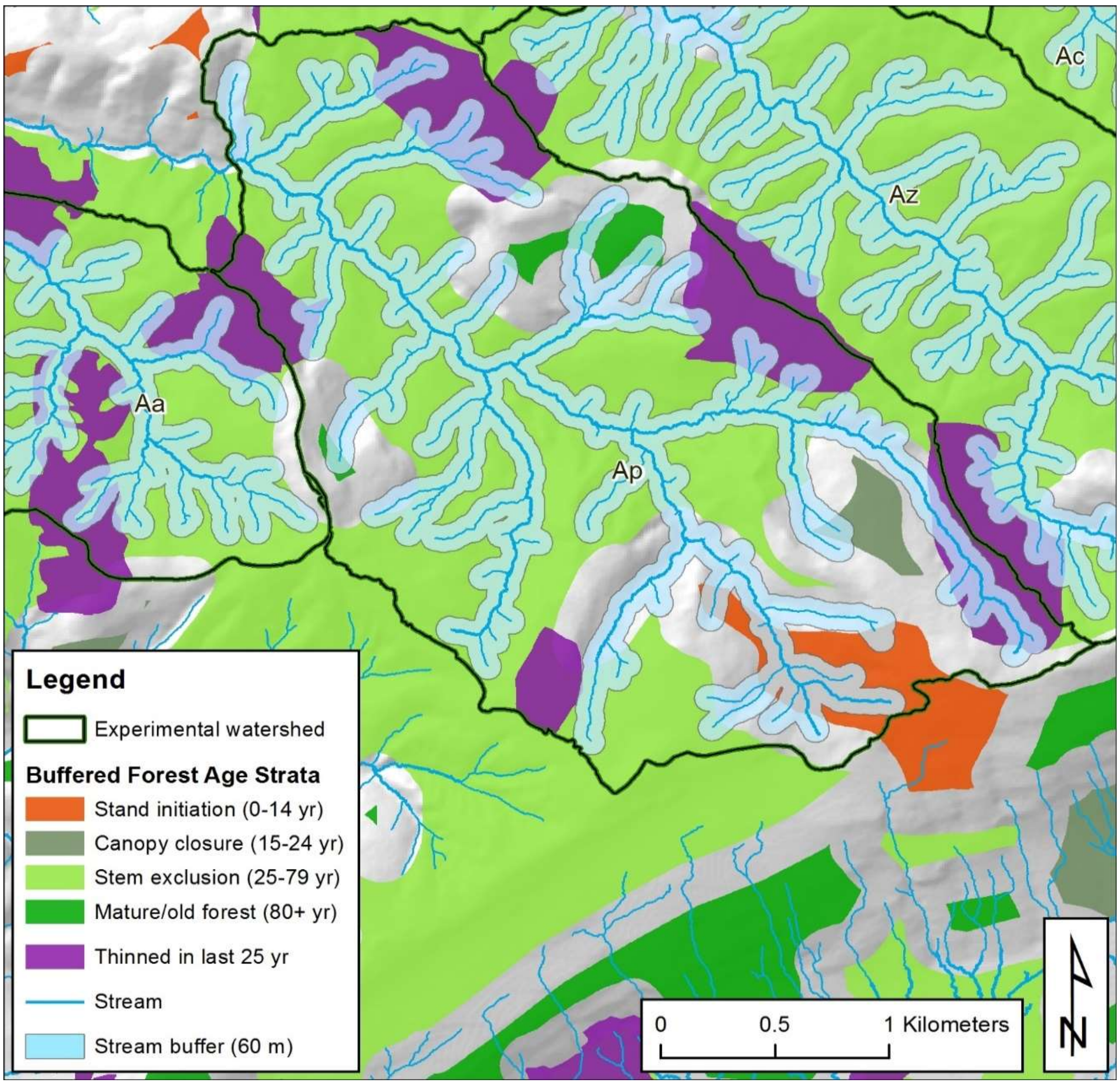

Figure 4. *Example of habitat patches (color polygons) where sampling stations can be placed. The grey areas represent buffers from forest edges, roads, and streams.*

Indicator Species

We selected ten bird species (Table 1) based on their abundance in the area, seasonal vocalization activity, associations with particular habitat, and home range size.

For association with particular habitat types, the indicator species are expected to respond to two primary gradients resulting from harvest practices: early-seral to late-seral forest, and contiguous to patchy forest (low to high edge density) (Rempel et al. 2016). Examples of directional hypotheses for indicator species include increased occupancy with stand age and percent coniferous trees for Pileated Woodpecker and reduced occupancy with stand age for Orange-crowned Warbler (Table 1).

For home range size, species with generally smaller home ranges were chosen. This helps meet the closure criterion of occupancy modeling - our analytical approach - which requires the area of the sampling unit to match the animal territory (refer to the section *Analytical Approach* for details on closure assumption). The effective detection area of our sound recorders is about 3 ha – a circular plot with about 100-m radius (Kuehne et al. 2019), which represents our sampling unit. The literature review on home ranges of the indicator species showed that all but two (Pileated Woodpecker and Varied Thrush) have home ranges within the 3-ha threshold.

Eleven additional bird species were selected for acoustic monitoring because of 1) WADNR commitment to monitor these federally listed species (Northern Spotted Owl and Marbled Murrelet) 2) their influence on WADNR-monitored species through competition or predation (Barred Owl and Corvids), or 3) state or federal listing (Golden Eagle, Northern Goshawk, Peregrine Falcon, and Vaux's Swift) (Table 2). Because of their rarity and/or large home ranges, these species are not good candidates for occupancy modeling and therefore will not be used to evaluate habitat function under our study design. However, their presence is of interest to land managers and regulatory agencies and their detection will be documented and reported. Refer to Appendix 3 for the conservation status of each species.

Table 1. Indicator species, their habitat associations and hypothesized responses to forest management.

#	Common name	Latin name	Abundance in the study area	Peak vocalization activity	Habitat association in the study area	Hypothesis for response to management	Spatial scale of response to management
1	Pileated Woodpecker	*Dryocopus pileatus*	Fairly common year around	spring - summer	mature conifer and deciduous forest	increased occupancy with stand age and percent deciduous	stand
2	Pacific-slope Flycatcher	*Empidonax difficilis*	Common	May-June	mature 40+ and old conifer	increased occupancy with stand age and percent coniferous	stand
3	Hutton's Vireo	*Vireo huttoni*	Fairly common year around	May -July (breeding season)	young forest obligate: dense poll timber with some deciduous, may disappear with thinning	reduced occupancy with stand age; reduced occupancy with stand thinning	stand
4	Chestnut-backed Chicadee	*Poecile rufescens*	Common year around	year around	mature forest obligate; conifer and mixed stands	increased occupancy with stand age and percent coniferous	stand
5	Bewick's Wren	*Thryomanes bewickii*	Fairly common	May -July (breeding season)	shrub vegetation and open woodland (early seral)	reduced occupancy with stand age	reduced occupancy with stand age
6	Pacific Wren	*Troglodytes pacificus*	Common year around	calls in winter, but mostly in spring	closed-canopy conifer forests during breeding season	increased occupancy with percent coniferous	stand
7	Varied Thrush	*Ixoreus naevius*	Common year around	May -July (breeding season)	forest generalist	reduced occupancy with stand age	stand
8	Brown Creeper	*Certhia americana*		May -July (breeding season)	mature conifer	increased occupancy with stand age and percent coniferous	stand
9	Orange-crowned Warbler	*Oreothlypis celata*	Common	May -July (breeding season)	early seral forest (saplings and shrub)	reduced occupancy with stand age	stand
10	Wilson Warbler	*Wilsonia pusilla*	Common	May -July (breeding season)	early to mid-seral forest	reduced occupancy with stand age	stand

Table 2. Additional species of interest for passive acoustic monitoring.

#	Common name	Latin name	Abundance in the study area	Peak vocalization activity	Habitat association in the study area	Hypothesis for response to management	Spatial scale of response to management
1	Northern Spotted Owl	*Strix occidentalis caurina*	Rare year around	April-May (breeding season)	mature conifer forest	increased occupancy with stand age and structure	landscape (unless nest site)
2	Barred Owl	*Strix varia*	Rare year around	April-May (breeding season)	mature conifer and deciduous forest	increased occupancy with stand age and percent deciduous	landscape (unless nest site)
3	Marbled Murrelet	*Brachyramphus marmoratus*	Rare year around	spring - summer, leaves by August	mature conifer forest	increased occupancy with stand age and structure	stand
4	Grey Jay	*Perisoreus canadensis*	Common year around	year around - no peak period	Extensive contiguous forest, not necessarily old	increased occupancy with lower percent of edge habitat	landscape
5	Steller's Jay	*Cyanocitta stelleri*	Common year around	year around - no peak period	forest edges, prefers patchy habitat	increased occupancy with higher percent of edge habitat	landscape
6	American Crow	*Corvus brachyrhynchos*	Common year around	year around - no peak period	forest edges	increased occupancy with higher percent of edge habitat	landscape
7	Common Raven	*Corvus corax*	Common year around	year around - no peak period	forest edges	increased occupancy with higher percent of edge habitat	landscape
8	Golden Eagle	*Aquila chrysaetos*	Rare year around	year around - no peak period	Open areas with rocky cliffs or large trees	N/A	N/A
9	Northern Goshawk	*Accipiter gentilis*	Rare year around	year around - no peak period	mature conifer forest	N/A	N/A
10	Peregrine Falcon	*Falco peregrinus*	Rare year around	year around - no peak period	Open areas near the coast	N/A	N/A
11	Vaux's Swift	*Chaetura vauxi*	Uncommon April-September	April-May (breeding season)	Forest with large snags and cavity trees	increased occupancy with stand age	N/A

The indicator species belong to several ecological guilds depending on their diet, foraging habitat, foraging substrate, foraging behavior, and activity period. This information is summarized in Table 3 and is used in the selection of recording periods and the development of the habitat survey protocol (Appendix 1) and acoustic data processing protocol (Appendix 2).

Table 3. Ecological guilds of indicator species.

Common name	Latin name	Diet	Foraging habitat	Foraging substrate	Foraging behavior	Activity period
Pileated Woodpecker	*Dryocopus pileatus*	insectivore	arboreal	bark	bark excavator	diurnal
Pacific-slope Flycatcher	*Empidonax difficilis*	insectivore	air		hawker	diurnal
Hutton's Vireo	*Vireo huttoni*	insectivore	arboreal – lower canopy	foliage	gleaner	diurnal
Chestnut-backed Chickadee	*Poecile rufescens*	insectivore	arboreal – lower canopy, shrubs	foliage	gleaner	diurnal
Bewick's Wren	*Thryomanes bewickii*	Insectivore	terrestrial	ground	gleaner	diurnal
Pacific Wren	*Troglodytes pacificus*	insectivore	terrestrial	ground (+fallen trees)	gleaner	diurnal
Varied Thrush	*Ixoreus naevius*	Insectivore (+ berries)	terrestrial	ground (+shrubs)	gleaner	diurnal
Brown Creeper	*Certhia americana*	insectivore	arboreal	bark	gleaner	diurnal
Orange-crowned Warbler	*Oreothlypis celata*	insectivore	arboreal – lower canopy, shrubs	foliage	gleaner	diurnal
Wilson Warbler	*Wilsonia pusilla*	insectivore	arboreal – lower canopy, shrubs	foliage	gleaner	diurnal

Number and timing of repeat acoustic surveys

To meet the assumption of closure to changes in occupancy within a breeding season, repeat surveys should be conducted within one breeding season (April-August). Repeated surveys are necessary at each sample station to minimize the possibility of a false absence and to estimate the probability of detection of an indicator species. The ARUs will be installed to record continuously for 10 days at each sampling station, from which four repeat surveys will be extracted, with a minimum of two days between surveys. MacKenzie and Royle (2005) recommend a minimum of three repeat surveys when the probability of detection is >0.5 and a greater number if the probability of detection is smaller. As our indicator species are common species, we expect that detection probabilities > 0.5; however, four surveys per station will be typical. Two days between surveys also strikes a good balance for not duplicating detection of the small number of indicator/focal species with larger home ranges (Table 1) between stations (MacKenzie and Royle 2005).

The sampling scheme will allow nearly complete sampling of 2 watersheds at the same time (using 30 ARUs), collecting all four repeat surveys (subsamples; see below) while the recorders are deployed over a 10-day period. The units will then all be collected and moved to saturate the next two watersheds, and so on throughout the breeding season, for a total of 8 deployment-and-retrieval campaigns per season. This approach ensures that all seral stages are sampled all season long, avoiding the potential problem of one seral stage being sampled primarily early in the season and another primarily late in the season.

We will also quantify temporal and environmental conditions that can affect the detection of species either because of change in their vocalization activity or the way which sound carries. These include Julian date, air temperature, humidity/precipitation, and time since sunrise. Tree density, which could also impact acoustic detection will be measured in habitat surveys.

The same survey effort will be repeated the following year (before the harvest activities occur) to provide information on inter-annual variation in occupancy.

Audio data processing and validation

The 10-day recording period described above will allow extraction of four discrete 24-hour periods (i.e., surveys), separated by at least two days between periods. A 24-hour period is unnecessarily long for a single acoustic survey; most acoustic studies are based on 20-45 minutes daily for repeat surveys. Although we could reduce audio file collection/storage by programming the ARU to collect subsamples, continuous 24-hour recordings are preferable in this project as they create a useful permanent audio record that can be repurposed in the future. For example, it facilitates future alternative sampling and processing that is better targeted toward species that are not part of our indicator suite but still of conservation interest (Table 2).

Our 24-hour periods will be subsampled by selecting 1-min audio clips for detection of indicator species. Each acoustic survey will consist of a total of 48 clips: four 1-min clips from each hour between 0400 and 1000 (at minutes 0, 15, 30, and 45), and two 1-min clips from each hour between 1000 and 2200 (at minutes 0 and 15).
Our subsampling strategy is based on the following reasoning:

- All 10 indicator species (Table 1) are diurnal. The maximum day length during the breeding period (April to August) in our study area is about 16 hours, with earliest sunrise at 0517 and latest sunset at 2119 (www.timeanddate.com).
- Records on vocalization behavior of the indicator species show most species calling actively in early to late morning (dawn chorus), a few calling before dawn, and several continuing to vocalize throughout the day until dusk (www.birdsoftheworld.org, Cornell Lab of Ornithology).
- Our literature review of acoustic sampling/analysis schedules found the length of a "survey" to range from 10-240 min per 24-hour period. However, the data collection and subsampling scheme is often strongly influenced by study limitations such as of personnel, recording units, battery, data storage etc. (La and Nudds 2016, Thompson et al. 2017). The small number of studies that have contrasted alternative subsampling schemes (e.g., use of 10 sec vs 5 min clips per day) suggest that short duration clips sampled intermittently (e.g., 15 sec – 1 min) are most effective and efficient (Cook and Hartley 2018, Metcalfe et al. 2020), particularly for species that are relatively common (Thompson et al. 2017).
- Our subsampling spreads across the entire daylight period, has higher sampling frequency in the morning, and does not exceed 60 min

Audio files will be subsampled and processed for detection of species in the office using protocols presented in Appendix 2. In general, the process involves matching audio survey data with a template (often termed a "detector") and registering a hit when a similarity threshold is reached (Araya-Salas and Smith-Vidaurre 2017, Katz et al. 2016, Shonfield and Bayne 2017). We will create our own detectors using vocalizations from previously recorded audio files from this region (Kuehne and Olden 2020), supplemented with vocalizations from sound samples in online repositories (Xeno-canto, McCauley Library). Once detectors are created, we will follow the protocols presented in Appendix 2 to process audio survey files and obtain encounter histories for each indicator species in each survey. These protocols include use of two approaches to reduce false negatives and false positives that can bias occupancy models, including manual validation (for false positives) of 10% of survey files.

Habitat surveys

We will sample habitat elements around each sampling station (i.e., ARU placement) that could be manipulated by silviculture treatments (harvest, site preparation, tree regeneration, vegetation management, and thinning). Key elements include tree species, size and density; percentage of canopy closure; canopy lift and canopy height; the amount of standing and down dead wood; and understory composition, height, and cover. These habitat elements will be measured in the field following the protocol described in Appendix 1.

We will also record landscape-level habitat characteristics that are known to influence habitat use by the 10 indicator species. Most of these are inherent (elevation, slope gradient and aspect, distance to stream) and others are affected by land management (distance to forest edge, distance to roads, habitat patch size, abundance of habitat within watershed or defined radius). These landscape characteristics will be derived from remote sensing data and analyzed using ArcGIS. Landscape-level patterns in other specific attributes may also be derived from WADNR's remotely-sensed inventory, such as tree densities, mean tree size, canopy heights/coverage, and proportion of hardwoods.

Each of the variables above will be considered for inclusion as covariates in the detection and/or occupancy models (see below).

Analytical Approach

Occupancy Modeling

Occupancy modeling (MacKenize et. al 2002) generally consists of simultaneous logistic regression analyses of both occupancy and detection probabilities. It is expected that the probability of a species to be present at a site is a function of habitat characteristics (forest structure, patch size, etc.), while the probability to detect a species if present is a function of certain measurable variables such as weather conditions (rain, air temperature, etc.).

Occupancy modeling has an important *closure assumption*, which is that sites are "closed" to changes in species[2] occupancy between repeated sampling occasions. In other words, the presence of the species within a spatially discrete sampling unit doesn't change during the sample season (MacKenzie and Royle, 2005, Rota et al. 2009). The closure assumption may be violated if the indicator species have home ranges larger than the effective detection area of ARUs, as a non-detection could mean the species was simply not available for detection in that portion of the individual home range. However, MacKenzie and Royle (2005) note the closure assumption can be relaxed and that, as long as changes in occupancy occur at random, occupancy estimation can remain valid, but should more appropriately be termed 'use.' A site may be considered used (even if not occupied at some instant) if one or more individuals have non-zero probability of being exposed to sampling (MacKenzie and Royle, 2005). At this point, we do not expect the need to replace the strict term "occupancy" with "use".

The presence/absence data for each indicator species at each station is derived from the acoustic recordings (see above and Appendix 2 for detail on the procedures). The habitat characteristics will be sampled in the field (see Appendix 1 for description of the field procedures) and derived from remote sensing data using ArcGIS. Both stand-level and landscape-level habitat data will be considered for the occupancy models to assess the importance of fine and large-scale habitat changes resulting from management and harvest treatments to habitat function (Furnas and Callas 2015, Rempel et al. 2016).

The decision whether to include a covariate depends on the degree to which it affects 1) bird occupancy, based on known biological requirements of the species, and 2) detection probability if present. We will include no more than one covariate per 5 sample stations (*n*) and will strive for 10 *n* per covariate. We will examine correlations among independent variables to avoid multicollinearity (e.g. canopy height and lift are expected to be correlated and we will use only one of them).

We will generate a set of statistical models for each of the 10 indicator species and rank them using Akaike Information Criteria (AIC) (Burnham and Anderson 1998) to indicate the best-fitting model. For sites that are sampled in more than one year (e.g., before-after harvest), the occupancy rates will be reported separately for each year so as not violate the requirement for closure. Because we are interested in both station-level and stratum-level estimates of bird occupancy, we will also explore the use of multi-level occupancy models as appropriate (Pavlacky et al. 2012). For this, we will consider

[2] We look for a sign of the species presence (in our case, through vocalization) and not for the presence of a specific individual. This is a difference between the occupancy modeling and mark-recapture studies where an individual is tracked for population estimates.

including a random effect for watershed to account for the less-independence of ARUs within a given watershed compared to across different watersheds.

If we have sufficient data, we will explore the possibility of species exclusion due to competition (i.e., for species pairs that might have competitive relationships) using occupancy models that assess independence of occupancy and detection (MacKenzie et al. 2002). These models are extremely data-hungry; however, we do not anticipate potential exclusion and need for analysis of more than species pairs (e.g., Bailey et al. 2009, Richmond et al. 2010). Hierarchical multispecies models are also an option that can overcome data deficiencies while allowing inference at species, guild, and community levels (White et al. 2019).

Exploring Wildlife Acoustic Activity to Identify Indices of Ecosystem Health/Ecological Integrity

This section corresponds to the optional study goal to "explore what integrative indices of biotic diversity, derived from the acoustic data sets, are useful to characterize habitat function". In addition to analyzing the audio files for acoustic activity of individual indicator species, we intend to use the audio data to derive metrics/indices characterizing higher levels of organization such as acoustic diversity and soundscape.

The authors are not ready to develop this section of the study plan at this point. However, the acoustic monitoring data and the study design described above will provide excellent opportunity for expanding the study in direction of soundscape ecology and biodiversity assessment. The papers below are for future consideration and for communication with potential collaborators.

Depraetere M, Pavoine S, Jiguet F, Gasc A, Duvail S, Sueur J (2012) Monitoring animal diversity using acoustic indices: implementation in a temperate woodland. Ecol Ind 13:46–54

Farina A, James P (2016) The acoustic communities: definition, description and ecological role. Biosystems 147:11–20

Farina A, Pieretti N (2014) Sonic environment and vegetation structure: a methodological approach for a soundscape analysis of a Mediterranean maqui. Ecol Inform 21:120–132

Gasc A, Francomano D, Dunning JB, Pijanowski BC (2016) Future directions for soundscape ecology: the importance of ornithological contributions. Auk 134:215–228

Gasc A, Sueur J, Jiguet F, Devictor V, Grandcolas P, Burrow C, Depraetere M, Pavoine S (2013a) Assessing biodiversity with sound: do acoustic diversity indices reflect phylogenetic and functional diversities of bird communities? Ecol Ind 25:279–287

Gasc A, Benjamin L. Gottesman . Dante Francomano (2018) Soundscapes reveal disturbance impacts: biophonic response to wildfire in the Sonoran Desert Sky Islands. Landscape Ecol.

Lellouch L, Pavoine S, Jiguet F, Glotin H, Sueur J (2014) Monitoring temporal change of bird communities with dissimilarity acoustic indices. Methods Ecol Evol 5:495–505

Pijanowski BC, Farina A, Gage SH, Dumyahn SL, Krause BL (2011a) What is soundscape ecology? An introduction and overview of an emerging new science. Landscape Ecol 26:1213–1232

Pijanowski BC, Villanueva-Rivera LJ, Dumyahn SL, Farina A, Krause BL, Napoletano BM, Gage SH, Pieretti N (2011b) Soundscape ecology: the science of sound in the landscape. Bioscience 61:203–216

Pieretti N, Farina A, Morri D (2011) A new methodology to infer the singing activity of an avian community: the Acoustic Complexity Index (ACI). Ecol Indic 11:868–873

Sueur J, Farina A, Gasc A, Pieretti N, Pavoine S (2014) Acoustic indices for biodiversity assessment and landscape investigation. Acta Acust United Acust 100:772–781

Towsey M, Wimmer J, Williamson I, Roe P (2014a) The use of acoustic indices to determine avian species richness in audio-recordings of the environment. Ecol Inform 21:110–119

Management Implications

The study will be implemented within an adaptive management framework, aiming to reduce uncertainties regarding the integration of habitat conservation and timber harvest, comparing current and innovative silvcultural practices, and informing continuous improvement of land management practices on state lands in Washington and beyond. The silvicultural manipulations of the broader management experiment are designed as forest management alternatives to current practices, and the environmental response variables, including the responses of the 10 indicator species subject to this study, are intended to inform WADNR and other land managers about the effectiveness and tradeoffs of these alternatives.

None of the 10 indicator species are federally listed under the Endangered Species Act and only the pileated woodpecker is state listed as a candidate species (Appendix 3). However, many bird species across North America, including those associated with western temperate forests, are experiencing generalized population declines (Rosenberg et ail. 2019). Land-use change and habitat loss are likely the top factors behind this decline. The bird families represented by our indicator species are among those experiencing declines over recent decades (Rosenberg et ail. 2019); as such, the data collected in this study could help elucidate how forestland management can contribute to declines or recovery of bird species over time.

Two of the species of interest in this study – northern spotted owl and marbled murrelet - are federally listed as Threatened and state listed as Endangered. WADNR has conservation strategies for both species that cover the study area. We will screen the acoustic files for their calls. Although the data will not be included in the occupancy models owing to the birds’ rarity and large home ranges, any detections will be communicated to WADNR managers and WDFW for further consideration.

Study Implementation

Timeline

Field reconnaissance of the 16 watersheds was completed in 2019.

Pre-harvest sampling of the 4 seral strata will take place in April-August of 2020 and again in 2021.

The harvest and regeneration treatments are expected to start in several of the stem exclusion forest stands in the fall of 2021. The harvests are administered by WADNR and implemented by private purchasers and operators.

The post-harvest repeat surveys will occur in the manipulated stands as soon as the timber harvest is completed, the earliest surveys will be in April-August 2022.

Depending on funding availability, postharvest sampling in additional harvested units and/or sites and/or repeated sampling in the initially harvested units will continue over several years.

Staff

Principal Investigator: Teodora Minkova, WADNR

Researchers: Daniel Donato, WADNR; Lauren Kuehne, Omfishient Consulting; Bernard Bormann, UW

Field crews will consist of volunteers recruited by the EarthWatch Institute. The study will be implemented as a citizen science project.

Funding

3-year grant from Earthwatch starting January 2020 with potential for extension.

Additional support from WADNR and UW-ONRC in the form of researchers' time, equipment, and data.

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Appendix 1. Habitat Sampling Protocol

Author: Dan Donato

Version: 3.0

Revision History

Protocol Version	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft	Dan Donato	Teodora Minkova	01/29/2020
2.0	Revisions after field testing	Lauren Kuehne	Dan Donato	9/7/2020
3.0	Revisions/updates	Dan Donato	Teodora Minkova	10/30/2020

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Purpose

Bird use of a site is directly related to the habitat (vegetation structure) present on that site. Vegetation structure is also what can be changed through forest management. This protocol details how forest vegetation is sampled to characterize habitat for birds and other wildlife in the vicinity of the acoustic monitoring stations.

Equipment

1. Diameter tapes – 5m or 10m (2)	13. Meter stick
2. Avalanche probe (2)	14. Hand Compass w/ declination (3)
3. Transect tapes – 50m or 100m (2)	15. BK Radio
4. GPS Unit	16. Spot beacon
5. Laser rangefinder	17. Keys for gates
6. Pin flags for marking subplots (>4)	18. Extra batteries for all electronics
7. Flagging (red)	19. 360 camera, charged/batteries
8. Tablet w/ electronic data sheets	20. Field vests, hardhats, gloves, safety glasses
9. Backup hardcopy data sheets	21. Pens, pencils, sharpies, Rite-in-Rain notebooks
10. Charging cable for tablet/phones	22. Clipboards
11. Protocol	23. First Aid kit
12. Colored chalk for trees (2 colors)	24. Quad maps, aerial photos, plot maps and/or UTMs
	25. “Field guide” w/4-8 most common trees, plants

General layout

Each acoustic monitoring station records wildlife sounds up to ~100 m away, effectively creating an 8-acre circle of recorded wildlife use. Within that circle, habitat (vegetation structure) is sampled in four plots, 40 meters away from the monitoring station in each cardinal direction (***Fig. 1***).

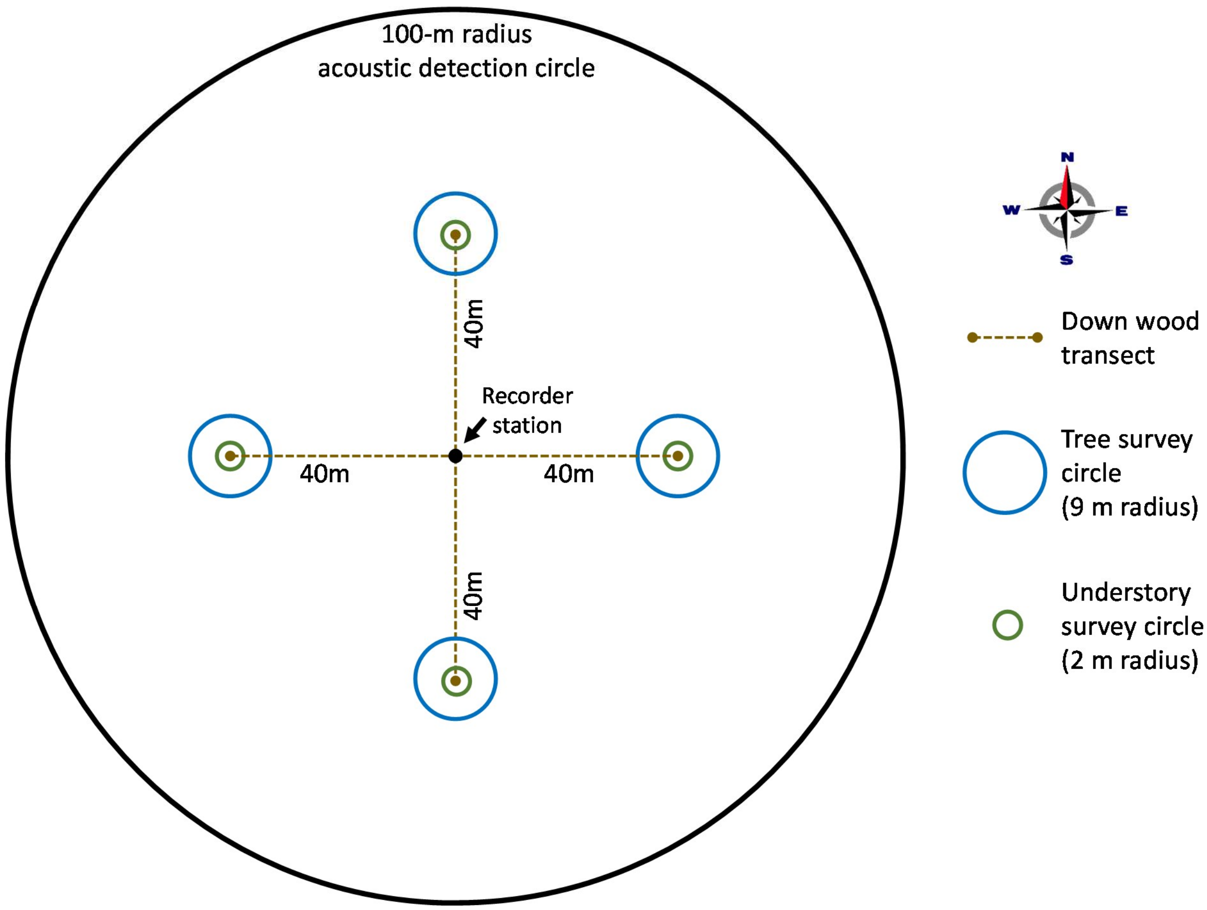


Figure 1. *Overall layout of the habitat sample plots around the monitoring station.*

Each of the four sample plots consists of two nested (concentric) circles. Trees are measured in a 9-meter radius outer circle, and understory vegetation is measured in a 2-meter radius inner circle. Down wood is measured along the 40-m transect line connecting the plot to the central monitoring station. See ***Figure 2*** for a detailed plot diagram.

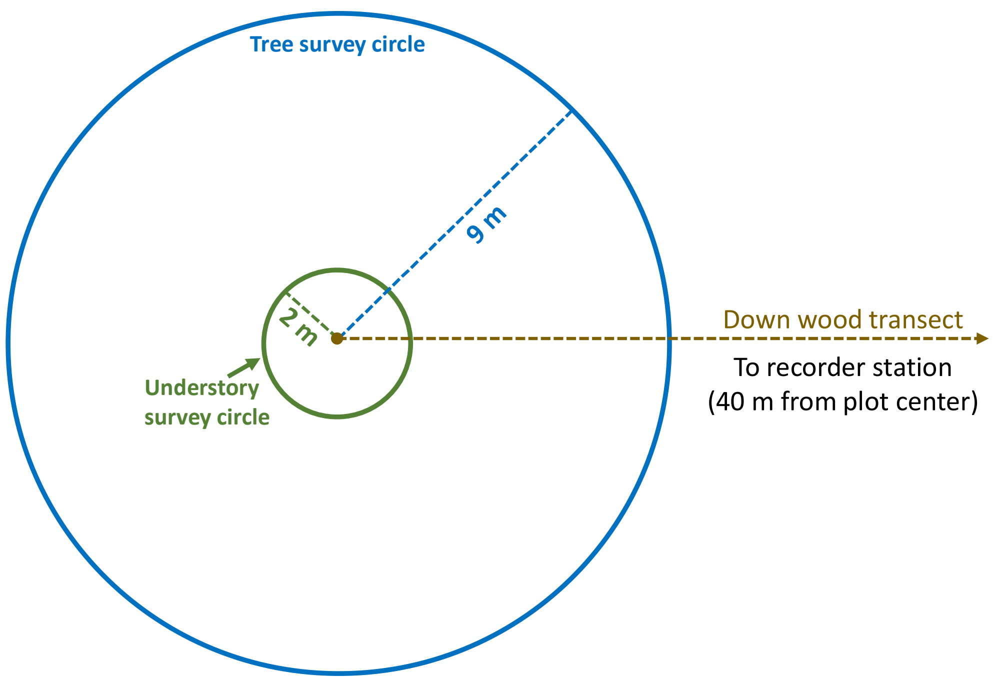


Figure 2. *Sample plot diagram.*

Plot Establishment

- For each sample plot, lay a transect tape from the monitoring station to the plot using a compass bearing (N, S, E, or W). Tape may rest on the ground – no need to pull perfectly taut.
- When marking plot boundaries, stay out of the plot as much as possible to avoid trampling understory vegetation
- If >5% of a plot falls within a water feature (creek, bog, seep, etc.) in which the dominant vegetation clearly changes, or leaves the intended stand (different stand/habitat type), make note and skip the plot.
- If any of the plot falls within a road or road shoulder, record the % of the plot in the road/shoulder, and otherwise measure the plot as normal. Indicate whether road is closed or active, overgrown or open.
- Mark the plot with red flagging, hung at plot center. If no branch is available, tie flagging around a stick and fix in the ground.
- Record GPS coordinates on datasheet/app and store a waypoint in GPS unit with station number and plot direction (e.g. N for north). Make sure GPS is set to NAD83, UTM.
- Standing at plot center and facing north, hold the 360-camera above your head and take a photo. Record the file name/time of the photo.

Measurements

<u>2-meter inner plot</u>

Understory vegetation cover

- Definition: All non-tree vegetation (plus tree species below 1.3 m height) within a 2-m radius circle (slope distance from center). Does not include mosses.
- Record % cover of herbs, grasses, and ferns.
- Record % cover of ground layer shrubs (0-0.5 m height).
- Record % cover of medium-height shrubs (0.5-2 m height).
- Record % cover of tall shrubs (>2 m height).
- Record the fraction of all shrubs that are deciduous (nearest 10%).
- Record what the two most common shrub species are (by canopy volume).
- Record % cover of tree species that are currently below 1.3 m height.
- Notes:
    - Visually estimate % cover for all categories. No need to visually trace every leaf during cover estimation; use the shape of the overall plant(s) – the general shadow or drip line.
    - Different vegetation classes can overlap in cover. Total cover can exceed 100%.
    - For all cover estimates, precision levels are: If less than 10%, estimate to nearest 1%; if more than 10%, estimate to nearest 5%.

Understory vegetation height

- Definition: All non-tree understory vegetation.
- At the edge of the 2-meter circle in each of the cardinal directions (N, S, E, W), as well as plot center, measure the height of understory vegetation using the 3-m probe. Units are meters, recorded to the nearest 0.1 m. Record these 5 height measurements for each plot.
- At each measurement point, the vegetation does not need to touch the probe. Record the tallest leaf within 0.5 m of the probe location. Tallest leaf may be outside plot.

Small-tree survey

- Definition: Live conifer and hardwood trees – woody species *capable* of growing >10 meters tall – with a current stem diameter of 0.1 to 10 cm (dbh; see below).
- Small trees that are dead are not recorded.
- For each small tree stem whose *center* is in the 2-meter plot, record the species, stem diameter in cm (to nearest 0.1 cm), and height in meters (to nearest 0.1 m).
- Stem diameter is defined as diameter-at-breast-height (dbh), meaning at 1.3 m above the ground on the uphill side. See figure A1 for details.

9-meter outer plot

Tree survey

- Definition: a) Live conifer and hardwood trees – woody species *capable* of growing >10 meters tall – with a current stem diameter (dbh) of 10 cm or greater; and b) Dead conifer and hardwood trees with stem diameter of 10 cm or greater, and height greater than 2 m height, provided they are still supported by their roots.
  - *Center* of tree must be in 9-m plot. For trees near plot edge, determine inclusion by shooting laser to object/person standing at tree and aligned with tree's center.
- For each tree, record the species and stem diameter at breast height in cm (to nearest 0.1 cm).
- Using the laser rangefinder, measure the tree's height and height to live crown, in meters (to nearest 0.1 m). Height to live crown (HLC) is the distance from the ground to the lowest branches that are contiguous with the tree's main crown.
  - In stem exclusion stands – height features are measured on only every third tree, in the order they are encountered as trees are surveyed around the circle.
- Record the live/dead status of the tree:
  - 0 = live
  - 1 = dead, sound wood
  - 2 = dead, soft/rotten wood
- Record whether the tree stem is broken.
- Forked trees: If fork is above breast height (1.3 m), measure the stem below fork and record crown characteristics collectively (one data row). If fork is below breast height, measure each stem as two separate tree records (two data rows). See appendix for further guidance on measuring dbh.

40-meter transect lines*Down wood survey*

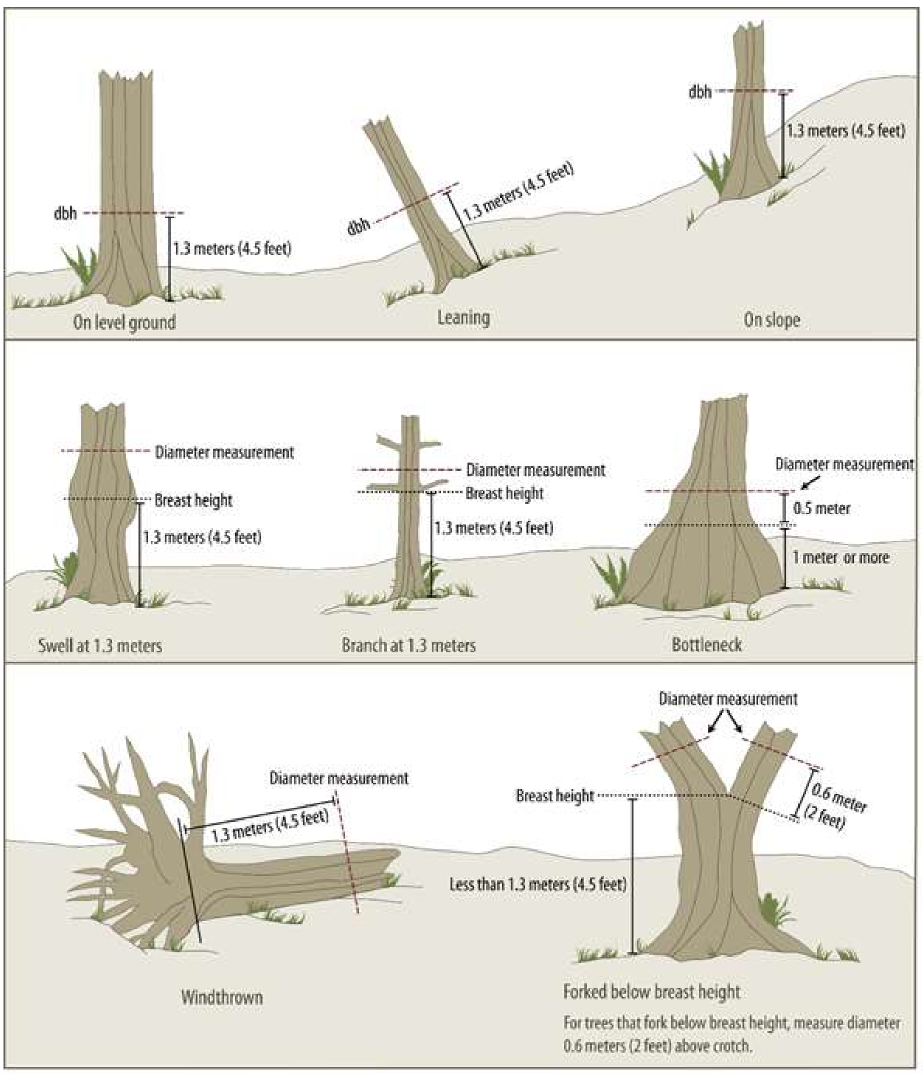
- Definition: Dead down wood, fallen and/or not supported by own roots, that is at least 10 cm diameter.
- Record down wood pieces that intersect the transect tape stretched from the monitoring station to the plot:
  - Central axis (e.g., pith) of piece must be above ground level. It may be suspended above or in contact with ground.
  - Transect must pass through central axis of piece, not just a corner.
  - If transect passes through a curved piece more than once, count each intersection as a separate data point.
  - If a single piece intersects both transects, count it both times.
- For each piece, record the transect azimuth, diameter at point of intersection (in cm, to nearest whole cm), and whether the piece is sound (hard) or rotten (soft).
- If slash pile(s) are encountered, skip the section of the transect that is slash and record "slash pile(s)" in notes. A pile is defined as >10 pieces >10 cm diameter, in contact with each other.

Measuring tree diameter

Find the height of 1.3 m (aka "breast height") on the tree measured from the ground. Find where 1.3 m height is on your body and use that point for each tree. Always determine breast height standing up slope from the tree because on steep slopes, the upslope and downslope breast heights are different.

When measuring DBH, wrap the diameter tape around the tree at breast height. *Use the diameter side of the tape!* Make sure the tape is perpendicular to the main axis of the bole, even if the tree is leaning. Press the tape flat against the tree, and measure the diameter to the nearest 0.1 cm. If the tree is covered by a thick layer of moss or lichens at breast height, peel these off before measuring diameter.

Measure trees <u>only if it is safe to do so.</u>



Adapted from Curtis and Marshall 2005

Figure A1: *Tree diameter measurements.*

Volunteer Training: Tips to organize trainings so that volunteers aren't overwhelmed and to reduce variability in survey data

Appendix 2. Protocols and Workflow for Processing Audio Data

Because of the large number of indicator species and sites to be evaluated, we will rely heavily on automated template recognition to detect presences. Our strategy to reduce false negatives and false positives is two-pronged. The first is to optimize the sensitivity and specificity of the correlation cutoffs used in template recognizers (i.e., detectors) based on previously collected acoustic data from the same region. Second, we will manually validate a subset of surveys, which will be incorporated into a multi-state detection model (i.e., the "Miller Model", Miller et al. 2011)

Audio recording protocols to facilitate processing

We will use a sample rate of 36 kHz, and files should be saved using the standard .wav format (i.e., no compression). Capacity and write speed of SD cards should be compatible with the ARU, and formatted per instructions prior to each deployment. Most of the ARUs are Songmeter Minis, which have only 1 channel; however, in the small number of surveys where a 2-channel ARU (i.e., SM2 or SM4) are used, recording should be done using the left-channel only for consistency and to save file space. Clocks on all ARUs should be synchronized prior to deployment. This can be done via the launch app for the Songmeter Minis, but will need to be done manually if the launch/schedule is instead done using a configurator file uploaded through an SD card; similarly, clocks on any SM2/SM4 will need to be synchronized manually. 24-hour recording periods should be scheduled to start at midnight, and be programmed to save in 1-hour file increments. All acoustic surveys will fall within Daylight Savings Time (DST), so there is no need to coordinate across a time change.

Creation of indicator species detectors

Detectors will be built for each indicator species, consisting of 12-15 vocalizations to capture potential variation in call loudness, duration, and frequency. Because this survey emphasizes the breeding season, territorial calls and songs will be emphasized in creating the detectors. As much as possible, vocalizations will be taken from an existing set of 3,500 hours of local audio recordings collected at five locations across the Olympic Peninsula in 2017-2018 (Kuehne and Olden 2020). However, if sufficient example vocalizations cannot be obtained from this dataset for some species, supplemental vocalizations will be obtained from online repositories (Xeno-canto.org, McCauley Library).

Example vocalizations will be isolated as spectrogram cross-correlation templates from audio files using the monitoR package (makeCorTemplate function) in R. The suite of templates for each species can be combined (corTemplateList function) to form the detector for each species.

Creation of audio survey files

Acoustic data will be collected to result in four discrete 24-hour periods of audio data per sampling station. Each of these 24-hour periods will be subsampled as 1-min clips (see "*Audio data processing and validation"*) to result in a total of 48 minutes of audio (i.e., a survey). Subsampling will be done by creating selection tables to automate extraction of audio clips (e.g., https://marce10.github.io/2017/06/06/Individual_sound_files_for_each_selection.html). The subsampled audio clips can then either be processed separately, or merged into a single 48-minute .wav file to reduce the number of files and simplify processing and validation. Detections from a merged file can be mapped back to a specific point (e.g., hour or minute of the day) in the originating audio data if necessary.

Template Matching and Validation

Audio files for each survey will be run through detectors (using spectrogram cross-correlation in the monitoR package in R) for each indicator species to generate encounter histories for occupancy models. We will use two approaches to reduce and account for incidence of false positive and false negatives, both of which can bias occupancy models. The first is to identify correlation cutoffs that maximize the sensitivity (i.e., reduces false negatives) and specificity (i.e., reduces false positives) of each detector by plotting rates of true false positives and true false negatives across incremental increases in correlation cutoffs. These are currently being generated from the previously collected data at five Olympic Peninsula locations; preliminary results indicate that optimized correlation cutoffs for most species will range from 0.20 – 0.45.

Second, we will adopt the "Miller model" to improve occupancy estimates by manually validating 10% of the surveys (from each habitat strata) for false positives*. These manual validations are added to the encounter history in the occupancy model as an additional survey with a different observation state.

**Note, we are also continuing to consider use of machine-learning options to reduce rates of false positives as a supplement and/or alternative to manually validating files (e.g., Campos-Cerqueira and Aide 2016, Clink and Klinck 2019); however, given our available personnel and expertise available for processing audio data, we believe the above protocols are going to be the best and most feasible match for this project.*

Appendix 3. Conservation Status of Indicator Species and Species of Interest

#	Common name	Latin name	Washington state conservation status	Federal conservation status	Role in the study
1	Pileated Woodpecker	*Dryocopus pileatus*	Candidate	None	Indicator species
2	Pacific-slope Flycatcher	*Empidonax difficilis*	None	None	Indicator species
3	Hutton's Vireo	*Vireo huttoni*	None	None	Indicator species
4	Chestnut-backed Chickadee	*Poecile rufescens*	None	None	Indicator species
5	Bewick's Wren	*Thryomanes bewickii*	None	None	Indicator species
6	Pacific Wren	*Troglodytes pacificus*	None	None	Indicator species
7	Varied Thrush	*Ixoreus naevius*	None	None	Indicator species
8	Brown Creeper	*Certhia americana*	None	None	Indicator species
9	Orange-crowned Warbler	*Oreothlypis celata*	None	None	Indicator species
10	Wilson Warbler	*Wilsonia pusilla*	None	None	Species of interest
11	Northern Spotted Owl	*Strix occidentalis caurina*	Endangered	Threatened	Species of interest
12	Barred Owl	*Strix varia*			Species of interest
13	Marbled Murrelet	*Brachyramphus marmoratus*	Endangered	Threatened	Species of interest
14	Grey Jay	*Perisoreus canadensis*	None	None	Species of interest
15	Steller's Jay	*Cyanocitta stelleri*	None	None	Species of interest
16	American Crow	*Corvus brachyrhynchos*	None	None	Species of interest
17	Common Raven	*Corvus corax*	None	None	Species of interest
18	Golden Eagle	*Aquila chrysaetos*	Candidate	None	Species of interest
19	Northern Goshawk	*Accipiter gentilis*	Candidate	None	Species of interest
20	Peregrine Falcon	*Falco peregrinus*	None	Species of Concern	Species of interest
21	Vaux's Swift	*Chaetura vauxi*	Candidate	None	Species of interest