A REVISED PROTOCOL FOR
SURVEYING MARBLED MURRELETS IN FORESTS

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Pacific Seabird Group
Marbled Murrelet Technical Committee

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GLOSSARY

On first mention, within each chapter, the following terms are identified in bold caps.

Audio-Visual Survey (AV Survey): the required method for determining murrelet use or occupancy in relation to proposed projects that affect murrelet habitat, primarily timber harvest. AV Surveys can also be useful for monitoring murrelet activity levels, locating nests, and establishing murrelet stand use patterns.

Breeding Season: the portion of the calendar year defined by the earliest known nesting and latest known fledging dates. The breeding season extends 24 March – 15 September in California, 1 April – 15 September in Oregon and Washington, 15 April – 15 September in British Columbia, and 15 May – 5 August in southeastern and south-central Alaska.

Canopy Height (Canopy): in relation to murrelet behaviors and weather conditions during surveys, is the height of the tallest tree within the station effective area. See *Appendix J: Data Forms and Instructions*. The term canopy may also refer to the forest layer comprised of the crowns of the overstory trees.

Conservation Zone: Conservation zones were established in the Recovery Plan (USFWS 1997) and divided the murrelet's range south of Canada into six zones. Zones 1 and 2 are in Washington (Puget Sound and western coast range), Zone 3 includes the northern and central Oregon coast range, Zone 4 includes southwestern Oregon and northern California (Siskiyou coast range), Zone 5 includes south of Cape Mendocino to San Francisco Bay (Mendocino), and Zone 6 includes the Santa Cruz Mountains. See Lorenz et al. (2021) and USFWS (1997) for maps of these zones.

Contiguous: (for the purpose of delineating survey areas) coniferous forest with less than 200-m (656-ft) gaps between platform trees.

Detection Type: murrelet detections can be classified into three categories of: occupied; presence; or no detections, depending on the types of behavior observed. Behaviors indicative of occupancy, or occupied behaviors, are associated with visual detections of murrelets below the forest canopy, or audio detections indicating a murrelet is close to the surveyor or stationary in a tree.

False Omission Rate: The False Omission Rate (FOR) quantifies: If the decision was that the area is not occupied, what is the chance that it was in fact occupied? See *Appendices A and B* for more details.

False Discovery Rate: The False Discovery Rate (FDR) quantifies: If the decision was that the survey area is occupied, then what is the chance that it was in fact not occupied? See *Appendices A and B* for more details.

Forest Stand: a contiguous group of trees relatively uniform in composition, age class, location, origin, size class, structure, and distribution.

Nest Platform (Platform): a relatively flat surface ≥10 cm (4 inches) in diameter; created by a wide bare branch, a mistletoe infection or witch's broom, broken top trees, or other deformity; with nesting substrate like moss, lichen, or other substrate. The platform is located on a branch or other surface ≥10 m (33 feet) high in the live crown of a coniferous tree.

Nesting Habitat (Habitat): is defined as a coniferous forest stand or stands with one or more platform trees, where the surrounding forest canopy (surrounding trees or within the platform tree itself) provides some cover and functional protection.

Not Occupied Area: if none of the behaviors or conditions for occupancy designation were detected anywhere in the survey area after completing the required number of surveys, the survey area is designated as not occupied for a period of five years.

Occupied Area (Occupied Site): survey area where at least one occupied behavior or condition is detected or, if using the **Presence Approach**, three or more survey visits with at least one presence detection of any type are documented. An occupied area is delineated as such in perpetuity, so long as the area continues to support nesting habitat.

Occupancy Classification: an occupancy classification of occupied or not occupied (formerly unoccupied), based on observed murrelet behaviors, applies at the scale of the entire survey area. Occupied results from one or more strata within a survey area apply to that entire survey area.

Occupied Only Approach: survey approach in which a detection of an occupied behavior (e.g., subcanopy flights, circling, and landings) at any station within the survey area leads to an Occupied Classification. This approach requires more survey visits than the **Presence Approach**.

Platform Tree: a tree of any age that provides a branch or branches with structures appropriate for murrelet nesting.

Presence Approach: survey approach in which three or more survey visits with at least one presence detection or a detection of occupied behavior leads to a survey area being classified as occupied. This approach requires fewer survey visits than the **Occupied Only Approach**.

Project Footprint: Geographic boundary of the proposed management action, including timber sales, planned new roads or quarries, etc.

Station Effective Area: the area surrounding an individual survey station where murrelets can be detected, either horizontally or vertically, during an AV survey. For the purpose of this protocol, the maximum station effective area is 100 m (328 ft) horizontally and 200 m (656 ft) vertically.

Stratified Random Sampling Strategy: method in which the habitat of the survey area is broken into one or more strata, and survey stations are randomly selected from each of those strata, which allows an inference or occupancy determination that applies to all of the habitat available for sampling. Under this protocol, where a survey area contains greater than 61 ha (150 ac) of habitat, it is divided into multiple strata to distribute effort more evenly across the survey area. After completing surveys, an occupancy determination applies to the entire survey area.

Subcanopy Behaviors: flights at, below, through, into, or out of the forest; dives; landings; or other behaviors observed below the forest canopy of an area.

Survey Approach: Occupied Only Approach vs. **Presence Approach**, to be determined before surveys are conducted.

Survey Area: the fundamental unit at which surveys are conducted and occupancy classification is determined.

Survey Area Assessment: an assessment to determine if there are platform trees in the project footprint, including a desk and on-site review.

Survey Period: the dates during which most detections occur in a given portion of the murrelet's nesting range. The survey period extends 15 April – 5 August in California, 24 April – 5 August in Oregon and Washington, 1 May – 31 July in British Columbia, and 15 May – 5 August in southeastern and south-central Alaska.

Survey Station: the specific location at which an AV survey is conducted.

Survey Strata (singular Stratum): a survey area can be divided into one to three subunits, called strata, to ensure that the survey effort is distributed more evenly across the survey area. Comparable to survey sites in terminology of the 2003 version of the survey protocol.

INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*), a Pacific seabird, was listed under the United States Endangered Species Act in September of 1992 and under the Species at Risk Act in British Columbia, Canada in 2003. The Pacific Seabird Group developed the first inland survey protocol in 1993 and published a major update in 2003 (Evans Mack et al. 2003). This document is an update to the 2003 protocol based on the latest research on Marbled Murrelet ecology and conservation status and an updated statistical analysis from data collected in California, Oregon, and Washington. The survey protocol in Chapter 2 is designed for forest surveys in Washington, Oregon, and California. For use in Alaska and British Columbia, this protocol may require some modifications and the statistical analyses may need revision by including survey data from Alaska and British Columbia. Each respective entity/agency using this protocol should seek specific guidance from their regulatory agency regarding requirements per the Endangered Species Act of 1973 (ESA; 16 U.S.C. § 1531 et seq.) and how the results of surveys conducted using this protocol can be used to ensure regulatory compliance.

The principal goals of the Pacific Seabird Group (hereafter PSG) are to increase the quality and quantity of seabird research through facilitating exchange of information, to identify and assess the importance of threats to seabird populations, and to provide land managers and researchers with guidance on understanding and managing seabird populations and the threats to species. The objectives of PSG are scientific, educational, conservational, and nonprofit. To advance these objectives, PSG's principal activities are:

(1) To increase the amount and quality of scientific research on Pacific seabirds;

(2) To educate PSG's members and the general public on the ecology and importance of Pacific seabirds and their environment;

(3) To disseminate publications and other information to accomplish this end; and

(4) To advocate for conservation of Pacific seabirds wherever they occur.

Purpose and Objectives

This document was designed to provide users with a summary of murrelet life history and conservation needs as well as direction for conducting inland **Audio-Visual Surveys**[1] (AV Surveys) for murrelets in forested habitat based on a revised survey protocol. The changes in the survey protocol (see Chapter 2) are based on updated statistical analyses of data from inland murrelet surveys conducted from 2003-2014 (Appendices A and B). It provides new recommendations for the number of survey visits and stand contiguity, among others (see below). This document is broken into two chapters addressing important aspects of murrelet

[1] Terms used in this document appear in bold caps at first mention in each chapter and are defined in the *Glossary*. These terms appear in normal fonts in all subsequent uses.

ecology (Chapter 1) and methods for conducting surveys (Chapter 2). Details on PSG's recommendations for managing murrelet habitat, delineating **Occupied Areas**, and providing critical conservation measures, once surveys are completed, are provided in *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/), a peer reviewed paper published simultaneously with this document. Research continues to broaden our understanding of murrelet ecology, both inland and at sea, and we expect that this protocol will need modification again in the future. Thus, it is intended as a working document, based on the best available data currently in hand, to be revised as new information is acquired.

The objectives of this document are to provide scientifically based methods for biologists, managers, and researchers to:

(1) Identify forest conditions meeting survey requirement needs;

(2) Document the occurrence of murrelets in a **Forest Stand** at the time of surveys; and

(3) Classify **Survey Areas** based on observations during surveys (i.e., classify as occupied or not occupied).

Significant Changes from the 2003 Protocol

Based on the most recent science and this new statistical analysis, the following five areas of the protocol have undergone substantial updates and revisions and special attention should be focused on these topic areas:

(1) Changes to the sampling effort (generally requiring more survey visits), as well as an option for alternate sampling design that treats three survey visits across a survey area with presence detections as occupancy and also reduces effort;

(2) Change in terminology from Survey Sites to **Survey Strata** (Survey Stratum singular), as well as how the survey strata are applied within a survey area;

(3) Updates to distances associated with **Survey Station** effective radius and stand contiguity;

(4) Interpreting survey results, including treating most circling behaviors as occupied behaviors; and

(5) An updated datasheet.

It is critical to recognize that a protocol intended for many different users and for a variety of forestland management-related purposes cannot cover all possible scenarios. This protocol is to be used hand-in-hand with additional requirements and/or consultation with State, Provincial, or Federal agencies as appropriate.

Statistical Analysis Overview

In 2018-2019, a new statistical analysis for this protocol was conducted by a Statistical Analysis Subgroup working under and in consultation with the PSG Marbled Murrelet Technical Committee (MMTC) Inland Survey Protocol (ISP) team (Appendices A and B). The purpose of the statistical analysis was to use existing murrelet survey data to determine the number of survey visits required to accurately determine the status of a survey area. In common with past protocols, a performance criterion of an error rate of 5% or less (i.e., a 0.05 probability of falsely determining non-occupancy when a survey area is in fact occupied) was selected by the ISP team for use to identify the required survey effort. Statisticians Aaron Springford and Jay Jones (Weyerhaeuser) conducted the analyses, with input from Jim Baldwin (USFS statistician).

Important ways in which the new analysis differed from previous analyses include:

- The statistical analysis used Bayesian statistical methods and employed an estimate of the probability of occupancy instead of the previously used detection probability. Estimates were based on a two-year sampling plan and considered heterogeneity in the probability of occupancy among **Survey Stations**;

- The candidate protocol performance assessment included a **False Omission Rate** and **False Discovery Rate**, which the ISP Protocol Team and its Statistical Analysis Subgroup determined to provide advantages over previously used performance measures;

- The model used for analyzing murrelet occupancy was expanded to include presence information;

- The analysis and protocol allowed for **Stratified Random** sampling of habitat, in contrast to the 2003 protocol, which had a target of complete sampling coverage of habitat;

- The effective detection distance for a survey station was reduced to 100 m (328 ft) from 200 m (656 ft) to improve the likelihood of detecting occupied behaviors; and

- The analysis included explicit evaluation of occupancy status at the entire survey area scale. The statistical analysis for the 2003 protocol was conducted at the site scale, where a survey area could include multiple sites.

CHAPTER 1: MARBLED MURRELET NATURAL HISTORY AND ECOLOGY

Overview of Behavioral Ecology and Breeding Biology

The Marbled Murrelet (*Brachyramphus marmoratus),* also known as murrelet, is a small diving seabird (Family Alcidae), occurring only in North America, nesting along the coasts from Alaska south to Santa Cruz, California (Nelson 1997), and wintering as far south as Baja California, Mexico (Erickson et al. 1995). Murrelets forage on small schooling fish and invertebrates in small to large groups in sheltered marine waters, usually within 5 km (3.1 mi) of shore. Unlike most members of the family Alcidae, Marbled Murrelets breed in mature coastal forests from Alaska to central California, nesting most often in trees but also nesting on the ground or rock ledges in parts of Alaska and British Columbia, with one cliff nest found in the Olympic Mountains of Washington (Bradley and Cooke 2001, Carter and Sealy 2005, Bloxton and Raphael 2009, Nelson et al. 2010, Barbaree et al. 2014).

As of the end of 2022, at least 519 tree nests and 63 ground nests have been located (Table 1-1). From the tree nest locations, it is apparent that murrelets nest in old-growth and mature coniferous forests throughout most of their range (Nelson and Sealy 1995, Ralph et al. 1995, Burger 2002, Nelson et al. 2006). They also have been found in younger forests with structural elements similar to old growth, such as remnant old-growth trees or younger trees with nesting platforms created by deformities or dwarf mistletoe infestations (Grenier and Nelson 1995, Nelson and Wilson 2002).

In some areas, murrelets are known to fly up to 112 km (70 mi) inland (see Table 1-2) to socialize and search for nesting locations, typically selecting stands with other murrelets (Plissner et al. 2015, Valente et al. 2021). Social behavior and co-occurrence of multiple pairs in stands are typical, especially in areas with higher populations. However, murrelets are secretive as they travel to and from their nesting areas (Day et al. 1983, Nelson and Hamer 1995a, Nelson 1997). Due to cryptic nesting behavior and the location of nests high in trees or on cliffs, murrelet nests are difficult to locate (Bradley et al. 2004, Peery et al. 2004, Baker et al. 2006, Barbaree et al. 2014).

Because murrelets are most closely associated with old-growth and mature forests for nesting (Ralph et al. 1995), population declines have been attributed in part to loss, modification, and fragmentation of forest habitat (USFWS 1997). Marbled Murrelets are Federally listed as Threatened in Washington, Oregon, and California (USFWS 1992) and State listed as Endangered in Washington, Oregon, and California (Washington Administrative Code [WAC] 220-610-010, Oregon Administrative Rules [OAR] 635-100-0125, and California Natural Diversity Database [CNDDB] 2022). They are also listed as Threatened in British Columbia (COSEWIC 2012). While this protocol is designed based on data from the U.S. listed range, data from British Columbia and Alaska will be included where possible.

For more details on murrelet ecology, habitat requirements, and behavior, see the following summary publications: McShane et al. 2004, Nelson et al. 2006, Piatt et al. 2007, Plissner et al. 2015, Raphael et al. 2018, Nelson 2020. See Appendix C for a description of murrelet eggs and eggshell fragments.

Table 1-1: *Known numbers of Marbled Murrelet nests throughout their range (as of August 2022).*

State/Province Nest type	# of Nests	References
Alaska		
Tree	47	Quinlan and Hughes 1990, Naslund et al. 1995, Kuletz et al. 1995, DeGange 1996, Whitworth et al. 2000, Nelson et al. 2010, Barbaree et al. 2014; M. Brown, M. Kissling, A. Russell, D. Youkey unpub. data
Ground	50	Hoeman 1965, Simons 1980, Hirsch et al. 1981, Day et al. 1983, Johnson and Carter 1985, Ford and Brown 1995, Kuletz et al. 1995, DeGange 1996, Piatt et al. 2007, Nelson et al. 2010, Willson et al. 2010, Barbaree et al. 2014; T. DeSanto, M. Gracz, K. Hocker, J. Hughes, M. Kissling, K. Kuletz, P. Mickelson, W. Rice, G. van Vliet, unpub. data
British Columbia		
Tree	246	Jordan and Hughes 1995, Manley 1999a, Jones 2001, Bradley 2002, Burger 2002, Piatt et al. 2007, Bloxton and Raphael 2009, Ryder et al. 2012, Lorenz et al. 2019, Barbaree et al. 2014, Kaiser and Keddie 1999, Conroy et al. 2002; SFU-Center for Wildlife Ecology unpub. data
Ground	12	Bradley and Cooke 2001
Washington		
Tree	59	Wilk et al. 2016, Hamer et al. 2021, Lorenz et al. 2019; T. Hamer unpub. data
Ground	1	Wilk et al. 2016
Oregon		
Tree	115	Nelson and Wilson 2002, Hamer et al. 2021; S.K. Nelson, J. Rivers et al. unpub. data
California		
Tree	52	Binford et al. 1975, Singer et al. 1991, Kerns and Miller 1995, Singer et al. 1995, Peery et al. 2004, Baker et al. 2006, Golightly et al. 2009; K. Benson, T. Hamer, B. Lovelace, S. Chinnici, S. Singer, D. Suddjian unpub. data
TOTAL Tree	519	
TOTAL Ground	63	

Behaviors Associated with Nesting

The first well-described Marbled Murrelet tree nest was not discovered until 1974 (Binford et al. 1975, but see Carter and Sealy 2005), making the murrelet the last bird in North America to have its nest documented. Murrelets are extremely secretive in their nesting behaviors, making nests difficult to find. Both adults participate in incubation, exchanging places on the nest at dawn, in low light levels. Chicks are fed primarily at dawn and dusk (Nelson 2020), but also receive food throughout the day (Nelson and Hamer 1995a). There appears to be an initial wave of fish deliveries to chicks coincident with sunrise (when low light conditions make a predator less likely to detect them). Second feedings occur, on average, 54 minutes after sunrise (SE 9.6, n = 40 observations) and as late as 225 minutes post-sunrise (Nelson and Hamer 1995a). Later arrival times generally are associated with cloudy mornings. Murrelets are rarely detected during the day except near an active nest, but opportunities to observe nesting behavior (i.e., adults flying into a stand to deliver fish) may occur during the day, particularly during the height of chick rearing.

Because of the difficulty in finding actual nests, behaviors observed during dawn surveys are used to indicate occupancy, a sign of nesting at a particular location. Murrelets nest solitarily (a single pair to a tree or group of trees as opposed to colonially or shoulder to shoulder like many of their relatives), but they also co-occur and more than one pair of birds is usually found in a single, **Contiguous**[2] stand (e.g., Hamer and Cummins 1990, Burger 1994, Naslund et al. 1995, Manley 1999a, Nelson and Peck 1995, Nelson and Wilson 2002, Suddjian 2003, Baker et al. 2006, Bloxton and Raphael 2009). Alcids are social birds and the interaction of alcids around nesting colonies is important for social and breeding purposes (Gaston and Jones 1998, Schreiber and Burger 2002, Valente et al. 2021). Although their **Nesting Habitat** differs, social interactions near and within nest sites are likely similarly important for Marbled Murrelets (Valente et al. 2021). While one or more pairs of murrelets nest in a stand, breeding is not synchronous among pairs and re-nesting after failure sometimes occurs. Therefore, murrelets could be nesting at different times and different places in the same stand, in the same year (Nelson and Wilson 2002, Hébert et al. 2003, Baker et al. 2006, Burger et al. 2009).

The following behaviors have been documented at or near active nests and can be observed during **Audio-Visual (AV) Surveys**, providing the rationale to use them as indicators of occupancy and nesting.

Flight

Murrelet flight is direct and involves rapid, continuous wing beats. Flight speeds typically range between 73-136 km/h (45-85 mi/h) and can reach maximum speeds of 158 km/h (98 mi/h; Hamer et al. 1995, Burger 1997, Cooper and Blaha 2002). Murrelets generally fly at higher altitudes over land between nesting and foraging areas and fly lower at or near nests. Although

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murrelets often fly only a few meters above the ocean, such low-level flight is rarely seen inland except occasionally along roadways, river courses, and near nests.

Subcanopy flights

Subcanopy flights include those at, below, through, into, or out of the forest **Canopy** within or adjacent to nesting habitat. Flight below the canopy is most commonly observed during the **Breeding Season** (O'Donnell et al. 1995) and is an indication of occupancy and nesting. Adults flying to nests approach from below the forest canopy, often along a route of small gaps, creeks, and other natural corridors (Nelson and Peck 1995, Singer et al. 1995). Nesting birds can consistently use the same flight path within a season, although each bird of a pair may have a different path, and arrival paths may differ from departure paths. Thus, a bird(s) flying along the same route on successive days indicates nesting. In addition to direct flights to nests, murrelets can engage in 'fly-bys' before and after visits to the nest, where a nesting bird flies past the nest tree below the canopy at nest height. 'Fly-bys' occurred during the incubation and nestling periods (Singer et. al. 1995), but also have been observed at nests after nesting was completed. While an observer may not be aware of a nest, these subcanopy flights indicate nesting. Subcanopy flights are often non-vocal, but wingbeat and jet sounds (diving birds), which are also indicative of nesting, can sometimes be heard (see sections on *Dives* and *Non-vocal Sounds* below). Observations of subcanopy behaviors generally consist of 1 to 2 birds.

Landings

Landings can occur at or near known nests throughout the breeding season or in trees with nests that were active in a previous year (Manley 1999a,b; Nelson and Peck 1995). Murrelets also land in trees prior to egg laying and during prospecting, presumably to inspect potential nest sites (Nelson and Hamer 1995a, Nelson and Wilson 2002) and to copulate (D. Buchholz, S. McAllister pers. comm.). Landings are an indication of occupancy and may also indicate territorial behavior, resting, or roosting (Naslund 1993b). Thus, the places where birds engage in courtship or other breeding-related activities might not be in the exact area or stand as a nest, but these areas and stands are likely important for the birds' life history.

Circling flights

Circling is common over murrelet nest sites (Nelson and Peck 1995, Manley 1999a, Nelson and Wilson 2002) and those of all other alcids (Gaston and Jones 1998, Schreiber and Burger 2002). Circling is an indication of occupancy and nesting. Circles can be small (~10-20 m radius) or greater than 1 km-radius (0.62 mi) and at varying distances above the canopy (Cooper and Blaha 2002). Circling behavior can include complete circles, partial circles, and any arc, curve, or turns that result in a change of direction of 45 degrees or more from the initially observed flight path (see Chapter 2 for more details). Upon leaving a nest, such as after an incubation exchange or fish delivery, breeding birds may join with other murrelets in circling behavior over the nest site before departing for the ocean (Nelson 1997, 2020). Murrelets also have been seen circling over non-habitat, but in most cases these behaviors were near or adjacent to nesting habitat. Appendix D provides data from observations of circling behavior in Washington State.

Dives

Shallow or steep dives, which often originate above the canopy but terminate below canopy, have been observed near known nest trees and are an occupied behavior (Nelson and Peck 1995, Witt 1998b). Steep dives followed abruptly by steep ascents have also been observed at nest trees (S. McAllister, pers. comm.) and likely function to decrease velocity before landing. Dives may also function to maintain pair bonds or be used in territorial defense (Nelson 1997). These power dives, or 'jet dives' often result in a jet-like sound.

Vocalizations

Murrelet vocalizations are described in Appendix E. The most audible call, the 'Keer' call, is heard at nest sites, while flying, and at sea (Nelson 1997). Vocalizations at the nest generally are soft and not readily audible from the ground but are given frequently by both adults during incubation exchanges and by chicks during feedings. Loud calls from the nest are extremely rare. Nevertheless, loud calls were heard from seven nests in Oregon while birds attended a chick or egg, or prior to egg laying (Nelson and Peck 1995, Nelson and Wilson 2002). In the Caren Range of British Columbia (P. Jones pers. comm.) and in California (Singer et al. 1995), however, no loud calls were recorded during approaches or exits from active nests. Calls that repeatedly emanate from one location can be an indication of nesting activity. Many 'Keer' calls are from birds heading to or departing from the local area, but some are from birds in flight traveling beyond the area being surveyed. It is harder to detect birds in areas with low densities as they call less frequently (Nelson 1997).

Non-vocal sounds

Non-vocal sounds made by murrelets are sometimes heard during inland surveys and in some instances, they may be the only form of detection. These wing sounds are indicative of occupied behaviors, as they are heard when murrelets are close to the surveyor, and thus are assumed to be sub-canopy, even if no visual detection accompanies the sound (S. McAllister, W. Ritchie, M. Gostin pers. comm.). Wing sounds, or wing-whir can be detected from murrelets flying nearby, usually below the canopy, and jet sounds are associated with dives (described under *Dives* above), both of which are associated with nests and **Occupied Areas.**

Seasonality of Nesting and Inland Activity

Although nesting sites are used primarily during the breeding season, murrelets have been observed at some inland locations during all months of the year (Carter and Erickson 1992, Cross

1992, Naslund 1993a, O'Donnell et al. 1995, Brown et al. 1999). Nevertheless, surveys are most effective during the spring and summer, when activity levels are greater and attendance is more consistent and longer in duration. Murrelet activity can fluctuate greatly at a given location throughout the breeding season (Manley et al. 1992, Rodway et al. 1993, Kuletz et al. 1995, Jodice and Collopy 2000), but generally increases to moderate intensity during spring and reaches a peak level from early to late July in California, Oregon, Washington, British Columbia, and Alaska (Rodway et al. 1993, Burger et al. 1994, O'Donnell et al. 1995, Dechesne 1998, Brown et al. 1999). The increase in activity in July might be associated with nesting birds, but also could be attributed to non-breeding birds prospecting for future nest sites (O'Donnell et al. 1995, Nelson and Peck 1995, Jodice and Collopy 2000, Whitworth et al. 2000). After this peak period, the number of detections decreases markedly, presumably because many birds have completed their nesting activities and have begun a flightless molt at sea.

The breeding season (not the survey season) is defined by the earliest known nesting and latest known fledging dates and is utilized by regulatory agencies to avoid adverse effects to the species. The breeding season extends from 24 March to 15 September in California; 1 April to 15 September in Oregon; 1 April to 23 September in Washington; and 15 April to 15 September in British Columbia (Burger 2004, Hamer and Nelson 1995b, Nelson 2020, USFWS 2012a, USFWS 2020). The **Survey Period** (see Chapter 2: *When to Survey*) is the time period surveyors are most likely to detect behaviors indicating nesting activity but does not include the entire breeding season. Therefore, there is a potential for opportunities to determine occupancy before or after the survey period. For example, 13 of 26 (50%) nests in California were active after, and four (15%) before the survey season (Hamer and Nelson 1995b). Of 68 active nests documented in Oregon to date, 12 (18%) were active after, and one before the survey season (Nelson and Peck 1995, S.K. Nelson unpubl. data, J. Rivers et al. unpubl. data).

Murrelet visitation to nesting areas during the non-breeding season is likely important in forming or maintaining pair bonds, retention of nest sites, and for selecting future nest sites (Naslund 1993a, Nelson 1997). At two locations in northern California, calling frequency (mean number of calls per detection) was greater during winter than spring and summer, although the duration of detections was shorter (O'Donnell et al. 1995). However, birds are also more likely to be absent during winter, leading to incorrect determinations if winter surveys are conducted (Brown et al. 1999).

Nesting Habitat

Murrelets have been found nesting primarily in old-growth and mature forests, and less frequently in young (≥50 years), naturally regenerated and planted forests that include trees with structures, dwarf mistletoe (*Arceuthobium* spp.) or other deformations that provide a **Nest Platform (Platform)** (e.g., Hamer and Nelson 1995a, Nelson and Wilson 2002, McShane et al. 2004, Baker et al. 2006, Hèbert and Golightly 2006, Wilk et al. 2016). A nest platform is a relatively flat surface on a limb or deformity that is ≥10 cm (4 inches) in diameter and ≥10 m (33 ft) above the ground in the live crown of a coniferous tree (Nelson and Wilson 2002, Hébert and Golightly 2006, Bloxton and Raphael 2009, Wilk et al. 2016), although murrelets are also known to occasionally use deciduous trees with platforms for nesting (n=4 nests; Bradley and Cooke 2001, Ryder et al. 2012, Rivers et al. unpubl. data). Platforms can be created by a wide branch covered with moss, lichen, or other substrate, or a dwarf mistletoe infection that creates wide branches, witches' brooms or other deformities (Hamer and Nelson 1995a, Nelson and Wilson 2002, Baker et al. 2006, Nelson 2020). Platforms can also be on broken top trees, animal-built structures, such as squirrel nests (e.g., Nelson and Wilson 2002), and other relatively flat surfaces that can support an egg and chick. Assessing the size and amount of substrate on top of the limb is usually not possible from the ground, so limb size assessments are made by looking at the bottom of the platform. Trees of any age that provide branches with structures appropriate for nesting are considered **Platform Trees**. For a platform tree to function as a nest tree, its platform(s) needs cover which is provided by the tree itself or by the surrounding forest.

Nests have been found in Douglas-fir (*Pseudotsuga menziesii*), coast redwood (*Sequoia sempervirens*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), yellow cedar (*Callitropsis nootkatensis*), mountain hemlock (*Tsuga mertensiana*), and Sitka spruce (*Picea sitchensis*) trees (Hamer and Nelson 1995a, McShane et al. 2004, Piatt et al. 2007). Given the breadth of coniferous tree types used by murrelets, habitat should not be limited based on certain coniferous tree species (i.e., there could be other conifer species used that are not listed here). While a majority of known nests have been in coniferous trees, so far two nests occurred in deciduous trees in coniferous forests in British Columbia (red alder [*Alnus rubra*] and big-leaf maple [*Acer macrophyllum*] [Bradley and Cooke 2001, Ryder et al. 2012]), and two nests occurred in big-leaf maple trees in Oregon (Rivers et al. unpubl. data). South of Canada, one nest was found on a cliff in a coniferous forest in the Olympic Mountains of Washington (Wilk et al. 2016). Many other cliff nests have been found in British Columbia and Alaska, where murrelets nest both in trees and on the ground in mountainous or elevated locations (e.g., Barbaree et al. 2014).

Both field studies and habitat modeling efforts have documented the presence of platforms with or without moss as a key stand characteristic for predicting murrelet occurrence (Hamer et al. 1994, Burger 2002, Waterhouse et al. 2009, Raphael et al. 2011, Hamer et al. 2021). Platform presence is a more commonly cited predictor of murrelet occurrence than tree size and stand age (Hamer 1995, Burger et al. 2010, Falxa and Raphael 2016, but see Nelson and Wilson 2002), although tree size can be an indicator of platform abundance in some areas (Hamer 1995, Burger et al. 2010, Raphael et al. 2011). While platform tree abundance appears to be a good predictor of murrelet occupancy, murrelets are known to nest in stands with low densities of platform trees and individual platform trees within patches of younger trees (e.g., Ralph et al. 1995, Nelson and Wilson 2002, USFWS Arcata Field Office files, and Appendix F of this document). As murrelets have been documented in stands with low platform tree densities, individual trees or legacy trees with such platforms are considered murrelet nesting habitat. In addition to nest platform structures, murrelet habitat includes the surrounding **Forest Stand** that balances environmental protection of the nest site (e.g., sufficient cover from predators and protection from microclimate changes and windthrow) while providing small natural openings that provide access to platforms (Raphael et al. 2002, Ripple et al. 2003, Hébert and Golightly 2006, Peery and Henry 2010, Falxa and Raphael 2016). Therefore, platform and non-platform trees in the forest stand or area surrounding any potential nest trees are important to murrelets and are part of murrelet habitat.

Larger, contiguous blocks of habitat provide higher quality nesting habitat for murrelets and are critical for nesting success and survival of the species (USFWS 1997). Larger blocks of habitat allow co-occurrence of multiple pairs and provide multiple options for nest tree selection within and between years, while supporting site fidelity at the stand level (see below). Murrelets may use multiple trees in a stand throughout their adult life and not nest in the same tree every year. Larger blocks not only increase the amount of available interior forest habitat (e.g., more cover), but also help reduce predation and prevent microclimate impacts such as increased temperatures and changes in moss abundance (e.g., Van Rooyen et al. 2011, Frey et al. 2016, Betts et al. 2017; see more details below). The importance of social information and conspecific attraction in nest site selection also indicate that large tracts of nesting habitat are key to supporting murrelet populations (Valente et al. 2021). See *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/) for recommendations on how to manage nesting habitat and delineate occupied areas.

While occupied areas include nest sites, they may also include habitat essential to murrelet reproduction (Nelson 1997, 2020). For example, in British Columbia, Oregon, and California, murrelets have been observed landing on branches not suitable for nesting or in non-habitat stands that are contiguous with or near nesting habitat (J. Deal, S.E. McAllister, S.K. Nelson, S.W. Singer, pers. comm.). These landings involved more than one murrelet, and birds remained standing in these young or otherwise unsuitable trees for a marked period of time. Such landings may occur outside the nesting season. Thus, places such as these, where birds engage in courtship or other breeding-related activities, or in activities that otherwise serve to maintain a bird or birds' connection to the nest stand or area, are important to the species' life history and may contribute to the nest success of the species.

Based on the information described above, murrelet habitat is defined as coniferous forest stands within the inland limits described in Table 1-2, with one or more platform trees, where the surrounding forest canopy (surrounding trees or within the platform tree itself) provides some cover and functional protection.

Nesting habitat (hereafter called habitat), therefore, has the following components, at a minimum:

- coniferous stand;
- one or more nesting platforms in one or more trees; and
- forest canopy (surrounding trees or within the platform tree itself) that provides cover and functional protection for nest platforms.

Additional information on habitat is provided in Appendix F. This appendix summarizes the available published and unpublished data on the density of platform trees surrounding known murrelet nest trees and in known occupied sites (which is not available at most nests or sites). Almost all of these data are from old-growth or older-aged forests on public lands; data from younger forests and private lands (only one study) for this summary were limited. The available data show that:

- Density of platform trees is a robust measure of the probability of occupancy as studies demonstrate that the probability of occupancy or nesting increases as density of platform trees increases (Appendix F, Figures F-3 and F-7). Thus, stands with high platform densities are more likely to be used by murrelets, but stands with lower platform densities are also used;
- Mean platform density and platform tree density in forests surrounding murrelet nests varies by land ownership and region, with higher densities observed on Federal lands and much lower densities on private industrial lands. Different forest management approaches likely contribute to this pattern, with Federal lands tending to include more and larger patches of mature, and un-harvested lands (Lorenz et al. 2021); and
- On Federal lands, most (95% or more) occupied sites or areas in older-aged forests have a platform tree density of two or more trees per acre (Appendix F, Figures F-8 and F-9); this platform tree density is likely to be lower on lands with younger or more intensively managed forests, such as private timberlands.

Nest Predation

Predation is a major factor contributing to poor murrelet reproductive success. Predation, in turn, is significantly affected by forest fragmentation (at stand and landscape scales) and proximity to human activity (Raphael et al. 2002, McShane et al 2004). An increase in corvids (jays and ravens) may lead to an increased risk of predation on murrelet eggs and young and/or aborted or delayed food deliveries to young. Human presence during murrelet nesting can also increase the presence of avian predators. Campgrounds, in particular, are known to have significant impacts on murrelets (Raphael et al. 2002, Peery et al. 2004, West et al. 2019) and through documented increases in predator numbers (Rosenberg et al. 2004, Goldenberg et al. 2016). Rates of nest success have varied throughout the murrelet's range (0.16 to 0.46) but are generally low compared to other alcids and in most cases well below levels needed to maintain the population (e.g., Beissinger and Nur 1997, Cam et al. 2003, McShane et al. 2004, Peery et al. 2004, 2006, Beissinger and Peery 2007, Rivers et al. unpubl. data). Known predators at active murrelet nests are listed in Appendix G.

Murrelets are vulnerable to increased nest predation associated with forest edges. The effects, however, vary somewhat with distance to edge, type of edge, structure of the adjacent forest, and proximity to human activity (e.g., Manley and Nelson 1999, Nelson and Hamer 1995b, Raphael et al. 2002). In general, successful nests were significantly farther from forest edges (>50 m [164 ft]) than failed nests (Nelson and Hamer 1995b, Manley and Nelson 1999, but see Zharikov et al.

2006, Burger and Page 2007), but in some studies the effect was seen only in close proximity to human activity (e.g., Raphael et al. 2002). Large stands without hard edges (e.g., a clearcut boundary) are thought to have higher murrelet nesting success (USFWS 1997, Marzluff et al. 2004, McShane et al. 2004). Simple-structured stands adjacent to nesting stands or areas (e.g., buffers) may decrease predation at murrelet nests (Raphael et al. 2002, Ripple et al. 2003). Malt and Lank (2007, 2009) found that predation rates at simulated murrelet nests in British Columbia were highest adjacent to harvest openings and lowest in interior forest and adjacent to regenerating stands and natural edges, suggesting that predation rates may decline over time at forest edges as adjacent harvested areas regenerate.

Site Fidelity

Murrelets have strong fidelity to stands previously used for nesting (e.g., Bradley 2002, Barbaree et al. 2014) and may also exhibit philopatry, like other alcids, where breeders return to sites where they hatched (e.g., Gaston and Jones 1998, Frederiksen and Petersen 1999, Nelson 2020). Surveys have demonstrated that nesting stands are used year after year, with many stands supporting 35+ years of murrelet use (Divoky and Horton 1995, McShane et al. 2004, Nelson 2020). Stands first found to be occupied in the late 1980s in Washington, Oregon, California, and British Columbia are still occupied today (unless they were modified by humans or fire; Hamer, McAllister, Nelson, unpubl. data). Social information (vocalizations of other murrelets) appears to influence murrelet breeding site selection and likely contributes to long-term stand occupancy (Valente et al. 2021). Because of this high fidelity, an occupied stand is considered occupied in perpetuity.

Interannual Variation in Breeding and Nesting Location

Individual murrelets may not nest every year (Manley 1999b, Nelson 2020). Condition, food availability, and habitat changes, including changing ocean conditions, may impact the within-year timing and between-year frequency of nesting. For this reason, some areas may not be used for nesting every year (Betts et al. 2020). These areas are still considered occupied as pairs will return to their nesting stands (high site fidelity) when the birds' health and foraging conditions are good, including frequent visits to nest stands outside of the nesting season, which may be important for maintaining territories or pair bonds (Naslund 1993a).

While forest patches, nest trees, and nest cups have been reused in subsequent or successive years (Singer et al. 1995, Nelson 1997, Manley 1999b, Hébert et al. 2003, Hébert and Golightly 2006, Burger et al. 2009, Golightly and Schneider 2011, Barbaree et al. 2014), pairs of murrelets often use more than one nest tree and use different parts of the same stand for nesting among years (Nelson 1997, Bradley 2002, Nelson et al. 2010). Most nest trees are not used in successive years, suggesting that breeding birds move elsewhere within a stand (likely to avoid predation) or may not nest every year (Bradley 2002, Nelson and Wilson 2002, Burger et al. 2009). Breeding in locations within 1-70 m (3-230 ft) of each other in successive years is known from marked birds (e.g., Bradley 2002, Barbaree 2011) and audio-visual surveys (e.g., Singer et al.

1991). Additionally, murrelets have been observed landing (before and during the breeding season) in previously used nest trees in a year when it was not used for nesting (Nelson and Peck 1995, Singer et al. 1995, Hamer and Meekins 1999, Manley 1999b). Therefore, once a stand is determined to be occupied, it should always be considered occupied (see more details on this in Chapter 2). Eliminating any part of a nesting stand may affect between year use of nest trees and impact co-occurrence and important social interactions that are key to murrelet nesting behavior; this is particularly true where nesting habitat is arranged in small fragments.

Betts et al. (2020) provided evidence that ocean conditions influence occupancy dynamics, and murrelets can be missing from their nest sites in the year following poor ocean conditions (low availability of prey species, generally associated with higher ocean temperatures, limited upwelling and changes in wind conditions); they also found some limited evidence of this occurring in the year of poor ocean conditions. Murrelets are less likely to nest successfully without an abundant supply of forage fish in the nearshore (Betts et al. 2020). This reported relationship of occupancy with ocean conditions suggests that surveys concluding a lack of occupancy, that were conducted during a period spanning two or more poor ocean years, may need to be re-evaluated. In this situation, additional year(s) of surveys during favorable ocean conditions would help ensure survey result accuracy. The updated statistical analysis captures some of the fluctuations in survey results over the last twenty years of surveys (up to 2016; Appendices A and B) and are thus factored into this protocol; however, the extremely poor ocean years of 2017-2020 were not included. As the frequency and duration of poor ocean year increases with climate change (e.g., Collins et al. 2013), the accuracy of the statistical analysis associated with this protocol will decline. It will be important to update the statistical analysis over time to factor in changes in breeding propensity and occupied site attendance, and for land managers to stay informed about ocean conditions and decide whether to conduct surveys in years when poor ocean conditions are known in advance of the survey season.

Known Inland Extent of Occurrence

The data in Table 1-2 document the extent of the inland range of murrelets as currently known. They are not intended as strict limits by state, but show the currently known extent of detections, occupied areas, and nests. It is important to note that nest searches have been conducted in fewer areas than audio-visual surveys, so the farthest inland detection should be used as the guideline for planning surveys.

Some regions within states might not support murrelet activity as far inland as the maximum distances for the state suggest. A study on the Rogue River Siskiyou National Forest and Medford District BLM demonstrated that murrelet occurrence in the Siskiyou Mountains in Oregon was associated with the extent of the hemlock/tanoak vegetation zone, which occurs up to 51 km (32 mi) inland (Dillingham et al.1995, Alegria et al. 2002).

Table 1-2: *Farthest known inland Marbled Murrelet nest sites, occupied detections, and presence detections, as of August 2022.*

	Farthest Inland from Marine Water (km*)					
State/Province/Region	**Nest Site**	**Source**	**Occupied Detection**	**Source**	**Presence Detection**	**Source**
Alaska	52	1,2				
British Columbia	52[a]	2,3				
Washington	71	4	84	4	112[b]	b
Oregon						
Coast Range	51	5	76	6		7
Cascade Range					129	7
Siskiyou Mountains					51	8,9
California						
North Coast [c]	39	10	39	10	39	10
Santa Cruz Mountains	16	11			18	12

*Rounded to the nearest km.

Sources: 1-Whitworth et al. 2000; 2-Nelson et al. 2010; 3-Lougheed 1999; 4-Washington Department of Fish and Wildlife Marbled Murrelet database; 5-Witt 1998a; 6-Oregon Bureau of Land Management GeoBOB database; 7-only inland detection from Cascades in OR. No other detections found despite follow-up surveys; S.K. Nelson, pers. comm.; 8-Dillingham et al. 1995; 9-Alegria et al. 2002; 10-A. Transou, pers. comm.; 11-U.S. Fish and Wildlife Service, Arcata Field Office; 12-D. Suddjian,, eBird.org.

a A grounded fledgling with an egg tooth was reported 101 km inland by T.L. Thacker (field notes) at Hope, BC on 12 July 1947 ((Rodway et al. 1992). It is unknown if this was an actual nest site or if the fledgling flew further inland from its nest.

b Audio detection of ~112 km from marine water in Cispus River drainage (D. Lynch, W. Ritchie pers. comm.)

c Includes Mendocino, Humboldt, and Del Norte counties but farthest distances all in Humboldt.

Marine Habitat

Birds occur offshore from Straits of Juan de Fuca south to central California) and also occur in small numbers off southern California and northern Mexico in the winter. Murrelets are usually found within 8 km (5 mi) from shore, and in water less than 60 m (197 ft) deep (Ainley et al. 1995, Burger 1995, Strachan et al. 1995, Nelson 1997, Day and Nigro 2000). In general, birds occur closer to shore in exposed coastal areas and farther offshore in protected coastal areas (Nelson 1997). Courtship, foraging, loafing, molting, and preening occur in marine waters.

Within the area of use, murrelets usually concentrate feedings in shallow, near-shore water less than 30 m (98 ft) deep (Huff et al. 2006) but are thought to be able to dive up to depths of 47 m (157 ft); (Mathews and Burger 1998). Although little information is available outside of the nesting season, information on winter distribution suggests murrelets disperse and move farther offshore in some areas (Strachan et al. 1995).

Throughout their range, murrelets are opportunistic feeders and utilize prey of diverse sizes and species. They feed primarily on fish and invertebrates in marine waters although they have also been detected on rivers and inland lakes (Carter and Sealy 1986, USFWS 1992). In general, small schooling fish and large pelagic crustaceans are the main prey items. Pacific sand lance (*Ammodytes hexapterus*), northern anchovy (*Engraulis mordax*), immature Pacific herring (*Clupea harengus*), capelin (*Mallotus villosus*), Pacific sardine (*Sardinops sagax*), juvenile rockfishes (*Sebastes spp*.), and surf smelt (*Osmeridae*) are the most common fish species taken (Fountain et al. 2023).

Squid (*Loligo spp.*), euphausiids, mysid shrimp, and large pelagic amphipods are the main invertebrate prey. Murrelets are able to shift their diet throughout the year and over years in response to prey availability (Becker et al. 2007). However, long-term adjustment to less energetically-rich prey resources (such as invertebrates), due to declines of higher quality prey, appears to be partly responsible for poor murrelet reproduction (Becker and Beissinger 2006, Norris et al. 2007).

Marbled Murrelet Conservation

Species Status

Marbled Murrelets are listed as both threatened (Federally) and endangered (State level and International Union for the Conservation of Nature 2020; https://www.iucnredlist.org/) in Washington, Oregon, and California. In Canada, the murrelet is listed as threatened under the Species At Risk Act (SARA 2002). In the range of the Northwest Forest Plan (USDA and USDI 1994) murrelet at-sea counts show no evidence of a trend range wide, but have continued to decline in the northern portions of the range, while trends in the southern portion appear to be increasing (McIver et al. 2022). Murrelet numbers are monitored every other year by **Conservation Zone** in Washington, Oregon, and California (e.g., McIver et al. 2022). Because reports are released every year, trends will not be static. New information from the Oregon Marbled Murrelet Project indicates many murrelets move between zones during the breeding season in both poor and good ocean years (J. Rivers et al. unpubl. data). These movements could affect at-sea counts and trend estimates. The most recent trend data can be accessed at: https://www.fs.usda.gov/r6/reo/monitoring/marbled-murrelet.php

The Marbled Murrelet Recovery Plan (USFWS 1997) and the USFWS listing decision (USFWS 1992) includes the following objectives for the species' recovery: (1) stabilizing and then recovering the population by maintaining and/or increasing productivity and removing and/or minimizing threats to survivorship, and by maintaining and/or increasing nesting success by maintaining and/or increasing marine and terrestrial habitat; (2) providing habitat conditions in the future that will allow the continued existence of viable populations; and (3) gathering data for developing scientific delisting criteria. The Recovery Plan identifies population stabilization and increases in habitat quality and quantity as the key methods for stopping population decline. Recent information indicates habitat in Washington, Oregon, and California continues to be lost, mainly to windthrow and fire on Federal lands and to harvest on non-Federal lands (USFWS 2019, Lorenz et al. 2021, Valente et al. 2023).

Habitat Status and Effects of Habitat Modification

Nesting habitat has declined throughout the murrelet's range by more than 70% from past logging and fragmentation (Strittholt et al. 2006, USFWS 1997, Falxa and Raphael 2016, Raphael et al. 2016, Valente et al. 2023); murrelet populations are thought to have declined by similar amounts from historic numbers (57 FR 45328). The Federal and State listing status of the species in the tri-state range, coupled with continued habitat loss (Lorenz et al. 2021, Valente et al. 2023), emphasize that the long-term retention of suitable and occupied habitat is a top priority.

In addition to declines because of habitat loss, murrelets are continuing to experience poor nest success due primarily to nest predation, which in turn is significantly affected by forest fragmentation and proximity to human development (Raphael et al. 2002, McShane et al 2004, Marzluff and Neatherlin 2006, West et al. 2019). Low fecundity levels as measured by nest success indicate a population that cannot currently sustain itself (e.g., Beissinger and Nur 1997, Cam et al. 2003, McShane et al. 2004, Peery et al. 2004, 2006, Beissinger and Peery 2007).

The continued loss of murrelet habitat threatens their survival by: (1) reducing the amount of habitat; (2) fragmenting occupied habitat and subjecting it to harmful edge effects, especially predation, that reduce nest success rate; and (3) reducing the availability of quality habitat, forcing murrelets to nest in lower-quality habitat, which diminishes nest success (USFWS 1997, 2012a).

For purposes of murrelet conservation, it is important to improve the distribution of large blocks of contiguous older forest throughout its listed range (e.g., northern Oregon Coast, southwest Washington; see complete list in USFWS 1997). This will allow for an improved population distribution within each Conservation Zone and help mitigate the effects of current and future climate change impacts, including fire, drought, windthrow, and forest diseases and/or insect infestations. See the *Climate Change* section below for additional information.

Details on protecting occupied areas and contributing to murrelet conservation can be found in *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/).

Effects of Disturbance

Human activities occurring near occupied areas have the potential to disturb murrelets while they are on the nest or as they approach or depart the nest stand. Recorded reactions are varied and generally more severe in adults than chicks, and in adults in remote locations versus adults in recreation areas with more human activity (e.g., Hamer and Nelson 1998, Long and Ralph 1998, Hebert and Golightly 2006). Human activity (e.g., day use, camping) can also attract corvids. An increase in corvids may lead to an increased risk of predation on murrelet eggs and young and/or aborted or delayed food deliveries to young (see *Predation Risk* section above). Additionally, trail use near murrelet habitat can impact nesting success of other avian species (Miller et al.

1998, Swarthout and Steidl 2001) and may impact the survival or nesting success of adult murrelets or survival of chicks by attracting predators, causing an incubating murrelet or chick to flush from the nest, or causing increased energy expenditures. Activities such as blasting, pile driving, and the use of large helicopters (e.g., Chinook 47d or larger) may also result in negative impacts to chicks and adults, including hearing impairment (USFWS 2012b, 2020). Activities that cause delayed or aborted nest establishment and/or feedings, or cause a murrelet to flush from its nest or nest site are considered harmful to murrelets and their young, as they have the potential to result in reduced hatching success, fitness, or survival of chicks or adults (USFWS 2012b). See *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/) for more details on disturbance.

Projected Impacts from Climate Change - Forests

The climate in the coastal areas of the Pacific Northwest where murrelets nest has been changing and is projected to continue to change through the 21st century (e.g., Littell et al. 2014). In general, where climate models are informative, projections for the forested habitats that murrelets occupy are largely unfavorable. Climate change is predicted to alter the terrestrial environment within the range of the murrelet by changing precipitation (the amount, type, and timing), temperatures (time of year/day and location), extending the fire season and increasing fire severity, increasing the prevalence of disease and insect infestations/outbreaks, and changing forest composition, including microclimate changes affecting epiphyte cover (van Rooyen et al. 2011, Littell et al. 2013).

Forest responses to climate change will depend on local conditions. While the marine climate associated with the forested areas of the Pacific Northwest generally leaves forests less exposed to drought/dry conditions, changing climatic variables have already been impacting the forests in this area. Tree mortality rates in undisturbed old growth forests (≥ 200 years old) tripled between the early 1970s and 2000 and affected trees of all sizes (van Mantgem et al. 2009). In the future, low elevation forests will experience more severe and/or longer duration water limitations resulting in decreased seedling regeneration and tree growth because the timing of the majority of precipitation is outside of the growing season (Littell et al. 2013). In coastal redwood forests, documented decreases in fog frequency over the past century have led to drier summer conditions, increased drought stress, and slower tree growth (Johnstone and Dawson 2010).

Historically, the fire frequency in the Oregon Coast Range and Olympic Mountains was 100-350 years (e.g., Ripple 1994, Long and Whitlock 2002), although low severity fires may have occurred at greater frequency in coastal Oregon (A. Merschel, pers. comm.). Future climate models indicate increases in fire size and severity over much of the Pacific Northwest (e.g., Halofsky et al. 2020); however, changes in the Coast Range may increase in severity, but not necessarily in size (Dalton and Fleishman 2021). Additionally, the moist Douglas-fir/Western hemlock forests of the Coast Range, particularly northern Coast Range, may provide some forest refugia into the future (Naficy et al. 2021). However, all portions of the murrelet's nesting range are at risk for increased fire frequency (both large and small) into the future (Littell et al. 2010, Sheehan et al. 2015, Halofsky et al. 2020, Turco et al. 2023). Although it is uncertain to what degree climate change will influence high-intensity, stand replacing fires within the range of the murrelet, warmer, drier summers are likely to produce more frequent and extensive fires, thus reducing the extent and connectivity of late-seral/old-growth forests potentially resulting in severe consequences for the murrelet (McKenzie et al. 2004, Littell et al. 2013, Williams et al. 2019, Halofsky et al. 2020, Turco et al. 2023).

Higher average temperatures, particularly warmer winters, and increased spring precipitation have contributed to an increase in the severity and distribution of Swiss needle cast in Douglas-fir (Stone et al. 2008, Sturrock et al. 2011, Zhao et al. 2011, Lee et al. 2013, Ritóková et al. 2016). Climatic variables within the range of the murrelet are currently suitable for outbreaks of bark beetles (Littell et al. 2010) and higher temperatures as the 21st century progresses will increase the potential for outbreaks (Bentz et al. 2010, Halofsky et al. 2011).

While wildfire, drought, and insect outbreaks are the primary agents for shifts in forest vegetation, the future climate is projected to also become less favorable for current forest composition. Within the western Northwest subregion, vegetation is predicted to change from predominantly conifer to mixed forests during the 21st century (Halofsky et al. 2011, Sheehan et al 2015). Changes will also occur in the epiphyte communities that are critical for substrate at nest sites. As temperatures rise, the distribution and abundance of vascular (e.g., *Polypodium* ferns) and non-vascular (e.g., mosses, liverworts, lichens) epiphyte communities on platform trees will likely change, affecting the suitability of platforms for murrelet nesting (e.g., Van Rooyen et al. 2011).

Though considerable uncertainty exists with respect to any regional-scale impacts of climate change due to the differences in trajectories of climate change scenarios, modeling results underscore the potentially large impacts on the PNW and California ecosystems. If climate projections are reasonably accurate, murrelets may not be able to evolve quickly enough to keep up with habitat changes (Quintero and Wiens 2013). Older-aged contiguous forests, with their multi-layered canopies, are known to buffer climate change by maintaining cooler summer temperatures (>2.5̊C) compared to plantations and younger forests (Frey et al. 2016, Betts et al. 2017). Providing larger blocks of contiguous older forest habitat, well distributed throughout the range of the murrelet, will likely help buffer interior portions of stands from some of these significant impacts. Creating buffers to existing murrelet habitat will also be important for minimizing wildfire risk. Working now to improve current and future older forest availability, distribution, and abundance will help mitigate current and future impacts of climate change and improve the likelihood of conservation of the murrelet. See additional details on climate change in *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/)

Projected Impacts from Climate Change - Marine Habitat

Climate change is also predicted to alter ocean temperatures and prey availability within the range of the murrelet. The Northern California Current, which occurs nearshore and extends from southern British Columbia to southern California, has experienced significant changes in the past several decades related to shifts in large-scale oceanographic processes such as temperatures, upwelling, winds, and currents. For example, between 2013 and 2016, the Northern California Current experienced an extensive warming event when a reduction of storms in the Gulf of Alaska created the blob, where warm surface water shifted south and prevented sustained upwelling (Bond et al. 2015). This was followed by one of the warmest El Niño events on record (Jacox et al. 2016) and then followed by another blob and warm water event in 2018-2019 (Harvey et al. 2020). This extended warming period had extensive impacts on the distribution and abundance of forage fish populations (Fisher et al. 2015), which likely affected murrelet productivity. These events caused mortality and reduced breeding in other seabird species, such as Common Murres (*Uria aalge*) (e.g., Jones et al. 2018, Piatt et al. 2020).

These types of anomalous marine events are expected to increase in frequency and duration in the future as climate change advances (Laufkötter et al. 2020, Oliver et al. 2018). The impacts to murrelet could be significant. In fact, current evidence shows that during poor ocean years murrelets often forgo nesting and many do not fly inland (Betts et al. 2020), likely related to lack of available prey in nearshore waters. Climate driven long-term changes in the abundance, diversity, and productivity of zooplankton and fish in our oceans will significantly impact marine food webs (Heneghan et al. 2023) and, in turn, seabird productivity and survival (e.g., Arimitsu et al. 2021). Managing climate change effects in marine waters will be more difficult than on land. However, minimizing greenhouse gasses and associated temperature increases, protecting and restoring marine and coastal ecosystems, and implementing adaptive measures, such as fish catch limits, may be some of the ways to mitigate changes in nearshore marine systems.

CHAPTER 2: DESIGNING SURVEYS AND CLASSIFYING SURVEY AREAS

Inland surveys for Marbled Murrelets (hereafter murrelets) are recommended prior to any proposed timber harvest or other management activities in forests within the U.S-listed range (Washington, Oregon, and California) that may affect this species. **Audio-Visual Surveys**[3] (AV surveys) such as described here are a valid method for determining murrelet use or occupancy. They can also be useful for monitoring murrelet activity levels, locating nests, and establishing murrelet stand use patterns.

The following AV survey protocol is designed for forest surveys in Washington, Oregon, and California. The protocol is a two-year design, requiring surveys to be conducted over two consecutive years. For use in Alaska and British Columbia, this protocol may require some modifications and the statistical analyses may need revision by including survey data from Alaska and British Columbia. Information available for Alaska and British Columbia that could be used to modify this protocol is included in Appendix H. Additionally, if the goal is to locate nests or determine the birds' spatial or temporal use patterns, more intensive surveys or other methods such as radio-telemetry may be needed.

Overview

The methods outlined in this protocol are designed to determine, over a two-year period, whether or not a **Survey Area**[4] is occupied by murrelets. Prior to the start of surveys, the survey area is determined by identifying the extent of habitat within 402 m (0.25 mile) of the **Project Footprint**. Once that area is defined, a random sample of **Survey Stations** is drawn from the potential survey station locations within that survey area. The number of stations to be sampled depends on the size of the survey area, and the selected **Survey Approach** (see *Survey Stations and Placement* below for details). Surveys are conducted over two consecutive years. By the end of year two, the survey results will be used to determine if the survey area is **Occupied** or **Not Occupied**. All unsurveyed habitat is assumed occupied until surveyed.

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[3] Terms used in this document appear in bold caps at first mention in each chapter and are defined in the *Glossary*. These terms appear in normal fonts in all subsequent uses.

[4] Note that while the survey area is the fundamental unit at which surveys are conducted and occupancy classification is determined, larger survey areas are broken into two or three strata to help distribute sampling effort more evenly. See *Defining Survey Area(s) and Strata* below for details.

Chapter 1 defines murrelet **Nesting Habitat** as a **Forest Stand** with at least one **Platform Tree**; hereafter in this chapter, for simplicity, habitat will refer to forest meeting this definition. This definition could be expanded to include areas with one or more platform trees and the **Contiguous** forest areas contributing to the microclimate, windthrow, and predation protection of the platform trees. In this protocol, AV surveys will usually be best implemented when focused on the portions of habitat in and near where murrelets nest (i.e., platform trees), and thus where behaviors indicative of nesting are more likely to occur and be observed.

This protocol defines the survey area(s) as those areas where surveys are conducted and occupancy status is determined. The need for surveys should be evaluated at the scale of the project footprint plus all habitat contiguous with the project footprint and within 402 m (0.25 mile) of the project footprint.[5] Within this area, the survey area will include the entirety of contiguous habitat. To meet the objective of identifying stands actively used for murrelet nesting, the survey design focuses on potential **Nest Platforms (Platforms)** within the survey area(s) and may exclude habitat features of ecological, conservation, and management importance for murrelets. For example, the survey area(s) might not include adjacent forest that is similar in structure or composition but lacks nest platforms. Those adjacent forest areas may provide important functions to nesting murrelets, such as providing buffers to the trees with platforms and connectivity with other nearby forest habitat with platform trees. See *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/) for guidance on managing occupied habitat and adjacent forest areas, and additional guidance on delineating occupied habitat.

Determining Whether to Conduct AV Surveys

In brief, if a proposed activity is within or contiguous with areas that would qualify as a survey area (as defined for this project), AV surveys should be conducted and completed prior to the initiation of the activity. A thorough **Survey Area Assessment** is necessary to determine if there are platform trees in the project footprint or within 402 m (0.25 mile) of the footprint. If the assessment concludes that no platform trees are present, then surveys are not necessary. If one or more platform trees are present, surveys are generally required (see *Habitat Characteristics*, below). Further steps, as outlined below, will determine if AV surveys should be conducted, and what areas to include in a survey. Alternatively, a manager could choose to classify and manage all forested stands that meet the habitat definition, as occupied, in which case surveys are not needed.

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[5] The focus on contiguous habitat within 402 m (0.25 mile) of a proposed project was selected as a result of discussions between the Marbled Murrelet Technical Committee and the U.S. Fish and Wildlife Service, to meet the ecological requirements of murrelets (see Chapter 1: *Nesting Habitat* for more on the importance of large, contiguous blocks of habitat).

Synopsis of Protocol Steps

Habitat assessments and AV surveys must be planned and conducted by people with the appropriate training, described in Appendix J. Once it has been determined that AV surveys are required, follow these steps to plan and conduct surveys.

1. Map all habitat (contiguous and not contiguous), within the project footprint and within 402 m (0.25 mile) of the project footprint. Alternative criteria to define habitat to map can be used in some situations but only in consultation with the regulatory agency. Chapter 1 describes habitat and Appendix F summarizes the available data on habitat characteristics. See also guidance in *Habitat Characteristics* below.

2. Within the areas mapped in Step 1, identify and map all habitat within or contiguous with the project footprint, using guidance in *Identifying Habitat Contiguity* below. This will form the survey area(s) for the project.

3. Compute total acres of habitat from Step 2. Use Table 2-1 to determine the number of survey areas and **Survey Strata** that will be required for your project. Note that if a project contains more than one survey area, the following steps apply to **each** survey area. See *Defining Survey Area(s) and Strata*, below.

4. Select either **Occupied Only Approach** or **Presence Approach**. This must be decided before surveys are conducted. See *Selecting an Approach and Determining the Required Number of Visits* below.

5. Choose potential survey station locations. Within the survey area(s), identify locations of potential survey stations, using a method that provides an even spacing between potential survey stations of 200 m (656 ft). This might be achieved, for example, by overlaying the survey area with a dot grid of points spaced 200 m (656 ft) apart, or by applying an appropriately sized hexagon grid over your survey area(s) on a GIS map, where each point on the dot grid or each center point of a hexagon represents a **potential** survey station. See *Survey Stations and Their Placement* below.

6. Determine the number of survey visits required using Table 2-2 and select which potential survey stations to survey (see *Survey Stations and their Placement* below for details).

    a. If for any stratum the number of visits required in each year is greater than the number of potential survey stations in the stratum, make survey visits to all the identified potential survey stations once, with repeat surveys at selected stations as needed to achieve the required number of visits for a stratum.

    b. If the number of visits will be less than the number of potential survey stations within a survey stratum, randomly select which stations to survey.

c. Conduct on-the-ground reconnaissance to determine the best location for survey station placement.

7. Plan surveys according to timing guidelines in Tables 2-3 or 2-4 (see *Timing of Surveys* below.

8. Conduct the required surveys for each of two consecutive years, following the survey protocol and timing guidelines, using recommended naming conventions, and recommendations for recording and submitting data (see *Data Collection and Reporting* below).

9. After completion of the two-year survey, interpret any observed murrelet activity to classify and delineate the survey area as occupied or not occupied (see *Classification of Survey Areas* below). In either survey approach (i.e., occupied only approach or presence approach), visits can be discontinued once a survey area is classified as occupied.

10. When a survey area is determined to be occupied, identify and map the area to be managed as murrelet habitat, in consultation with regulatory agencies (see *Occupancy Classification* below).

Identifying Habitat Contiguity for the Purpose of a Survey

After mapping areas that meet the definition of murrelet nesting habitat, if a portion of that habitat is separated by 200 m (656 ft) or more from the project footprint or from habitat that is contiguous with the footprint, areas beyond the 200 m (656 ft) gap do not need to be included in the survey area (Figures 2.1 and 2.2). For this purpose, the 200 m (656 ft) gap is measured as the distance between platform trees. Note that, in the interests of erring on the side of habitat conservation in the face of forest fragmentation, this version of the protocol uses a distance of 200 m (656 ft) to define a break in contiguity, whereas the 2003 protocol version used 100 m (328 ft).

Figure 2-1: *Relationship of project footprint and survey area. The project footprint is shown in yellow, the survey area is shown in black, and the 402 m (0.25 mile) boundary in pale gray. The blue dots indicate platform trees.*

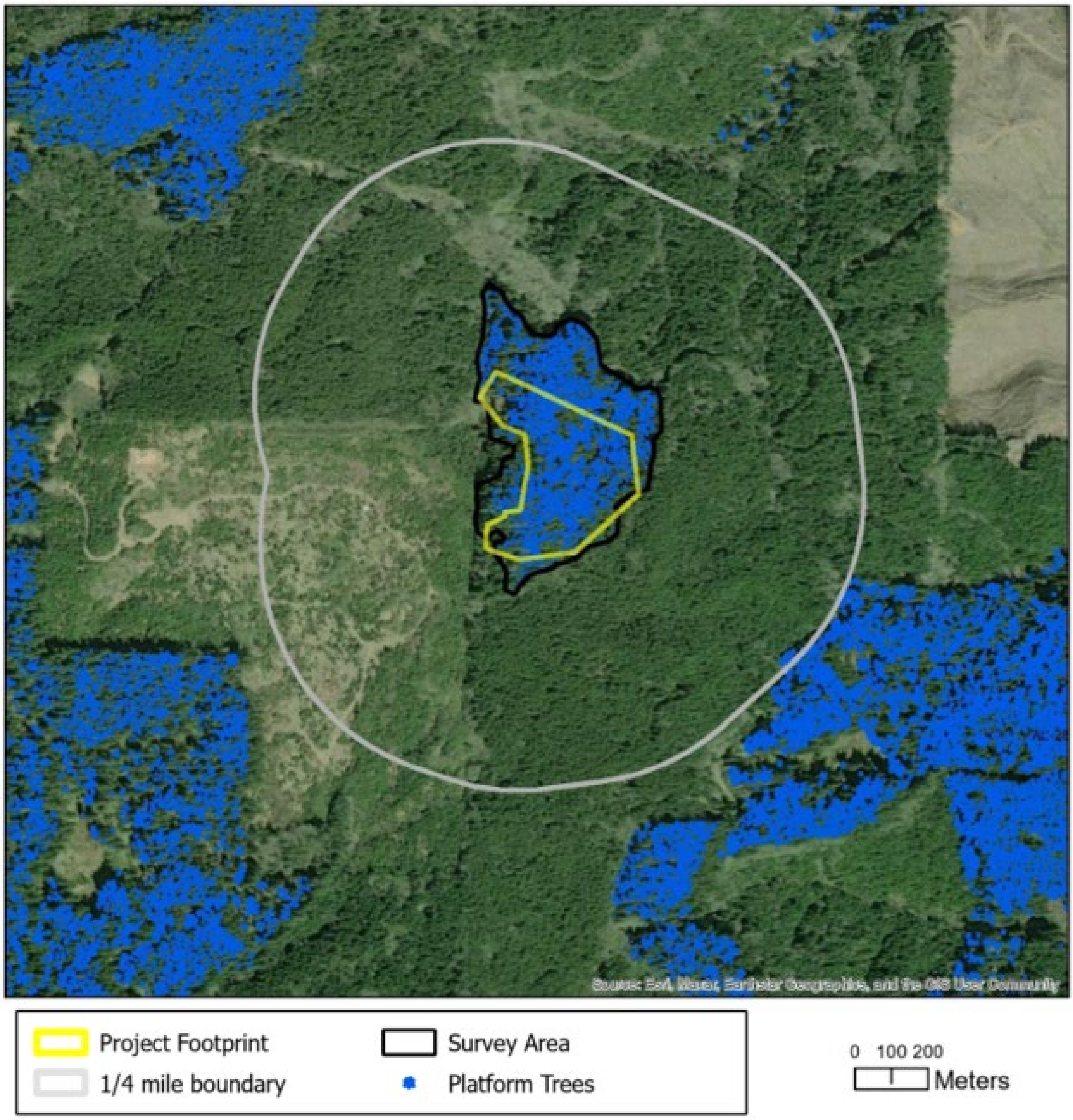
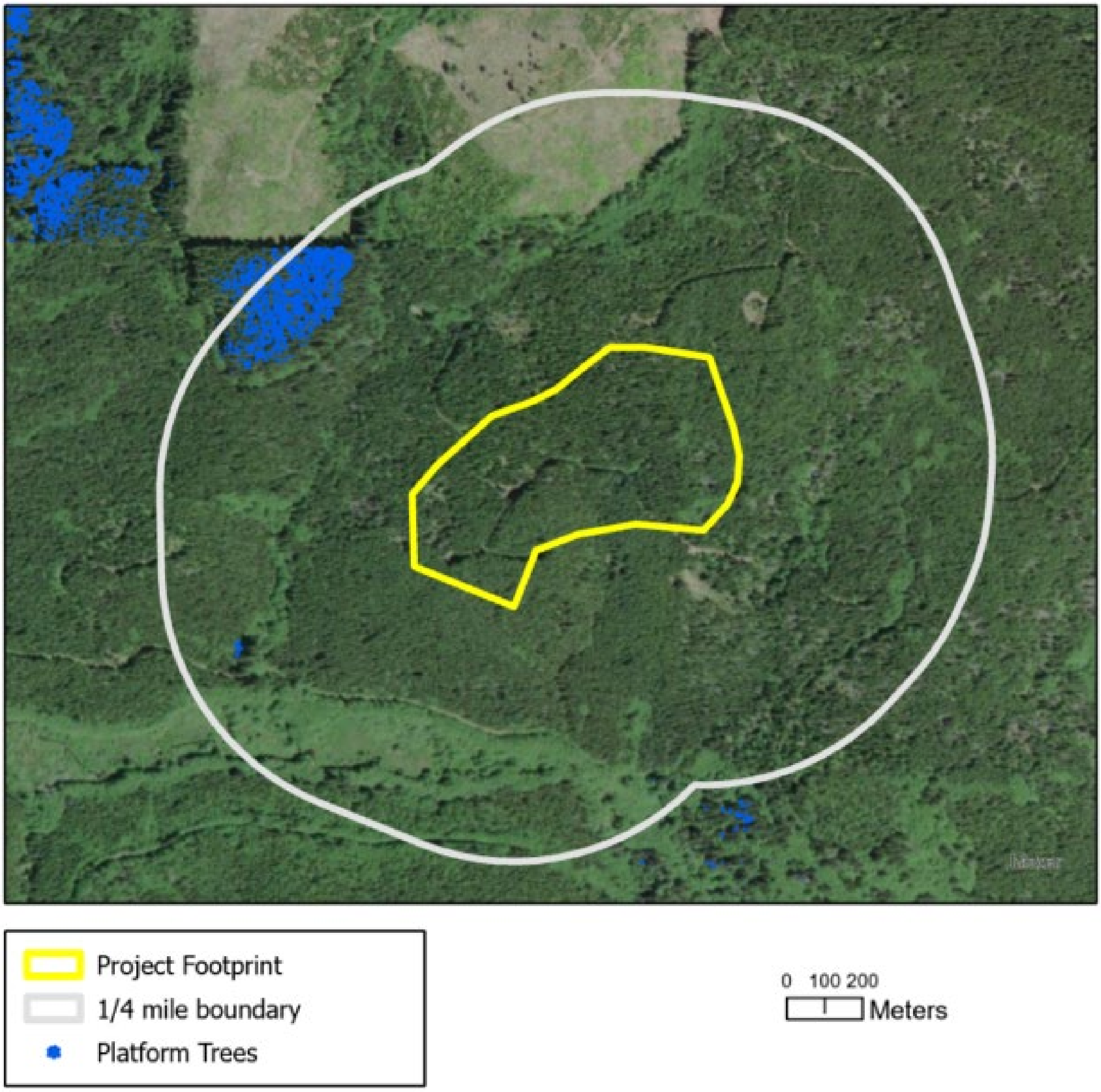


Figure 2-2: *Example where the only platform trees present are greater than 200 m (656 ft) from the project footprint, which means surveys are not required.*



Identifying Survey Area(s)

Identifying the survey area(s) requires multiple steps, including:

- Determining whether the project location falls within the inland extent of murrelet habitat in the project's region;
- Evaluation for presence and extent of habitat;
- Identification and mapping of habitat to be surveyed; and
- Using the size of the area identified to be surveyed to determine the number of survey area(s) required, as well as the number of survey strata within each survey area.

The basic definition of survey area presented below is designed to provide bounds for murrelet habitat in which surveys should be conducted (see Chapter 1: *Nesting Habitat* for details). It includes the range of conditions known to be used by murrelets for nesting and breeding. Any questions about habitat to be surveyed should be discussed in greater detail with the appropriate regulatory agencies.

Inland Extent of Murrelet Habitat

The inland extent of murrelet detections by state is shown in Chapter 1, Table 1-2. These data are provided as guidelines when identifying survey area(s) and planning surveys, particularly if the intent of surveys is to encompass all areas potentially used by murrelets. By state, the farthest known inland detection (not necessarily known nest) guides habitat identification:

- For Washington, surveys should be conducted in habitat up to 112 km (69.5 mi) inland;
- For Oregon, surveys should be conducted in habitat up to 80 km (50 mi) inland, except where it is known that murrelets do not occur inland to that extent; and
- For California, surveys should be conducted in habitat up to 39 km (24 mi) inland north of San Francisco Bay, and up to 18 km (11 mi) inland in the Santa Cruz Mountains.

Consult your regulatory agency if you are unsure of the inland extent of potential murrelet habitat in your region.

Habitat Characteristics

Correctly identifying and mapping the presence and distribution of potential murrelet habitat is a critical first step in following the protocol. As noted above, murrelet habitat is defined as a forest stand with at least one platform tree. See *Nesting Habitat* in Chapter 1 for details on the key features of murrelet habitat.

In addition, the presence of forest **Canopy** provides cover to the nesting platform and reduces predation risk. In most situations, the nest tree itself provides some cover, but adjacent trees can also provide needed cover to protect murrelets and the nest tree from the elements. Forest canopy cover for this protocol is defined as when the height of surrounding trees reaches or exceeds the height of the lower limbs of the platform tree(s). When no canopy overlap occurs for an isolated platform tree with no other platform trees within 200 m (656 ft), that platform tree would not trigger the need to survey (Figures 2-3 and 2-4).

Figure 2-3: *Examples of a single remnant platform tree surrounded by smaller trees whose canopy heights (A) overlap the height of the lower limbs of the platform tree, thus triggering surveys, and (B) do not overlap the height of the lowest limbs of the platform tree. The example in B would not be considered a potential nest tree if this were the only platform tree present (i.e., no other platform trees within 200 m (656 ft)). Under those conditions it would not trigger the need to conduct surveys. See also Figure 2-4.*

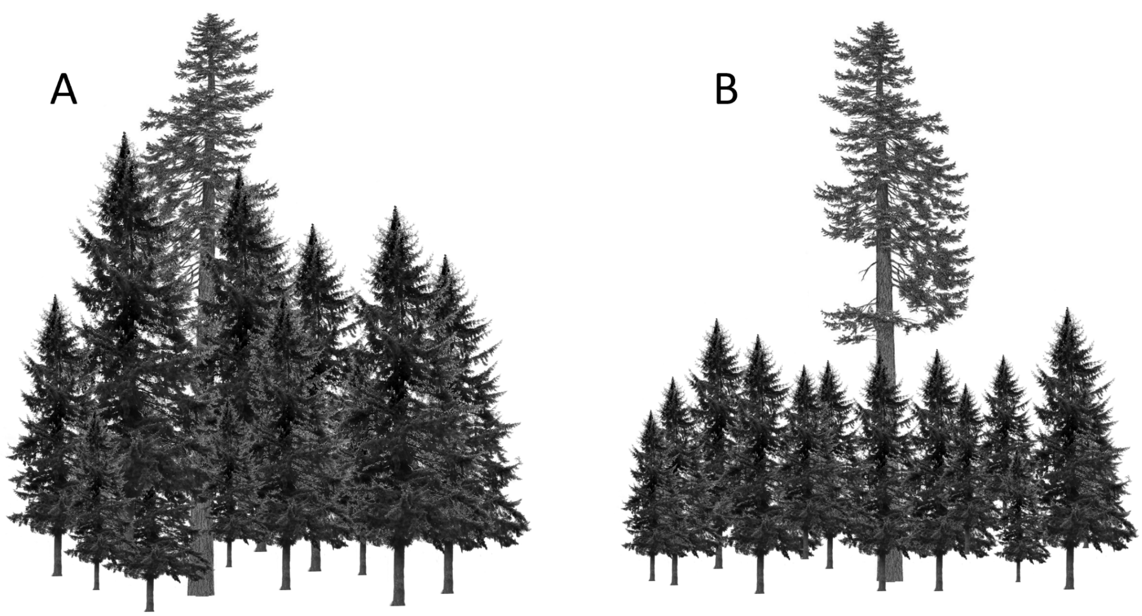
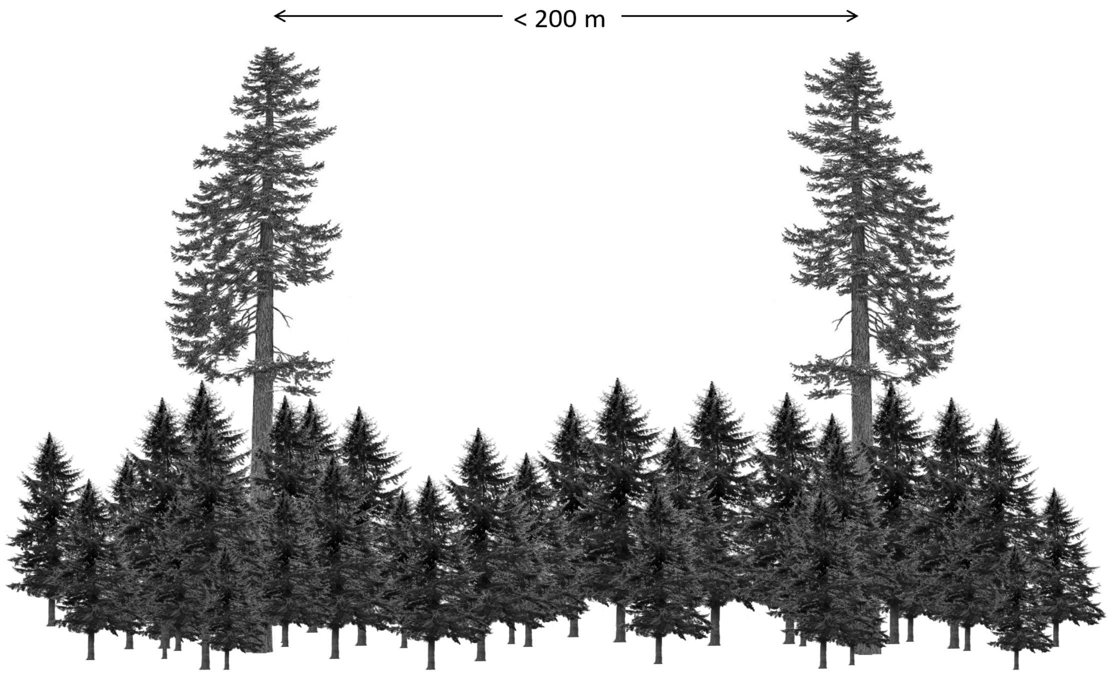


Figure 2-4: *Two or more remnant or isolated platform trees within 200 m (656 ft) of each other would be considered habitat to survey, whether or not the canopy height of surrounding trees overlap the height of the lower limbs of the platform trees.*



Survey Area Assessment

Surveyors should conduct an assessment in the project footprint and the 402 m (0.25 mile) surrounding area to identify habitat (Figure 2-1). Habitat outside of the 402 m (0.25 mile) boundary does not need to be included, but a land manager may choose to do so. For example, a land manager may choose to include extra areas so that contiguous habitat can be surveyed outside the boundary and/or where it would help them meet their management objectives with respect to murrelets at the landscape scale.

The assessment should include:

1) a desk review to identify habitat, including remnant and legacy trees, using aerial photos and Light Detection and Ranging (LiDAR) data, if available, **and**

2) an on-site review, which is a physical ground evaluation of forest conditions within the project footprint and surrounding 402 m (0.25 mile), looking specifically for the presence of platforms and platform trees, while bearing in mind that many platforms will not be visible from the ground.

In younger-aged forests, on-site reviews should include looking for individual or small patches of mature/old-growth forest, remnant trees, or younger trees with platforms, as complete information can be missed when relying solely on maps, aerial photos, or LiDAR. A physical ground evaluation of forest conditions is essential to verify the absence of platforms, as potential platform features such as broken tops and trees with deformities are not likely to be visible with current remote analysis tools.

Mapping Guidance

Habitat should be identified and mapped as described in the following bullets:

- Map the areas meeting the definition of murrelet habitat within 402 m (0.25 mile) of the project footprint (this can include forest beyond the edge of the platform trees). This includes forested areas with many platform trees as well as forested areas with scattered remnant platform trees. Features such as ridges, floodplains, rockslides, and lakes or large rivers may create the edge of a stand, naturally separating forested areas that contain platform trees from areas that do not contain platform trees. In managed landscapes, boundaries of previously harvested areas often form such edges when they create a break in habitat contiguity (see *Identifying Habitat Contiguity* above);
- Identify the mapped areas that are contiguous with the project footprint (see *Identifying Habitat Contiguity* above). The resulting map will comprise the survey area(s); and
- Calculate the total number of acres within the survey area(s).

Coordination with Adjacent Land Managers

Coordination with adjacent land managers or landowners for habitat assessment, planning, and conducting surveys is recommended. Due to land ownership patterns, some lands within 402 m (0.25 mile) of the project may include other land ownerships with limited access or which are inaccessible. Habitat assessment, survey design, and implementation needs to proceed to the fullest extent possible within 402 m (0.25 mile) of the project footprint. If unable to assess and/or survey habitat within 402 m (0.25 mile) of your project footprint due to ownership patterns, consult your regulatory agency.

Permission and Data Sharing

Permission should be obtained from landowners or managers, including on public lands, before conducting on-the-ground habitat assessments or planning and conducting surveys on their lands. Similarly, the results from any surveys should be shared with land managers and adjacent landowners. Coordination in delineating occupied areas and data sharing can maximize protection of murrelets and occupied habitat and can minimize survey effort. Data should also be shared with State databases held by State agencies or other entities as appropriate (see *Data Collection and Reporting* below).

Defining Survey Area(s) and Strata

The survey area is the fundamental unit at which surveys are conducted and **Occupancy Classification** is determined (Figure 2-5). The design of this protocol uses survey strata (survey stratum[6] singular) as subunits within a survey area, both to ensure consistency with the underlying statistical analysis, and to distribute survey effort more evenly within a large survey area. Depending on its size, a survey area may need to be divided into one to three survey strata.

Once the habitat to be included in the survey area(s) has been mapped, the number of survey areas and survey strata are based on the number of mapped acres. A single survey area may contain up to 182 ha (450 ac). This maximum size equals three strata of 61 ha (150 ac) each, the upper limit for stratum size used in the statistical analysis (Appendix B). While these size limits should be followed wherever possible, they may be applied plus or minus 10% to provide flexibility in fitting survey areas and strata to a project's habitat configuration (Table 2-1). Thus, the absolute maximum size of a survey area is 200 ha (495 ac), which is 182 ha (450 ac) plus 10%. If the size of the mapped habitat to be surveyed exceeds this maximum, it needs to be divided into two or more survey areas in such a way that minimizes the separation of contiguous mapped habitat.

Scattered remnant trees and platform trees separated by gaps smaller than 200 m (656 ft) do not justify a separate survey area designation. Forested areas where remnant platform trees are scattered throughout a younger cohort (at varying distances) are considered contiguous habitat (Figure 2-6) and should be surveyed as a single survey area.

If the 402 m (0.25 mile) boundaries around project footprints, such as for timber harvests, overlap, stations would not need to be double sampled if surveys in the overlapping survey areas are conducted during the same two-year time frame. If the 402 m (0.25 mile) boundaries around timber sales or other projects overlap but surveys are not conducted in the same two-year time frame, the area of overlap would need to be re-surveyed as part of the later effort, unless it was previously classified as occupied during surveys for another project. In this case the later-in-time survey area would be considered occupied if contiguous with habitat determined to be occupied by a previous survey. For further direction, consult your regulatory agency.

[6] For those familiar with the 2003 Survey Protocol, survey stratum replaces survey site. This terminology change was made to reflect the fact that the statistical analysis underlying this protocol explicitly evaluated occupancy at the survey area scale and statistically treated multiple survey strata within a survey area as strata within the survey area. The statistical analysis for the 2003 protocol was conducted at the survey site scale.

Figure 2-5: *Example of identifying the survey area. In the figure below, the blue dots represent platform trees, which help us identify habitat in these exercises. The survey area is represented by the black outline. While there are additional platform trees to the north, these are more than 200 m (656 ft) from the project footprint or habitat contiguous with the project footprint and are thus not required to be part of the survey area.*

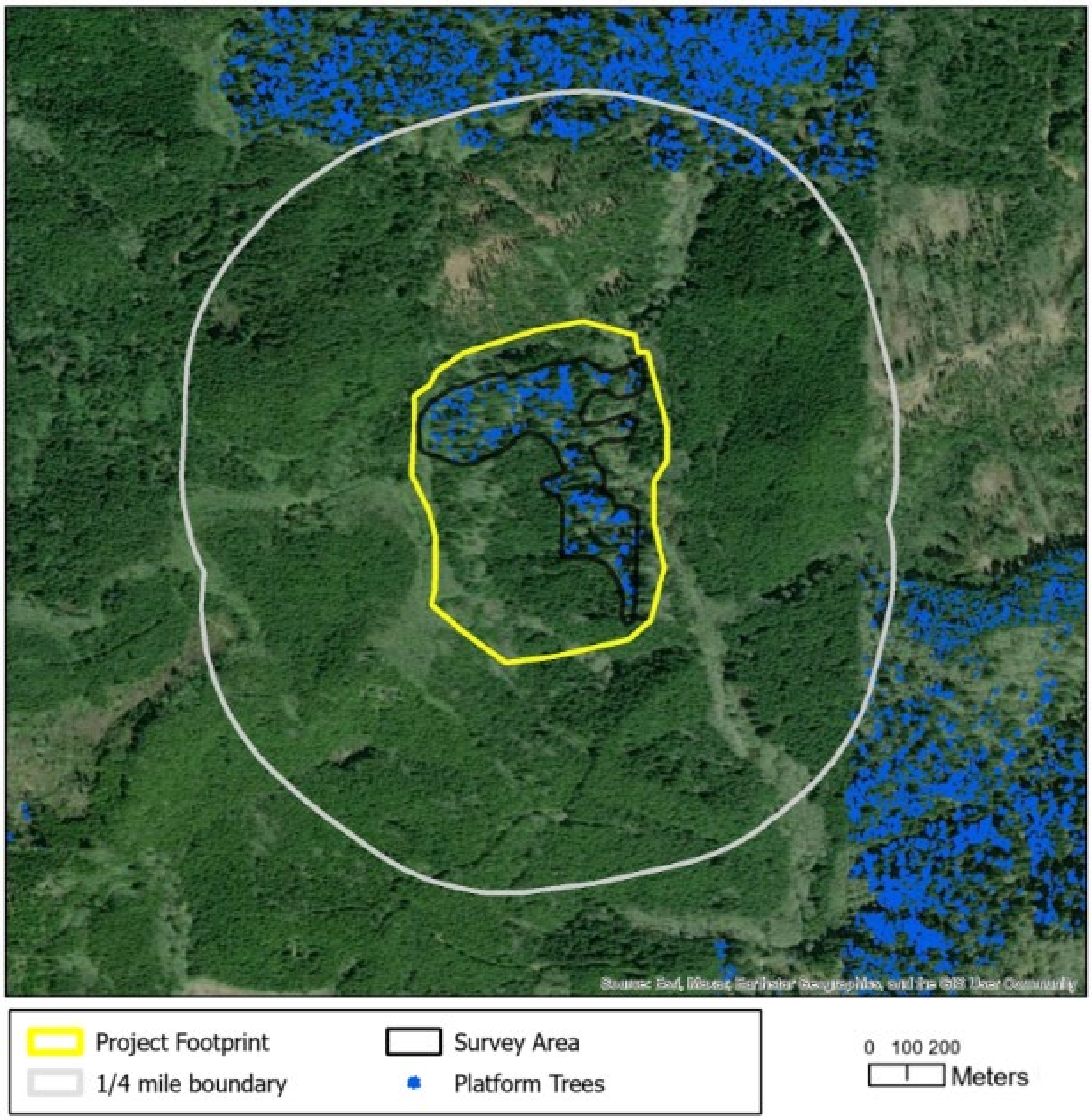
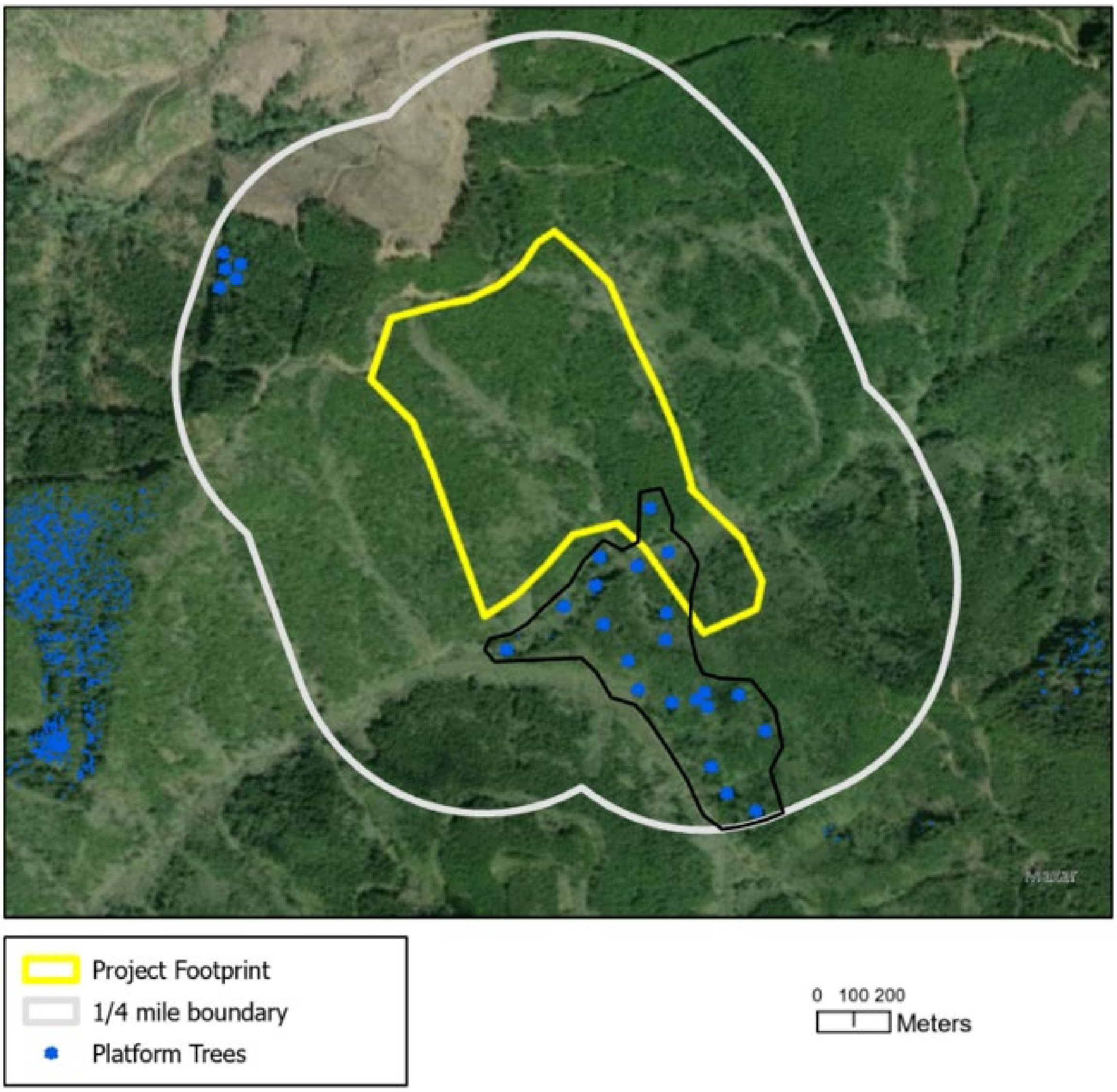


Figure 2-6: *Stands with habitat in the form of scattered remnant trees. The scattered platform trees to the south are within or contiguous with the project footprint or with other platform trees considered contiguous with the project footprint. The patch of forest containing these trees is part of the survey area. The cluster of platform trees to the northwest is not contiguous with the project footprint and is thus not part of the survey area. Note that the survey area boundary may not align with forest stand boundaries. In this example, the survey area boundary encompasses only the remnant trees, but in some situations the survey area boundary could be extended to the edge of the forest stand containing the remnant trees. See Mapping Guidance in text for details.*



Number of Survey Strata

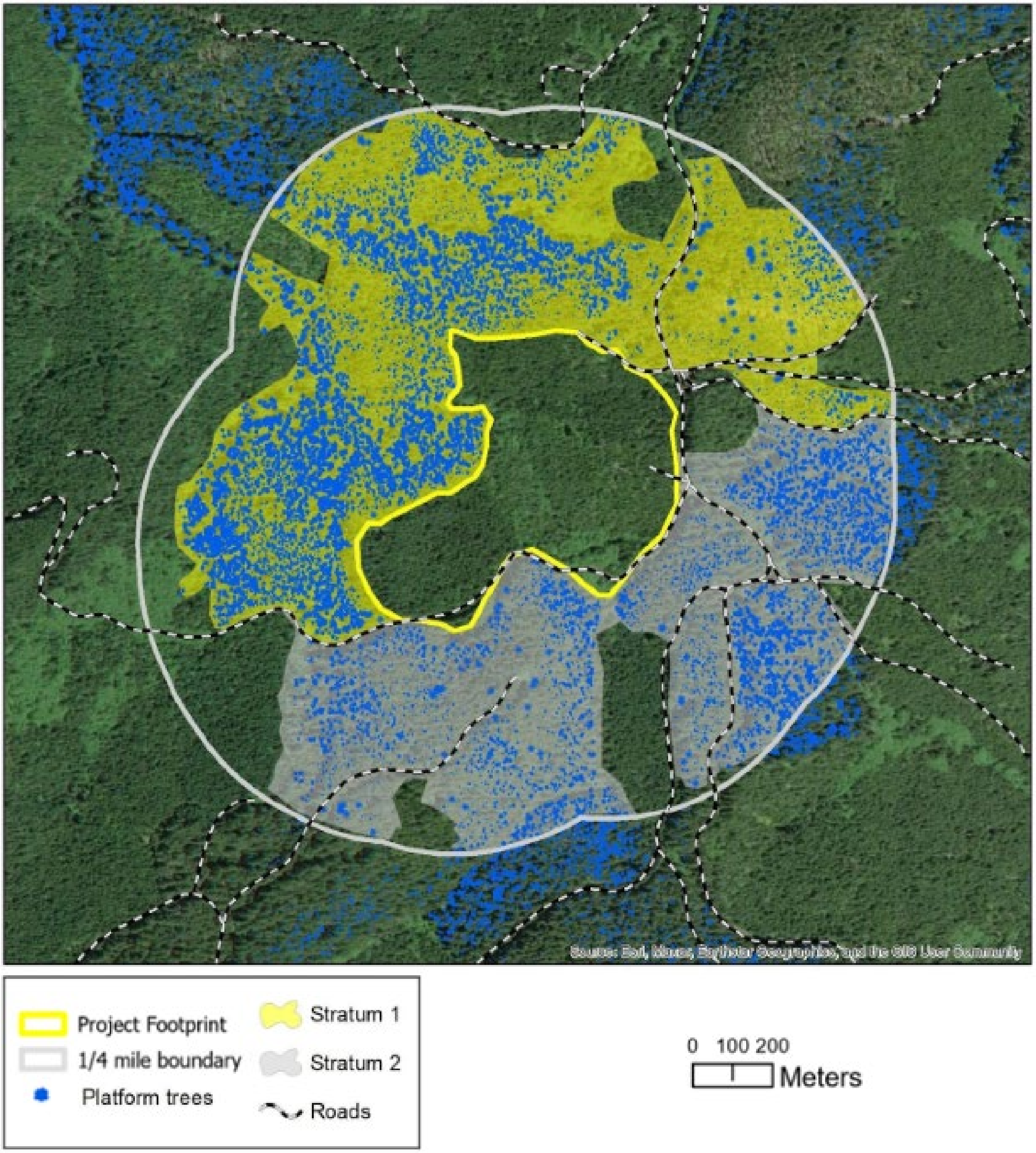
Depending on the number of acres in a survey area, there may be from one to a maximum of three survey strata within a survey area. The acreage mapped during the habitat assessment is used to calculate how many strata are needed, as explained in *Defining Survey Area(s) and Strata* above and summarized in Table 2-1. A survey area containing more than 61 ha (150 ac) +/- 10% of habitat will be split into multiple survey strata with an approximately equal area of habitat in each stratum (Table 2-1 and Figures 2-7 and 2-8). If a survey area has less than 61 ha (150 ac), then it contains one stratum. Each survey stratum will have an equal number of survey visits, to ensure that the survey effort is evenly distributed within the survey area when implementing the sampling protocol.

Within a survey area, habitat distribution and topographic features (roads, ridges, streams) should be used to determine the boundaries between survey strata where feasible (see Figure 2-7). If there are multiple patches with higher densities of platform trees, and the habitat configuration permits, draw stratum boundaries so that each stratum has some areas with higher densities of platform trees to avoid a disproportionate amount of habitat in a single stratum. This may not always be feasible, such as where all areas with higher densities of platform trees are within a contiguous block that logically (e.g., based on topography and location) would fall within one stratum.

Table 2-1: *The number of survey strata and survey areas required, based on the number of hectares/acres to be surveyed, and increments of 61 ha (150 ac) for a stratum, +/- 10%. The maximum allowable size for a survey area is 182 ha (450 ac), +/- 10%, consisting of a maximum of 3 strata.*

Total Area to Survey	Number of Survey Strata	Number of Survey Areas
≤ 61 ha (150 ac) +/- 10%	1	1
61-121 ha (150-300 ac) +/- 10%	2	1
121-182 ha (300-450 ac) +/- 10%	3	1
182-364 ha (450-900 ac) +/- 10%	use above criteria	2

Figure 2-7: *A project footprint with 61-121 ha (150-300 ac) of habitat requires one survey area with 2 strata, shown in different colors. In this example, habitat occurs only outside the project footprint, and roads provide a break from which to delineate the survey strata. Where possible, use features such as roads, stand breaks, topography, and other features to divide strata, while attempting to keep them as equally sized as possible.*



Although surveyors are encouraged to determine the number of survey strata based on acreage alone, multiple survey strata can be defined before reaching the limits listed in Table 2-1 in order to increase survey effort and ensure appropriate distribution of effort. For example, land managers may want to define a separate survey stratum on the other side of a ridge or in a distinct forest type to make sure they have sufficient survey effort to detect murrelet activity, even if the survey strata are less than 61 ha (150 ac). However, this approach requires more effort than required to meet the performance thresholds for this protocol. Also, survey areas with less than 182 ha (450 ac) +/- 10%, can only contain up to a maximum of 3 survey strata. Only projects with associated habitat greater than 182 ha (450 ac) +/- 10%, can be divided into separate survey areas (Figure 2-8).

Selecting an Approach and Determining the Required Number of Visits

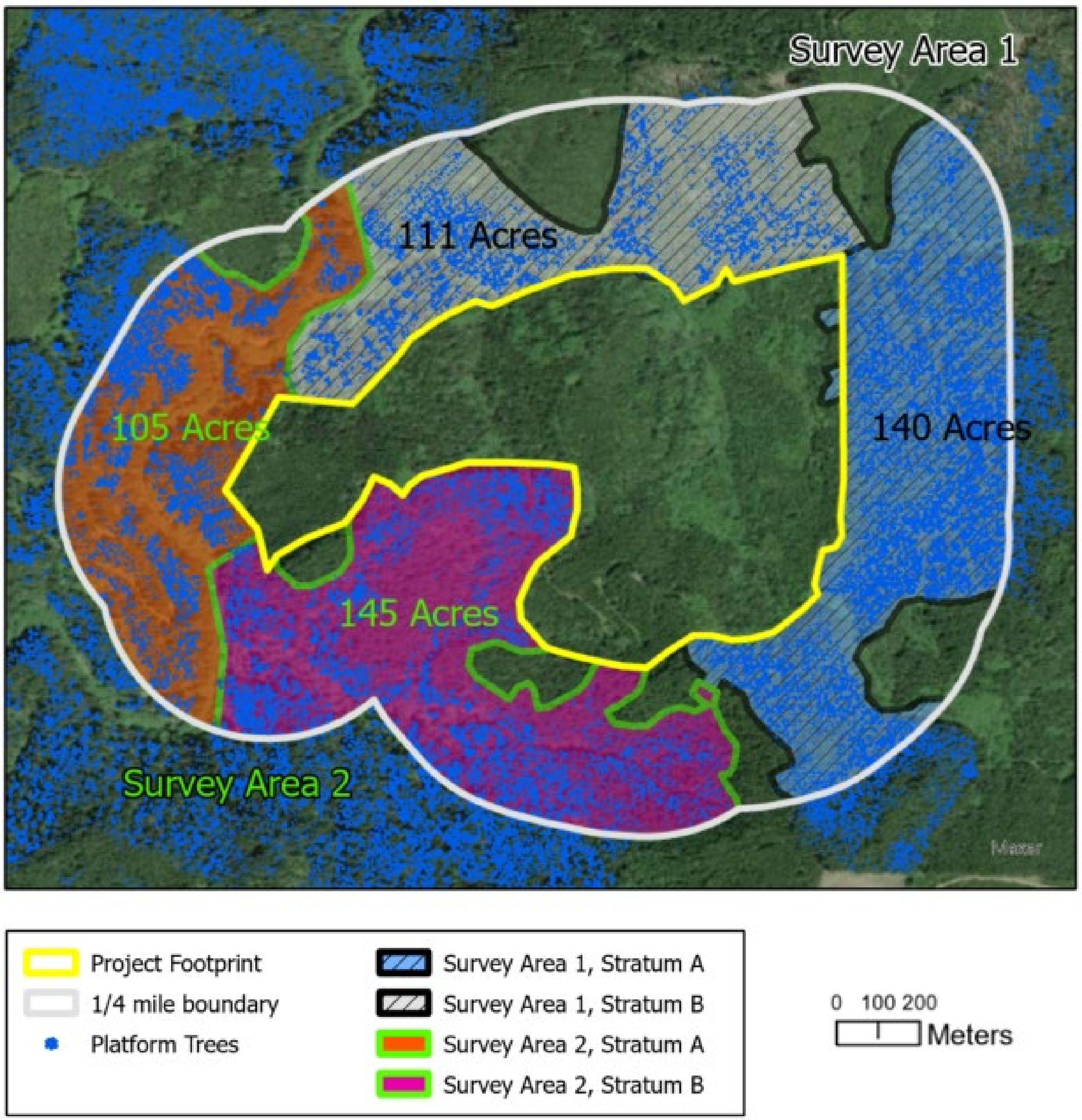
The goal of this two-year survey protocol is to accurately classify habitat as either occupied or not occupied at least 95% of the time while also achieving survey efficiency. These goals can be achieved using one of two *approaches* for conducting surveys (see Appendix A). The first, the Occupied Only Approach, is similar to earlier versions of the protocol, in that a detection of an occupied behavior (e.g., subcanopy flights, circling, and landings) at any station within the survey area leads to an occupied classification. Because only occupied behaviors are used in classifying the survey area in this approach, more surveys will be needed to achieve high confidence that the habitat is classified correctly. In the second approach, called the Presence Approach, multiple presence detections can also lead to a survey area being classified as occupied. Using the presence approach, an occupied designation for a survey area is made when either: (1) an occupied behavior is detected, or (2) presence detections[7] occur during three or more survey visits, considering all survey visits over the **entire survey area** across two years. Because the presence approach uses information from any type of detections made during a survey, it requires fewer survey visits than the occupied only approach (Table 2-2).

The survey approach must be decided and documented before beginning the two-year survey effort. The statistical basis is different for each approach and its associated survey effort, and so it is necessary to use the same approach throughout to meet the performance measures and classify areas with confidence (See Appendix A).

In either approach, visits can be discontinued once a survey area is classified as occupied. Also, depending on the objective of the surveys, a land manager may choose to continue surveys after occupancy is confirmed. One consideration when deciding whether to continue or discontinue surveys at this point may be the effects a shortened survey schedule could have on survey team members and management.

[7] Number of visits with one or more presence detections, not the number of presence detections on any given visit.

Figure 2-8: *Example of a project with more than 182 ha (450 acres) (+/- 10%, see text) of habitat within the project footprint and its 402 m (0.25 mi) boundary. In this example, the total habitat area of 501 acres requires 2 survey areas with 2 strata each, based on the survey area sizes. The two survey areas are similar in size, with a riparian and stand break dividing the two areas. The strata, while slightly different in size, use landscape and stand features for breaks.*



It is important to understand that, while both approaches have a small risk of classifying a survey area as not occupied when it is in fact occupied (i.e., the False Omission Rate; see Appendices A and B), the two approaches differ in that the presence approach has the added risk of False Discovery (survey area determined to be occupied when in fact it is not occupied). While the survey design in this protocol minimizes the False Discovery Rate (see Appendices A and B for details), there remains a low risk of this error. Therefore, land managers should consider site-specific factors that could result in False Discovery before selecting an approach (e.g., whether or not the survey area occurs along a known or possible flight corridor, which could lead to repeated presence detections associated with transiting murrelets).

Table 2-2: *Required survey visits.*

Number of Strata	Survey Approach	Visits per Year per Stratum	Visits per Year per Area	Surveys with Presence Detections needed for Occupied Designation
1	Occupied Only	12	12	NA
	Presence	8	8	3
2	Occupied Only	17	34	NA
	Presence	10	20	3
3	Occupied Only	20	60	NA
	Presence	11	33	3

Survey Stations and their Placement

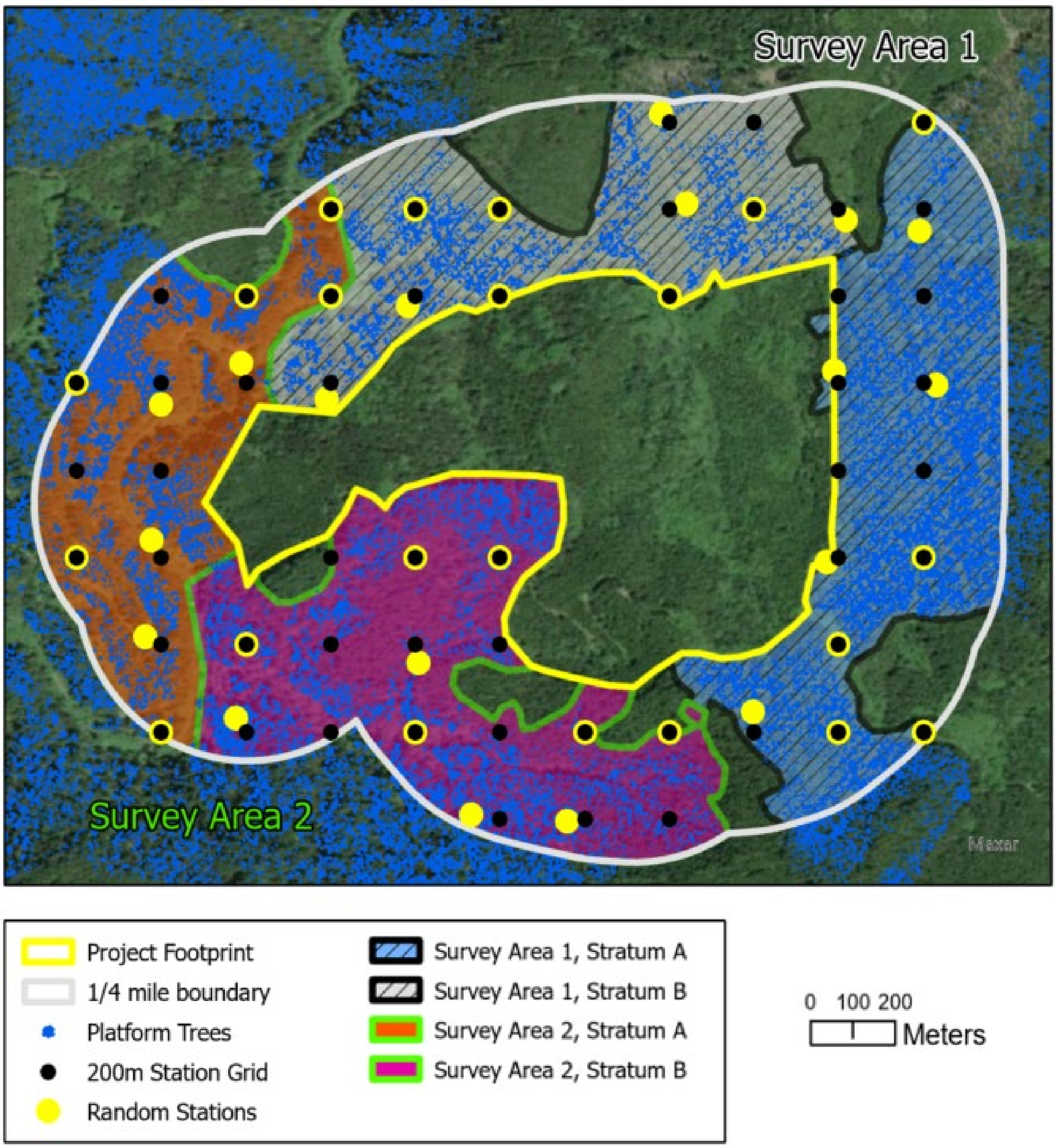
A **Survey Station** is the specific location at which an AV survey is conducted. For AV surveys, the assumed maximum visual detection distance is 100 m (328 ft) and the assumed maximum audio detection distance is 200 m (656 ft) (Ralph et al. 1994; Cooper and Blaha 2002). For the purposes of survey station layout, a spacing of potential survey stations of 200 m (656 ft) apart is recommended (Figure 2-9), based on the 100 m (328 ft) maximum visual detection distance. However, in certain situations, a station may cover less area and reduced station spacing may be desired; for example, in an area with closed canopy, limited visibility, and/or steep terrain with several drainages. See *Survey Area Placement* below for guidance on station placement in an opening to maximize visibility.

This protocol applies a **Stratified Random Sampling Strategy** across the survey area, in contrast with the previous protocol, which was based on 100% coverage of a survey area. As a first step in station placement, create a map of potential survey stations throughout the survey area(s), based on a spacing of 200 m (656 ft) between stations; this may be accomplished using a dot matrix grid, a hexagonal grid, or similar tool. In larger survey areas, this process may identify more potential survey stations than the number of survey visits required for each year. If this occurs, randomly sample available stations within each stratum of the survey area. The stratified random sampling strategy is described in the following steps and should be used to determine the location of stations to survey within a survey area:

- Use Table 2-2 to look up the required number of survey visits, based on the number of survey strata and the chosen survey approach (occupied only approach vs. presence approach);
- If the number of survey visits required in one year is greater than or equal to the number of potential survey stations within individual survey strata, then survey all of the survey stations and conduct repeat surveys as needed with a priority on: a) survey stations with presence detections, then b) survey stations with areas of higher platform tree densities and/or better viewsheds. Survey stations where louder or repeated audio detections occurred should also be prioritized for repeat surveys. Likewise, locations where murrelets are seen flying in a straight flight path close to, but above the tree canopy, should receive priority for repeat survey visits. Timely review of survey data by an experienced professional with knowledge of murrelets for any detected behaviors will maximize the likelihood of detecting murrelets;
- If the number of survey visits required in one year is less than the number of potential survey stations with individual survey strata, then not all potential survey stations will be sampled (Figure 2-9). Within each survey stratum, randomly select stations to survey from the pool of potential survey stations, up to the required number of visits for the year. The stratified random sampling process is to be repeated in year two of surveys, thus requiring a new random selection of potential survey stations each year (mapping and numbering stations will need to follow guidelines. See *Data Collection and Reporting* below);
- If areas of higher platform tree density are present but the random sample does not include any points in those areas, then up to one point within each stratum with areas of higher platform tree density can be substituted for one randomly selected point; and
- Survey stations need to be placed at an optimum location around the selected point to maximize the likelihood of detecting murrelets, for example minimizing visual obstructions and noise interference (see *Survey Station Placement* below) and placement close to platform tree(s). To achieve this, the survey station can be placed up to 50 m (164 ft) from the selected point.

Survey station placement at the selected point is one of the most crucial aspects of survey implementation. Because of this, it is imperative that station placement around each point be reviewed by an experienced professional with knowledge of setting up murrelet surveys prior to beginning a survey (see *Training Required* in Appendix I).

Figure 2-9: *Example of station placement for a presence approach survey, for the project in Figure 2-8, requiring two survey areas, each with two survey strata. In this scenario, each stratum requires 10 survey visits per year. A dot grid was placed over the survey areas, with 200 m (656 ft) spacing between dots to represent potential survey station locations. Because each stratum supports more than 10 potential survey station locations, 10 actual survey stations were randomly selected within each stratum. For smaller strata, with fewer survey station locations than required survey visits, random selection is not needed, and some stations may need to be surveyed multiple times to achieve the survey visit requirement. As described in the text, the actual survey station should be placed in the best survey location within 50 m (164 ft) of the mapped station location.*



Murrelets can be difficult to detect in and around their breeding areas due to their small size, rapid flight, cryptic plumage, and crepuscular behaviors. Where the likelihood of detecting murrelet activity is low, such as where a small number of birds may be nesting due to small stand size or extreme distance to marine waters, good station placement is imperative. Sensible placement of survey stations must consider site specific conditions, including forest and platform density, weather, river noise, or road activity, that may limit the observer's ability to see and/or hear murrelets.

The following bullets summarize the most important aspects of survey station placement within selected points:

- The goal of station placement is to maximize the surveyor's opportunity to detect murrelets, and specifically murrelet behaviors indicative of nesting. Because nesting birds are often silent, stations require a view of the sky to maximize the opportunity to see murrelets;

- Stations should be located in openings and adjacent to potential nest trees where the observer has the best opportunity of seeing and hearing murrelets. On-the-ground assessment and placement is required to determine the best locations for survey stations within each stratum;

- The silhouette of a dark bird flying directly overhead against the light-colored sky is easier to see than a bird flying against a dark background when viewed from the top of a ridge or high point. If the survey area includes a ridgetop, mid-ridge, or river bottom, stations should be placed to effectively survey those areas, but not necessarily be placed at the ridgetop, mid-ridge, or river bottom. The ability to detect murrelets may be better when observing those areas from another location near a selected point;

- Stations should be placed in forest clearings, on quiet roads, or adjacent to rivers or streams. Murrelets often use stream, road, or river corridors as flight paths to access nest sites. Surveys at stations along streams can be noisy, but the increased opportunity to observe occupied behaviors might outweigh the negative aspects of noise (see *Environmental Conditions Affecting Surveys* for more discussion regarding conducting surveys under these conditions);

- Stations must be located within 50 m (164 ft) of the randomly selected station location, with some flexibility to improve the probability of detecting murrelets as described in the next section;

- If the number of required surveys exceeds the number of potential survey stations, a new random selection of stations to survey is conducted each year, from the same pool of potential survey stations; and

- Survey area, strata, and station names must remain consistent between years (see *Data Collection and Reporting* below).

AV surveys can involve locations with challenging access, unsafe terrain, or other safety concerns. For areas that are difficult or unsafe to access in the dark because they have steep slopes, cliffs, thick brush, or are long distances from roads, it may be necessary to hike into the station before dark the evening before the survey visit, set camp, and then survey in the morning. Access may also be challenging due to land ownership patterns. Contact adjacent land managers as needed with any access issues.

Flexibility to Move Survey Station Locations

In general, station locations should not be moved between visits. However, the observer has the flexibility to move the survey location up to a maximum of 50 m (164 ft) from the generated survey station point, either during a survey or on a subsequent visit, in order to improve the probability of detecting murrelets from that station. For example, if habitat or other conditions have changed since the station was set up or if there is a better chance of observing murrelet activity nearby for any reason, station movement within the above parameters is allowed. This includes station movement to respond to local **temporary** conditions, such as road traffic or a nearby loud singing songbird.

If the surveyor needs to move after the survey has begun, they should reach their new survey location as quickly as possible. Whenever an observer moves, the time of the start and end of the move and the distance and direction moved must be documented in the notes in the data form. If the station is moved permanently due to access issues, for example a landslide prevents access, this must be noted clearly on the data form and the station number needs to be associated with the original station (e.g., if the original station was Station 1, the new station would be Station 1A).

Some examples for the need to move a station include: deciduous trees leafing out and covering the gap over the station, a creek being louder than initially thought, a nearby gap in the canopy becoming apparent that was not observed initially, or nests being established in the area that may cause issues (e.g., owls, insects). Another example aimed at improving the chances of detecting murrelets would be if murrelets were heard in a nearby gully during a survey visit, then the observer could move the station in the gully to increase the probability of observing subcanopy behavior.

Flexibility to Add More Stations

In some cases, land managers may want to conduct more than the recommended number of surveys, which may include adding new stations. In this case, naming and tracking the data are important. The new stations should be numbered to reflect the relationship, if any, between new and original stations, while the survey area and strata names should remain the same.

If extra surveys at new stations are added outside the original survey area and strata boundaries, for example to get more information on murrelets detected on the edge of the survey area, they should continue to be linked to the original survey area and strata names. In these situations, land managers may want to consult with the appropriate regulatory agencies to determine how to best interpret results in delineating occupied and not occupied areas beyond the original survey area borders.

Timing of Surveys

Time of year

The following **Survey Periods** were defined based on reviews of past survey data and current knowledge: 15 April to 5 August in California (Carter and Erickson 1988, O'Donnell et al. 1995); 24 April to 5 August in Oregon and Washington (unpublished review of latest survey data by the authors of this protocol); 1 May to 31 July in BC; and 15 May to 5 August in southeastern and south-central Alaska (Kuletz et al. 1994, but see Brown et al. 1999 for a potentially earlier start in southeastern Alaska). These dates encompass a substantial portion of the incubation period and early nestling period, based on chronologies identified by Hamer and Nelson (1995b), but should not be confused with **Breeding Seasons** for these areas (see Chapter 1: *Seasonality of Nesting and Inland Activity*).

Occupied behaviors documented outside the survey season are considered observations that qualify for classifying an area as occupied (Naslund 1993a, b; O'Donnell et al. 1995). However, surveys performed outside of the survey season are not appropriate for survey area classification as not occupied. Only surveys conducted during the official survey period can be counted towards the required number of surveys for a survey area in a given year.

Distribution of Visits Throughout the Season

To help maintain an even distribution of survey visits throughout the nesting season, surveys should be conducted according to the survey periods and date ranges described below and in Tables 2-3 and 2-4. The number of surveys conducted in each period depends on the survey approach selected (i.e., occupied only or presence approach). Following the table guidelines, repeat visits within a single stratum must have a minimum of one calendar day between surveys. But for multi-strata survey areas, surveys can be conducted in different strata on the same day. Surveys in the last few days of the survey season should be used sparingly due to a lower probability of detection. If additional surveys are needed in the first five days of August, they should be limited to no more than one survey for the presence approach and no more than two surveys for the occupied only approach.

Guidance for the distribution of surveys throughout the survey season are as follows:

- Early Season (15/24 April – 15/21 May): 10–25% of total survey effort; (based on approach and stratum/strata);
- Mid-Season (16/22 May – 27 June): 40–50% of total survey effort; (based on approach and stratum/strata);
- Peak Season (28 June – 5 August): 35–45% of total survey effort (based on approach and stratum/strata);
- For the presence approach, limit the number of surveys conducted in August to no more than one; and
- For the occupied only approach, limit the number of surveys conducted in August to no more than two.

If the required number of visits are not distributed according to the schedule below, talk with your regulatory agency for guidance.

Table 2-3: *Time periods and associated survey distribution for AV Surveys in California.*

Survey Distribution by Time Period – California						
	Occupied Only Approach (Min – Max)			**Presence Approach (Min – Max)**		
Period	1 Stratum	2 Strata	3 Strata	1 Stratum	2 Strata	3 Strata
1 (15 April – 15 May)	1 – 3	3 – 9	6 – 15	1 – 2	2 – 5	3 – 8
2 (16 May – 27 June)	5 – 6	14 – 17	24 – 30	3 – 4	8 – 10	13 – 16
3 (28 June – 5 Aug)	4 – 5	12 – 15	21 – 27	3	7 – 9	12 – 15
Total Surveys/Stratum	12	17	20	8	10	11
Total Surveys/Area	12	34	60	8	20	33

Table 2-4: *Time periods and associated survey distribution for AV Surveys in Oregon and Washington.*

Survey Distribution by Time Period – Oregon/Washington						
	Occupied Only Approach (Min – Max)			**Presence Approach (Min – Max)**		
Period	1 Stratum	2 Strata	3 Strata	1 Stratum	2 Strata	3 Strata
1 (24 April – 21 May)	1 – 3	3 – 9	6 – 15	1 – 2	2 – 5	3 – 8
2 (22 May – 27 June)	5 – 6	14 – 17	24 – 30	3 – 4	8 – 10	13 – 16
3 (28 June – 5 Aug)	4 – 5	12 – 15	21 – 27	3	7 – 9	12 – 15
Total Surveys/Stratum	12	17	20	8	10	11
Total Surveys/Area	12	34	60	8	20	33

Time of day

The survey period is defined as at least a two-hour period from 45 minutes before to 75 minutes after official sunrise or for 15 minutes after the last detection, whichever is longer. Exceptions to this timing are detailed below under *Environmental Conditions Affecting Surveys*. By following these guidelines, some survey visits will last longer than 75 minutes after sunrise, especially on cloudy days or days with heavy fog, when detections generally continue longer. If a survey visit included observation of an occupied behavior during the regular two-hour survey period, staying longer is not necessary, but we recommend completing the survey as this could yield additional supporting detections. Surveys beginning earlier and ending later than the official survey period are encouraged, as positive detections during this time are valid in determining presence or occupancy.

Use the nearest Nautical Almanac reporting location to determine sunrise times as specific as possible for your survey area. Do not rely on tide tables, local newspapers, or television stations because they can vary up to 15 minutes from official sunrise. Do not rely on GPS reported sunrise times, as they have unreliable accuracy. Sunrise tables can be obtained at: https://www.esrl.noaa.gov/gmd/grad/solcalc/ (put a red pin on your location and enter a date or request sunrise tables for the year). Be sure to identify the sunrise table referenced on the survey forms.

Murrelets also can be detected inland during the evening. Radar surveys generally find consistent but lower volume of inland evening flights compared with morning surveys (Cooper et al. 2001). Evening AV surveys or incidental observations while camping at a station could be useful in determining presence or occupied behavior and should be used to define survey area status.

Environmental Conditions Affecting Surveys

The effects of environmental conditions on murrelet surveys are twofold. They can affect: (1) the timing, duration, and intensity of murrelet activity; and (2) the ability of observers to detect the birds audibly and/or visually. Murrelet activity begins later, lasts longer, and is often more intense on mornings with overcast conditions, fog, drizzle, or rain than on mornings with clear conditions (Hamer and Cummins 1990, Manley et al. 1992, Naslund 1993b, Rodway et al. 1993, Nelson and Peck 1995). If rainy, cloudy, or foggy conditions exist at the end of the regular two-hour survey period, observers may continue to survey for an additional 30 minutes to detect possible late activity, but this is not required. Foggy conditions are defined as a continuous cloud ceiling or significant cloud layer that reduces vertical viewing to $\leq$1 canopy height[8] or by the presence of low fog, including ground fog, which decreases horizontal visibility to less than 100 m (328 ft). Use the tallest tree observable from the survey station and within the survey stratum as the reference for one canopy height.

The conditions described above potentially limit an observer's ability to detect murrelets both visually and audibly. Low cloud ceilings or thick fog make it difficult to see murrelets. Rain and wind can make it difficult to hear murrelets calling. If visual impairment or noise conditions that limit murrelet detectability (e.g., fog, heavy rain, hail, strong wind, logging activity, vehicle traffic, or loud aircraft) exist for more than 10% (12 minutes) of the survey period, the survey visit must be rescheduled and repeated again on another morning soon after, unless occupied behaviors are detected on that morning. Similarly, if using the presence approach, and there are one or more presence detections, the survey applies, and its results should be used. Note that the 12-minute limitation refers to 12 minutes of interrupted observations (continuous or discontinuous) once the survey visit is underway, and only applies to the original two-hour survey. Because murrelets might still be detected during these conditions, the observer should remain for the duration of the two-hour period unless conditions threaten their safety. Observers should also not abort a survey visit if occupancy behaviors are observed but should remain to gather additional detection data for the duration of the two-hour period unless conditions threaten their safety.

[8] While visibility to two canopy heights is optimal for detecting some occupied behaviors (e.g. circling), requiring visibility to at least one canopy height is consistent with the previous PSG protocol (Evans Mack et al. 2003) and with the statistical analysis underlying this protocol.

The following is a list of scenarios that may void an official survey (consult with your regulatory agencies if any of these occur). If any of these singly or in combination limit your detection ability for 12 minutes or more, the survey visit will need to be repeated, unless either (a) using the presence approach and there were one or more presence detections, or (b) using either approach and there was an occupied detection.

(1) Surveying with any attire or any scenario that would interfere with the ability to see and hear murrelets (e.g., your raincoat hood up, ears covered, sunglasses, or hat with a bill [not including hard hats]);

(2) Weather or other environmental conditions that interfere with your ability to see murrelets 100 m (328 ft) horizontally or hear murrelets at 200 m (656 ft);

(3) Environmental conditions that interfere with your ability to see up to at least one canopy height at your survey station;

(4) Natural or human-caused noise sources, such as stream noise or vehicle traffic on highways. Observers should move away from these noises before or during the survey if possible (but see limitations on moving stations above, under *Flexibility to Move Survey Station Locations*). As another option, stations could be surveyed in tandem, with one observer placed adjacent to a stream or busy road that has good visibility but limited hearing, while, concurrently, a second observer is at a station with good hearing but limited visibility, provided the two stations essentially cover the same effective area; this survey strategy would only count as one survey visit.

The Statistical Basis for the Sampling Strategy and Interpreting Results

The primary objective of the survey design is to achieve a high confidence that habitat is classified correctly (occupied, not occupied), while a secondary goal is to achieve survey efficiency, (i.e., optimize the number of surveys needed to classify occupancy). The statistical analysis (Appendix B), which informs these two goals, included:

- use of Bayesian analytic methods;
- explicit evaluation of occupancy status at the survey area scale;
- metrics to evaluate the performance of survey design options; and
- a survey option that uses presence detections to inform the classification of occupancy.

Based on this analysis, the survey protocol can result in one of two decisions regarding occupancy status: occupied or not occupied. In statistical terms, and using the chosen performance metric thresholds, if a survey area is in fact occupied, then the survey protocol is expected to result in a not occupied classification less than 5% of the time. Also, when using the presence approach, if a survey area is in fact not occupied, there is a low probability (about 5%

or less) that the survey protocol will result in an occupied classification; when the occupied only approach is used, occupied classifications are not expected to be in error.

The results of the surveys conducted using this protocol will determine an occupancy classification that applies to the **entire survey area**, as described below. See more detail on the statistical analysis in the *Introduction* and Appendices A and B.

Interpreting Survey Results

Occupied Behaviors

Finding nests is difficult as birds are cryptic in plumage and difficult to detect (Nelson 1997, 2020; McShane et al. 2004). Therefore, a set of behavioral criteria has been established to determine if habitat is occupied by murrelets. The behaviors described below, which have been documented at active nest sites and can be observed during an AV survey, are used as indicators of occupancy. Full details on the biology of different murrelet behaviors can be found in Chapter 1: *Behaviors Associated with Nesting*. This section highlights the significance of different behaviors in determining occupancy of an area.

Circling
Circling is a behavior associated with murrelet nesting and occupancy in forest stands (Nelson and Peck 1995; Manley 1999a; Nelson and Wilson 2002; Appendix D). Flight designated as a circling behavior can include complete circles, partial circles, and any arc, curve, or turns that result in a change of direction of 45 degrees or more from the initially observed flight path (Table 2-5). When there is a question about interpreting circling, it is important to continue with planned surveys and to consider additional surveys as soon as possible after the first detection, especially if it is late in the season, to try to detect the birds again and determine association of the murrelet's behavior with the area in question. Any questions can be addressed during communication with regulatory agencies.

Table 2-5: *Classification of Circling Behavior.*

		Flight Arc Observed (Degrees)	
		≥45°	**<45°**
Height of observed circling	≤1 Canopy (subcanopy)	Occupied	Occupied
	>1 to 3 Canopies	Occupied	Presence
	>3 Canopies	Talk to your regulatory agency[9]	Presence

[9] In relatively rare situations where a bird is observed to circle above 3 canopy heights, it may be difficult to associate the behavior with specific habitat on the ground. In other relatively uncommon situations, if the single detection is a partial arc less than 45 degrees above the canopy of a stream corridor, it may represent a murrelet traveling a sinuous path along a stream corridor and not be associated with the area being surveyed. Consult your regulatory agency with any questions about your observation.

Subcanopy behaviors
Subcanopy behaviors include flights at, below, through, into, or out of the forest, dives, landings, or other behaviors observed below the forest canopy of an area. Subcanopy flights are often non-vocal, but wingbeat sounds and jet sounds (diving birds) can be heard (see sections on *Dives* and *Non-vocal Sounds* below). Landings at either active nest sites or other trees are also strong indicators of nesting nearby. Any subcanopy detections indicate that the survey area is occupied.

Dives and Jet Sounds
Shallow or steep dives, which often originate above the canopy but terminate below the canopy, have been observed near known nest trees. These power dives, or jet dives often result in a jet-like sound. Jet sounds and dives that end at or below the canopy are occupied behaviors.

Wingbeats
Murrelet wing beats are unique in a forest setting (typically 10-12 beats per second). These wingbeat sounds are often heard if a murrelet is flying close to the observer and are indicative of occupied behaviors, as they are often made by murrelets flying below the canopy. If there is uncertainty that the wingbeats heard were from a murrelet, then at least one followup survey (in addition to the required number of survey visits) should be conducted as soon as possible at or near the same station to follow up on this detection.

Presence Behaviors

The following behaviors indicate the presence of murrelets. If using the presence approach*,* multiple survey visits with observations of these presence behaviors will indicate occupancy (See *Classification of Survey Areas* below).

Vocalizations
Murrelet vocalizations are described in *Appendix E: Marbled Murrelet Vocalizations*. Interpreting the association of calling (an audio detection) with the status of an area is difficult. Many ‘Keer’ calls are from birds heading to or departing from the local area, but some are from birds in flight traveling beyond the area being surveyed. Calls that emanate from one location within the survey area may be an indication of nesting activity. Vocalizations without an accompanying visual detection are treated as a presence detection.

Above canopy flights
Murrelets generally fly at higher altitudes over land between nesting and foraging areas and fly lower at or near nests. Direct (non-circling/arcing less than 45° **arc**) flights above the canopy are

considered presence detections. While this could indicate nesting, birds could also be flying over the area on their way to habitat elsewhere.

Classification of Survey Areas

The survey results for each survey area should be used to determine the occupancy classification for each survey area.

Occupancy Classification

A classification of occupied or not occupied (unoccupied in the 2003 version of the PSG Inland Survey Protocol) applies at the scale of the entire survey area, based on the following behaviors. In all cases, an **occupied determination based on results from any stratum within a survey area applies to the entire survey area**. Additional guidance on delineating an occupied area can be found in *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/).

Occupied Areas
An occupied area is a survey area where one or more of the following occupied behaviors or conditions is detected:

- discovery of a nest as evidenced by a fecal ring or eggshell fragments (see Appendix C) on structures in the forest canopy, or an old nest cup and landing pad;
- discovery of a downy chick, an egg, eggshell fragments, or marine forage fish on the forest floor;
- birds flying below, through, into, or out of the forest canopy within or adjacent to the survey area, including birds flying over or along roads, young stands, or recently-harvested areas adjacent to habitat;
- birds circling over the survey area (see Table 2-5 in *Circling* section above);
- diving flights, including power dives or other vertical flights that end at or below the canopy, and jet sounds, as detected visually or auditorily;
- wingbeats made by murrelets flying below the canopy;
- birds perching, landing, or attempting to land on branches;
- birds calling from a stationary location within the survey stratum (a detection is considered stationary when three or more calls are heard at less than 100 m (328 ft) from the observer and the position of the bird does not appear to change; rare in most regions); or

- if using the presence approach, three or more survey visits with at least one presence detection of any type, counted across the entire survey area and the two years of surveys (see *Presence Behaviors,* above).

For the presence approach, presence detections include:

- audio detections, except for those types described above as occupied behaviors;
- visual detections of direct (straight line) flights above the canopy; or
- circling detections where murrelets are observed circling at a height greater than three canopy heights and/or flying less than a 45-degree arc at a height greater than one canopy height (see Table 2-5).

Where survey areas overlap, and surveys in two or more survey areas are conducted in the same timeframe, the classification of each survey area should be done independently, based on the survey results within a given survey area. If the detections that led to an occupied classification occurred in the area of overlap, then both survey areas are classified as occupied. If the detections that led to an occupied classification occurred in one survey area outside the area of overlap, the occupancy determination would only apply to that survey area. Additional guidance on how to interpret survey results in such situations can be found in *Terrestrial Habitat Management Recommendations for Marbled Murrelets* (PSG Technical Publication 7; https://pacificseabirdgroup.org/psg-publications/technical-publications/).

Not Occupied Areas
If none of the above behaviors or conditions were detected anywhere in the survey area after completing the required number of surveys over each of 2 consecutive years (see Table 2-2), the survey area is classified as not occupied for a period of five years. Specifically, the following situations would result in a not occupied classification:

- no murrelets were detected;
- when using the presence approach, murrelets were detected in two or fewer surveys and only non-occupied behaviors were observed; or
- when using the occupied only approach, murrelets were detected, but only non-occupied behaviors were observed.

An occupied classification lasts indefinitely, unless there is a catastrophic stand replacement event, in which case we recommend consultation to assess whether the delineation of occupied habitat should be adjusted. **A not occupied classification lasts for five years**, after which habitat would need to be resurveyed or assumed occupied. For example, if you surveyed in 2019-2020, the not occupied classification would last through 2025.

A not occupied classification represents a low likelihood that birds are occupying a survey area for nesting during the years of the survey. However, murrelets may skip nesting during periods of unusually warm ocean temperatures (such as the warm 'blob' in the northern Pacific with unusually high temperatures in the California Current during 2013-2019; Bond et al. 2015, Jacox et al. 2016, Harvey et al. 2020). A not occupied result from a survey conducted during a poor multiple-year ocean period may mean that birds are not present or nesting within the survey area during those years, but may return when ocean conditions are adequate for nesting (strong site fidelity; Betts et al. 2020; see discussion on ocean conditions and site fidelity in Chapter 1).

The analysis used to develop this protocol included data from good and poor ocean years (2003-2014) although it included only the first year of an extended seven-year period of unusually warm ocean temperatures in the California Current. This began with the 2013-2016 warm blob (marine heatwave), followed by the warmest El Niño on record (Jacox et al. 2016) and then another blob and warm water event in 2018-2019 (Harvey et al. 2020, 2021). Data suggest that there is a trend toward more frequent and longer periods of poor ocean conditions (e.g., Wang et al. 2019); if this trend persists, the average occupancy and performance thresholds would likely change from the values used in the statistical analysis. Future work will hopefully provide more clarity and guidance for how to identify poor ocean years, what to do in those cases, and how soon the statistical analysis used in this protocol will need updating.

Recording of Detection Types

In addition to the occupancy classification, associated databases should record the **Detection Type(s)** observed for each survey area, which is useful information for future habitat assessment, survey layout, and/or landscape level analyses. The three detection types possible for a survey area are:

- **occupied** if there are any occupied detections in the survey area (see list of behaviors and conditions under *Occupied Areas* above);
- **presence** if there has been at least one presence detection in the survey area; and
- **no detections** if there have been no detections in the entire survey area.

Data Collection and Reporting

Naming Conventions for Survey Areas, Strata, and Stations

It is critical that each survey area and stratum be identified by a unique name and number that will accurately identify that particular survey area and stratum through time. The survey area, strata, and station names must not change between survey years, even though station locations might. The boundaries of survey area and strata and the survey station locations need to be clearly delineated using GIS mapping (preferably), and/or on a topographic map or aerial photo. The data form for each survey station must include UTM or latitude/longitude coordinates, and legal description (see *Appendix J: Data Forms and Instructions for Completion*). It must be clear which stations belong to a stratum and which strata belong to a survey area, as there is no other way of determining if the strata and survey area were surveyed with the requisite number of visits.

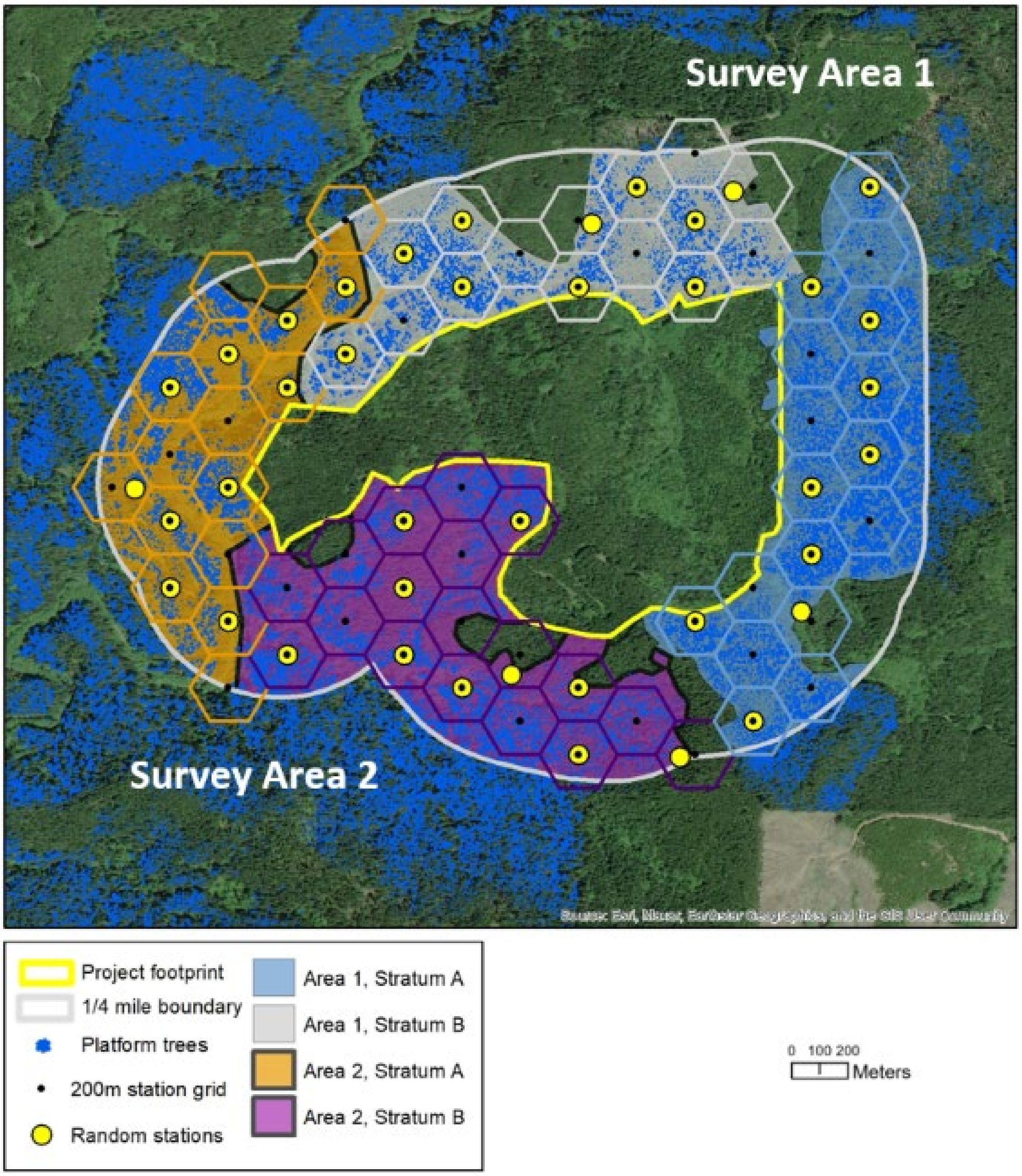
The survey area and Strata names should indicate their connection. For example, if a survey area is named Bullhorn, the two strata within that area should be named Bullhorn 1 and Bullhorn 2. Stations within each stratum should also have unique identifiers; all stations within a stratum must share the same stratum name (e.g., Bullhorn 1, Station #1; Bullhorn 1, Station #2, etc.). Figure 2-10 illustrates one example of this type of naming convention to identify stations, strata, and survey areas. In the case where survey areas overlap, we recommend creating a naming convention that links the two survey areas, for example Bullhorn and Bullhorn Again, and stations in the area of overlap do not need separate names. If this is not possible, it is important to identify UTMs and note the overlap in the notes of the data form and in any survey reports.

Data Forms

Data collected during survey visits need to be recorded on the data form following the instructions provided (*Appendix J: Data Forms and Instructions for Completion*).

Detailed information on murrelet behavior, including flight direction at the beginning and end of the visual detection, needs to be recorded with each observation. In the Notes section of the form, record information on the location of the bird's flight (over drainage, ridge, etc.), unusual behaviors or interactions, and details on subcanopy behaviors (e.g., ‘bird flew between two trees and then headed up the Drift Creek drainage’). Sometimes low-flying birds are observed over non-habitat such as in steep canyons or crossing ridgelines. If there is any question about the significance of subcanopy behaviors, please consult with your regulatory agency. We recommend that observations of birds landing in trees, and chicks, eggshells, or marine forage fish on the forest floor, be reported as soon as possible to your regulatory agency so that active nests can be searched for and contributions can be made to our understanding of murrelet nesting.

Figure 2-10: *Hypothetical station placement for an example using the presence approach. Two survey areas with two strata each are required due to there being greater than 182 ha (450 acres) +/- 10% of habitat associated with the project footprint. Following Table 2-2 for the presence approach, each stratum would have 10 stations. In this example, a hexagonal grid is used to map out the potential station locations, with a spacing of 200 m (656 ft). Note the suggested naming and numbering conventions so that it is clear which hexagons correspond to*



Data Quality and Management

Data quality must be assessed at successive levels, including:

1) review by the field technician after returning from the field;

2) a data form review by a supervising field biologist, who has experience with murrelet surveys; and

3) a final review as data are entered into the appropriate database and/or submitted to a regulatory agency.

This review should ensure that:

- correct and consistent survey area, strata and station identifiers were used;
- the survey visit started and ended on time;
- observations were not disrupted for more than 12 minutes total; and
- occupied and presence detections were accurately defined and recorded.

In addition to each land manager, agency, or entity housing their own survey data, we strongly encourage that survey data also be submitted to State or regional databases. For example, the Washington Department of Fish and Wildlife requires copies of the data as part of a Forest Practices Application for proposed forest practices. In Oregon, data should be submitted to the Oregon Biodiversity Information Center (ORBIC). In California, data should be submitted to the California Department of Fish & Wildlife's Biogeographic Information & Observation System (BIOS) and the USFWS's Arcata Fish & Wildlife Office. For land managers and others housing their own survey data, an Access database template and a PDF-format template for entering survey data electronically can be found on PSG's website under Technical Publications (https://pacificseabirdgroup.org/psg-publications/technical-publications/). While in some states surveys and survey results conducted on private lands are not required to be shared or submitted, we recommend that private land managers submit results from these lands to help understand murrelet distribution.

Data managed consistently using this template will facilitate more options for statistical analysis and future updates to the protocol with more comprehensive and consistently managed data. These data are also critical for scientific research (e.g., looking at changes in occupancy over time). Complete survey data (one line per detection), and consistent data management and naming conventions are essential for this level of analysis.

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APPENDIX A: BACKGROUND INFORMATION ON STATISTICAL ASPECTS OF THE SURVEY PROTOCOL DESIGN AND LEVEL OF EFFORT

Assembled by Gary Falxa and Martin Raphael, with help from the Statistical Analysis Subgroup

The Statistical Analysis Subgroup

The Statistical Analysis Subgroup, which conducted and reviewed the statistical analyses of survey data and the modeling of survey options, was comprised of:

Carol Aron, *Bureau of Land Management, OR*
Jim Baldwin, *U.S. Forest Service, Pacific SW Research Station (retired), CA*
Gary Falxa, *U.S. Fish and Wildlife Service (retired), CA* (Chair)
Tom Hamer, *Hamer Environmental, WA*
Jay Jones, *Weyerhaeuser, WA*
Deanna Lynch, *U.S. Fish and Wildlife Service, WA*
S. Kim Nelson, *Oregon State University, OR*
Nick Palazzotto, *Oregon Department of Forestry, OR*
Martin G. Raphael, *U.S. Forest Service, Pacific NW Research Station (retired), WA*
Aaron Springford, *Weyerhaeuser, WA*
Jake Verschuyl, *NCASI, WA*

The subgroup met 17 times between 30 April 2018 and 7 June 2019, via online video conferencing. The subgroup communicated regularly with PGS's Inland Survey Protocol (ISP) Team, providing progress reports and receiving input and guidance from the Team; most members of the subgroup were also on the ISP team. Statistician Jim Baldwin provided valuable initial exploratory work on topics including Bayesian analyses and the use of 'presence' detections to inform decisions about occupancy. Statisticians Aaron Springford and Jay Jones joined the subgroup in May 2018. Springford, Jones and Baldwin all provided their expertise to the subgroup through the process, and Springford and Jones conducted the primary statistical analyses, after Baldwin's initial work, and prepared a detailed report on their statistical analyses (Springford and Jones 2019, which is Appendix B of this protocol).

Introduction

The overall objective of the survey design is to achieve a high confidence that the occupied status of a survey area is classified correctly. A secondary goal is to achieve survey efficiency, i.e., optimize the number of surveys that are needed to classify occupancy. This protocol relies in part on a new statistical evaluation (Appendix B) conducted to inform the protocol developers how to best achieve those two goals. The statistical evaluation for this protocol differed from that for the 2003 protocol in several ways. These are detailed in the statistical report (Appendix B) and elsewhere in this protocol, but most notably included use of Bayesian analytic methods for explicit evaluation of occupancy status at the survey area scale, new metrics to evaluate the performance of survey design options, and the inclusion of a survey option which uses presence detections to inform the determination whether or not a survey area is occupied by Marbled Murrelets.

Metrics and Thresholds Used to Evaluate Survey Design Performance

Previous analyses, including those for the 2003 ISP and MacKenzie's 2016 analysis, were based on estimating the probability of failing to observe occupancy when a site is in fact occupied, which we term False Negative Rate. This was the primary measure for assessing protocol performance. The statistical analysis for this protocol provided several measures of survey design performance. Candidate survey designs were thus assessed using an expanded set of measures compared to past protocols, including the use of False Omission Rate and False Discovery Rate, which the ISP Protocol Team and its Statistical Analysis Subgroup determined to provide advantages over previously used performance measures, which focused on False Negative Rate.

- The **False Omission Rate (FOR)** quantifies: If the decision was that the area is not occupied, what is the chance that it was in fact occupied?
- The **False Discovery Rate (FDR)** quantifies: If the decision was that the survey area is occupied, then what is the chance that it was in fact not occupied?
- The **False Negative Rate (FNR)** quantifies: The chance that an occupied survey area is surveyed according to the protocol and is found to be unoccupied.

These new metrics provide the ability to evaluate the performance of a candidate protocol design by answering the question "Given that we have followed the protocol, collected the data, and made a decision about whether or not a survey area is occupied, what is the probability that our decision is incorrect?" Previous analyses assessed performance using the FNR, which was also calculated for the new analysis. FNR differs from FOR in that it measures the probability that the survey of a truly occupied Area will determine it to be unoccupied. In contrast, FOR measures the probability that an Area is in fact occupied, if a survey was conducted and determined it was not occupied. A key difference between FNR and FOR is that FOR is based on a condition that is known (a survey's outcome), while FNR is based on an unknown condition (occupancy status of a given survey area). While the differences between FOR and FNR appear subtle, the ISP Team and Statistical Analysis Subgroup determined, in consultation with member statisticians, that the ability to evaluate performance in the context of a survey’s known outcome provided FOR an advantage over FNR, and for FDR.

Due to the conservation and listed status of the Marbled Murrelet, the ISP team chose to focus on achieving a low FOR as the primary assessment measure, to minimize the probability of a survey incorrectly classifying an occupied survey area as not occupied. Following the recommendation of the Statistical Analysis Subgroup, the ISP team set a performance target for FOR of 0.05 or lower, which means that 5% or fewer unoccupied determinations would be in error (and in fact occupied). The 5% value is a statistical criterion familiar to biologists and managers and was acceptable to the ISP team in balancing error rate and required survey effort. In addition, while not setting a specific target for the FDR, the ISP team identified a goal to keep FDR low. The latter is important to land managers because a higher FDR could lead to protection of forest stands from harvest that are in fact not occupied. If managers would like to eliminate the possibility of a false discovery, the protocol provides an option to select the occupied only approach before surveying has begun. This method, which requires a greater number of surveys, is described below in the Sampling Strategy section. Finally, we note that the 2003 protocol used FNR as the primary performance metric. As shown in Tables A-1 to A-3, FNR is sometimes greater than FOR, sometimes similar to FOR, and sometimes less, for a given level of survey effort.

A Comment on the Bayesian Approach

The statistical analysis used to inform this protocol version used a Bayesian analytic approach, which differed from the 2003 protocol, which employed classical or frequentist statistical techniques. The analysis process involved two general steps:

1. Fit a model to existing murrelet survey data to get estimates of the parameters (such as station-level probability of occupancy by murrelets (occupancy as defined in the Glossary) and probability of detection) needed to estimate performance metrics; and

2. Generate protocol performance measures (described in the section *Metrics and Thresholds Used to Evaluate Survey Design Performance*) using the parameters estimated in Step 1.

These steps could have been completed under either a Bayesian or classical framework. The motivation for using a Bayesian approach was pragmatic, as it:

1. Simplified model set-up (Step 1, above);

2. Allowed for the propagation of uncertainty from model estimates to protocol performance assessments (Step 2, above); and

3. Accounted for the non-linear relationship between model estimates and expected performance measures (Step 2, above).

In contrast to classical methods, Bayesian methods require the specification of a prior probability of occupancy (in terms of an area being occupied by murrelets, as defined in Glossary), which represents prior knowledge or ignorance regarding model parameters (used in Step 1, above) before data have been summarized. The choice of prior probabilities has a direct effect on model results. In this analysis, prior probability was based on the calculation of mean probability of occupancy by murrelets derived from the survey database used by the analysis.

Philosophical differences between the Bayes and classical approaches have little practical bearing on how we interpret the protocol assessment results and will not be discussed here.

Estimating probability of an area being occupied using Bayesian methods

If any visit to a survey area results in observing occupied behavior or (if using the presence approach as described in the protocol) surveys result in the requisite number of visits with presence detections, then that area is declared to be occupied. If all required surveys have been completed following the protocol, and the determination for the survey area is not occupied, then one is interested in estimating the probability that the site is actually occupied despite failing to observe occupied behavior or having the requisite number of visits with presence detections.

A Bayesian approach helps. Below we describe how this would be applied in the case of the simpler occupied only approach survey design option. The same principles apply to surveys conducted under the presence approach option, except that the latter case is slightly more complex, because an occupied determination is applied when either an occupied behavior is detected *or* a predetermined number of survey visits with one or more presence detections occurs.

Basic set-up

For any Bayesian analysis, we need to be able to quantify our prior belief about the probability of an area being occupied. Suppose that prior to any surveys we believe that the probability of a particular area being occupied is $\Psi Prior$ and the probability of detection on a single visit is $\boldsymbol{p}$ (a known value). This prior probability can come from professional judgment, from a model prediction, or from previously collected data.

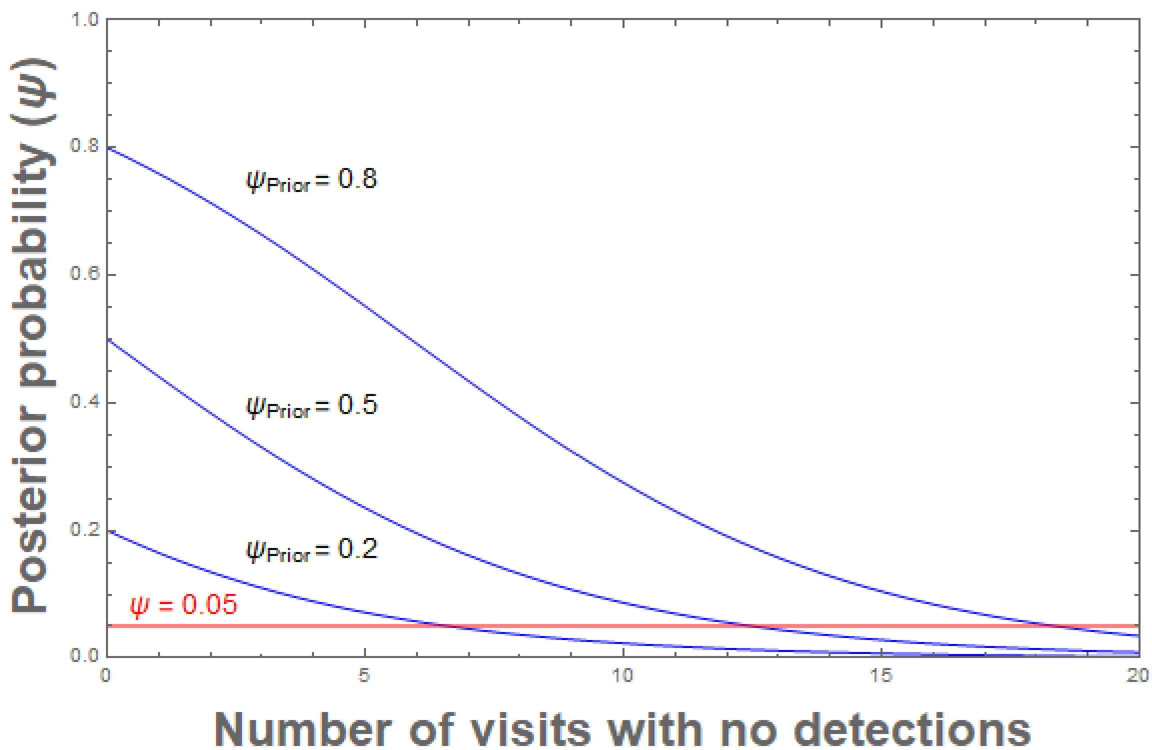
Under this framework, if any survey visit results in an occupied behavior observed, then we know for certain that Ψ equals 1, where Ψ is the posterior probability of a survey area being occupied (note that Ψ differs from $\Psi Prior$). But what is the probability of the area being occupied if we have $\boldsymbol{v}$ visits with no occupied behaviors observed? Note this latter probability is what is measured by the False Omission Rate (if the decision was that the area is not occupied, what is the chance that it was in fact occupied).

We use the standard Bayesian approach and determine what we should now think about Ψ after observing no occupied behaviors in ***v*** visits. "What we should now think about Ψ " is also expressed as a probability distribution (which is called the posterior distribution).

Given a selected prior probability that a site could be occupied (which could be from existing data, professional judgment, or a prediction from a model) and assuming that we can estimate the probability of detecting an occupied behavior at an occupied site during a single visit, we can show how many visits are needed to have a posterior probability of, say, 0.05 or less, that a truly occupied site will be determined by the survey to be not occupied. Setting of a threshold value, such as 0.05, is a subject matter decision rather than a statistical decision, and was determined by the ISP Working Group.

To illustrate how choice of the prior probability (Ψ*Prior*) affects survey requirements, Figure A-1 below shows the resulting posterior probability of occupancy (*Ψ*) under three different prior probability values (0.2, 0.5, and 0.8) and assuming the probability of detection on any one visit is 0.21. Note that the figure and values used for it were chosen simply for illustration purposes and do not represent actual values for this protocol; the principles illustrated apply to either survey design option.

Figure A-1: *Example of the relationship between the choice of prior probability (ΨPrior), number of visits with no detections, and the posterior probability (Ψ). The latter represents the probability that the survey area is in fact occupied when a survey has been conducted according to the protocol and the area determined to be not occupied.*



As illustrated in this theoretical example, to achieve a posterior probability of occupancy of 0.05 or lower when a “not occupied” determination is made, one would need to conduct about 7 survey visits if the prior probability is 0.2, about 13 visits if the prior is 0.5, and about 18 visits if the prior is 0.8. This demonstrates that the number of visits required to meet a given threshold for probability of occupancy increases as the prior probability increases.

The statistical analysis for this protocol version estimated the prior probabilities using average occupancy rates observed in the large dataset of surveys conducted under the 2003 protocol between 2003 and 2014. More details on that dataset and the choice of prior for each situation (which varies by size of survey area—the number of strata) can be found in the statistical report (Appendix B of this protocol).

As noted above, the prior probability used in the analysis for this protocol is based on observed occupancy rates for the 2003-2014 period. Because occupancy rates may change over time (for example, in response to changed ocean conditions under ongoing climate change), we recommend that the prior probability assumptions of this protocol’s analyses be reviewed in the future when sufficient data from new surveys have accrued, and the statistical analyses be redone with the new data if necessary.

Sampling Strategy

In contrast to the sampling strategy of the 2003 protocol, which aimed for full coverage of the habitat by the surveys, the sampling strategy of this protocol, and its underlying statistical analysis, uses a stratified random sampling method. With this sampling strategy, all habitat within the survey area will be covered by potential survey stations and have a chance of being surveyed. In addition, the total number of survey visits required for a survey area are to be evenly (versus randomly) distributed among the survey strata within the survey area; this represents stratification of survey effort at the stratum scale for larger (i.e. multi-strata) survey areas. Equal survey effort is applied to each stratum. This helps ensure that survey effort is applied relatively evenly across the strata. Thus, if the survey calls for 30 survey visits per year for a 3-stratum survey area, 10 survey visits would be assigned to each stratum. Assigning visits randomly across the entire survey area was not recommended by the Statistical Analysis Subgroup because it could result in unequal distribution of survey effort spatially, across available habitat.

When the number of survey visits required in a year is less than the number of potential survey stations in a stratum, not all stations and thus not all habitat will be surveyed that year. See Chapter 2 of this protocol for details on how stations to be surveyed are selected.

Survey Area and Strata Size Limits

The fundamental spatial scale for the protocol is the survey area, which includes the murrelet habitat within the actual project area (such as timber harvest unit) plus a 0.25-mile buffer. Occupancy status is determined at this scale. The statisticians, in consultation with the Statistical Analysis Subgroup and full ISP Working Group, evaluated (modeled) survey designs representing a range of survey area sizes from 1 to 3 strata ("sites" under the 2003 protocol) of up to about 150 ac per stratum, or a maximum of about 450 ac for a survey area of 3 strata. The 150 ac stratum size limit matches the guidance for maximum "site" size under the 2003 protocol, and thus in the data used in the current statistical analysis. This range of survey area sizes was initially determined to represent the large majority of projects. The first round of statistical modeling included 1-stratum and 3-strata survey areas; 2-strata designs were later evaluated and included, by request from the working group. These multi-strata designs provided a statistically-robust protocol that could be applied to survey areas containing more than 150 acres of habitat, up to about 450 acres. Subdividing larger survey areas into strata also spreads survey effort more evenly across the larger areas.

For multi-strata survey areas, the statistical analysis assumed that the occupancy status of a stratum was independent of the occupancy status of other strata within the survey area. This assumption was a result of the data available for the statistical analysis (collected under the 2003 protocol) being at the stratum (Site) scale. The database did not indicate which Sites had been part of larger survey areas; this prevented a robust evaluation of how the occupancy status of one stratum is affected by the occupancy status of other strata within a survey area. We note that while independence has one form and is simple to model, dependence (non-independence) can take many forms mathematically, and could not be evaluated with the available data.

Assuming independence among strata is a conservative approach, helping ensure that the probability of falsely concluding non-occupancy when a site is actually occupied is at least as low as indicated by the statistical analysis. The probability of at least one stratum being occupied under the independence assumption is greater than under a dependence assumption. As a result, the protocol calls for a greater number of survey visits under the independence assumption, than would be required under a dependence assumption.

Survey Design Options

Based on decisions by the ISP Working Group, with advice from the Statistical Analysis Subgroup, the protocol will include having the choice, in advance of starting surveys in a survey area, of either of two survey designs, both of which require surveys over 2 years:

> a) **Occupied Only Approach**: only uses occupied detections to determine occupancy of the survey area. This will require more survey visits than the other option. As in the 2003 protocol, a single occupied detection results in the survey area being classified as occupied; and

b) **Presence Approach**: Uses presence detections, as well as occupied detections, to determine occupancy of the survey area. A survey area is classified as occupied after either a single occupied detection or a specified number of survey visits with 1 or more presence detections (below, and tables A-1 to A-3). The threshold for this number is applied at the scale of the entire survey area and is cumulative over the 2 years of surveys.

In both options, surveys may stop if occupancy is determined prior to completion of all surveys in the survey area.

The second survey design approach is provided to take advantage of new statistical analyses that showed that repeated survey visits with presence detections are a strong predictor of eventually observing occupied behaviors. Thus, using the information from presence detections to inform the occupancy determination allows achieving a determined performance level with fewer survey visits, compared to the first design approach. The ISP Working Group felt that providing this option, which requires fewer survey visits, was merited, particularly considering that this new protocol version generally requires more survey visits than previous versions. This approach does introduce a small FDR probability (Table A-1), reflecting the possibility that a site is not in fact occupied despite multiple visits with presence detections. This protocol also includes the occupied only approach which requires observation of occupied behaviors to determine that a site is occupied, but which requires more survey visits. This approach is similar to previous protocol versions, and was included to provide users an option which minimizes FDR, but at the cost of conducting more surveys.

To maintain consistency with the statistical analysis methods and assumptions, the decision for which option to use must be made and documented prior to initiating any surveys in a survey area. Once survey visits have begun, the survey design for that survey area must not be changed. A protocol which allows switching survey design has been advised against by multiple statisticians, including all those who participated in the analysis for this protocol, primarily because the existing statistical analysis cannot be applied to a design allowing switching. For example, switching from the option using presence detections to the one using only occupied detections is problematic, as doing so could use information from initial surveys with presence detections to change to a design that ignores those detections, violating assumptions of the statistical modeling. This kind of adaptive approach would require further analysis to quantify expected performance.

Within a larger program with many survey areas, different survey design options may be selected for different survey areas, but the survey design option still needs to be chosen in advance of any surveys for each individual survey area.

Relationship Between Current Statistical Analysis and Previous Analyses

The statistical analysis underlying this protocol is detailed in Appendix B. It is built on, but differed from, previous analyses, including those done for the 2003 protocol and the more recent work of MacKenzie (2016). The MMTC ISP commissioned Dr. Darryl MacKenzie to conduct an initial statistical reanalysis of the 2003 survey design, to inform a revised protocol (MacKenzie 2016). Key findings of MacKenzie (2016) included: 1) the occupancy rate of surveyed sites appeared to have declined since 1998 (the last year of data included in the analysis for the 2003 protocol), and 2) contrary to the assumption of prior analyses, not all Stations within an occupied Site are occupied (spatial heterogeneity in occupancy exists at this scale).

To meet the needs of the ISP revision, the MMTC ISP team decided to pursue a new analysis that would use a Bayesian approach and which could incorporate features that were not present in the MacKenzie 2016 analysis. Ways in which the analysis of this protocol differed from MacKenzie's analyses include:

- The protocol analysis evaluated 2-year survey designs; MacKenzie's analysis evaluated a 1-year survey design;
- The protocol analysis allowed use of presence detections to inform occupancy determinations, and treated observation of circling behavior as an occupied detection. This reflects decisions by the MMTC ISP Working Group in 2018-2019 to treat most circling as an occupied behavior in this protocol version;
- The protocol analysis updated and did additional quality control of the survey results database used by the analysis;
- The protocol analysis focused on False Omission Rate as the performance metric; MacKenzie used a metric based on False Negative Rate; and
- The current analysis explicitly incorporated uncertainty throughout the analysis, from model parameter estimation through the final estimates of protocol performance.

Tables with Performance Information Used to Inform Protocol Design Decisions

Tables A-1 to A-3 below are a condensed version of tables provided by Springford and Jones (2019) in the statistical analysis report (see also Appendix B of this protocol), and were used by the Statistical Analysis Subgroup and ISP Working Group to help guide decisions about protocol design, including the number of survey visits required under the protocol for different survey area sizes and survey design options *(Presence Approach* or *Occupied Only Approach).* These have been condensed from the original tables in the statistical report to provide the critical performance metrics of interest (columns), and to focus on the design options (rows) with performance values in the range of performance targets identified by the ISP Working Group (FOR of 0.05 or lower, relatively low FDR). For each performance measure, the chart provides the mean values from the many simulations conducted for each scenario as part of the statistical analysis. The Statistical Analysis Subgroup decided to use the mean values; other statistical values such as measures of confidence around the mean values, are provided in the original tables (Appendix B).

These tables present the relevant performance measures from the statistical analysis report across a range of survey effort levels. These are shown for the 3 survey area sizes addressed by the protocol, as indicated by the value in the "Number of Strata" column:

- survey areas containing 1 stratum (area of about 150 ac or smaller, Table A-1);
- survey areas containing 2 strata (area of about 150 to 300 ac; Table A-2); and
- survey areas containing 3 strata (area of about 300 to 450 ac, Table A-3).

In each case, performance is measured at the scale of the entire survey area, and the occupancy determination is applied at that same scale. For design options which use presence detections to evaluate occupancy, the number of surveys with presence detections is assessed at the survey area scale and across the 2 years of surveys.

Presence Designs:

Each chart provides performance measure results for a range of survey visits with presence detections ("Presence Threshold" column) that would be required to conclude "occupied" status for a survey area. The values shown (2 through 4) represent the number of surveys with presence detections that would be required to assign occupied status. Note that a single occupied detection would also assign occupied status to the survey area. The ISP team decided to focus on a threshold of 3 surveys with presence detections to best minimize both FOR and FDR; the charts include values of 2 and 4 for illustrating the tradeoffs between different thresholds. "NA" in the Presence Threshold column indicates a row which provides performance measures for an occupied only design, which would not use presence detections, requiring an occupied detection to determine "occupied".

Note that the charts have 2 columns representing the number of survey visits: one is the number of visits per year per stratum, the other is the number of survey visits per year for the entire survey area. These 2 values are equal for a single-stratum survey area. Note also that the total surveys required over the 2-year survey period will be double that of the column with survey visits at the Area scale.

Occupied Only Designs:

- Each chart (scenario) begins with rows showing the performance metrics for a design which only uses occupied detections to evaluate occupancy. These have “NA” in the Presence Threshold column;

- For the occupied only designs, the number of surveys required per stratum increases non-linearly as the number of strata increases; all else being equal, survey areas with more strata require more survey visits per stratum per year to achieve the same performance. This is a result of: 1) the assumption of independence of occupancy status of strata within a survey area; and 2) in order to demonstrate non-occupancy for the entire survey area, the design needs to demonstrate non-occupancy in each of the multiple strata; and

- Note that for the single-stratum case, FNR ("FN mean" column) is higher than FOR. This is because FOR and FNR measure performance slightly differently (see Appendix B for more on the metrics). For multi-stratum survey areas, FNR tends to be equal to or smaller than FOR.

Tables A-1 to A-3: *Performance measures for 1-stratum, 2-stratum, and 3-stratum survey areas, for selected levels of survey effort. Values are from the statistical report (Springford and Jones 2019, and Appendix B of this protocol). The rows highlighted in each table represent the rows relevant to the protocol's recommended level of survey effort for the occupied only design (blue; "Occupied Only Approach" in the protocol) and for designs using presence detections to inform occupancy determinations (yellow; "Presence Approach" in the protocol). In Table A-2, two rows are highlighted in blue as the recommended level of effort, 17 survey visits per year per stratum, is interpolated between the 2 rows provided by the statistical report.*

Table A-1: One-Stratum Case

(Based on Scenario 4 in statistical report)

Number of Strata	Presence Threshold (at Area scale)	Visits per Year (for Area)	FOR mean	FDR mean	FN mean	FP mean	Visits per Year per stratum
1	**NA**	**12**	**0.047**	**0.000**	**0.118**	**0.000**	**12**
1	NA	14	0.036	0.000	0.083	0.000	14
1	NA	18	0.019	0.000	0.045	0.000	18
1	2	6	0.045	0.036	0.109	0.015	6
1	2	8	0.021	0.061	0.050	0.025	8
1	2	10	0.011	0.085	0.024	0.038	10
1	**3**	**8**	**0.041**	**0.005**	**0.109**	**0.002**	**8**
1	3	10	0.023	0.009	0.054	0.004	10
1	4	10	0.037	0.001	0.086	0.000	10
1	4	12	0.021	0.001	0.050	0.001	12

Table A-2: Two-Stratum Case

(Based on Scenario 7 in statistical report)

Number of Strata	Presence Threshold (at Area scale)	Visits per Year (for Area)	FOR mean	FDR mean	FN mean	FP mean	Visits per Year per stratum
2	**NA**	**32**	**0.053**	**0.000**	**0.053**	**0.000**	**16**
2	**NA**	**36**	**0.039**	**0.000**	**0.039**	**0.000**	**18**
2	1	12	0.033	0.232	0.023	0.306	6
2	1	16	0.015	0.276	0.008	0.393	8
2	2	12	0.083	0.052	0.082	0.052	6
2	2	16	0.039	0.078	0.036	0.085	8
2	**3**	**20**	**0.039**	**0.022**	**0.037**	**0.023**	**10**
2	3	24	0.019	0.036	0.018	0.038	12
2	4	20	0.063	0.003	0.064	0.003	10
2	4	24	0.035	0.007	0.034	0.007	12

Table A-3: Three-Stratum Case

(Based on Scenario 6 in statistical report)

Scenario	Number of Strata	Presence Threshold (at Area scale)	Visits per Year (Area)	FOR mean	FDR mean	FN mean	FP mean	Visits per Year per stratum
6	**3**	**NA**	**60**	**0.047**	**0.000**	**0.026**	**0.000**	**20**
6	3	NA	66	0.033	0.000	0.018	0.000	22
6	3	1	24	0.020	0.219	0.005	0.528	8
6	3	2	24	0.049	0.085	0.024	0.167	8
6	3	2	30	0.026	0.115	0.010	0.240	10
6	3	3	30	0.052	0.036	0.025	0.067	10
6	**3**	**3**	**33**	**0.039**	**0.043**	**0.020**	**0.081**	**11**
6	3	3	36	0.025	0.052	0.011	0.102	12
6	3	3	42	0.014	0.072	0.007	0.142	14
6	3	4	36	0.046	0.014	0.024	0.027	12
6	3	4	42	0.028	0.023	0.014	0.043	14

Literature Cited

MacKenzie, D.I. 2016. Probability of MAMU Occurrence Reanalysis. Proteus Wildlife Research Consultants. 77 pages including appendices.

Springford, A. and J. Jones. 2019. Evaluation of a set of survey protocols for marbled murrelets. Report prepared for: The Pacific Seabird Group Marbled Murrelet Inland Survey Protocol statistical subcommittee. 326 pages including appendices. Available at: https://pacificseabirdgroup.org/psg-publications/technical-publications/

Appendix B: Evaluation of a set of survey protocols for marbled murrelets

Report prepared for

The Pacific Seabird Group marbled murrelet
Inland Survey Protocol statistical subcommittee

Aaron Springford and Jay Jones

July 12, 2019

Note: Appendix B includes the text of the 2019 statistical report by Springford and Jones, but does not include over 300 pages of tables and figures which are in an appendix to that report. See the full statistical report with all the figures and tables at: https://pacificseabirdgroup.org/psg-publications/ technical-publications/

Executive summary

We describe a statistical analysis of marbled murrelet survey data and the evaluation of a set of survey protocols to inform the formulation of a new inland survey protocol.

This report expands on the work of MacKenzie (2016) in several ways:

1. The occupancy model includes a possible change in occupancy status between the two years of the survey. This addition was suggested by MacKenzie (2016) and others.
2. The occupancy model includes presence detections as a possible outcome of a survey visit (Baldwin, 2018).
3. The set of possible survey protocols includes a threshold number of visits with presence detections beyond which an Area is classified as occupied (Baldwin, 2018).
4. The set of performance measures have been expanded to consider false positives (due to the use of presence detections in Area occupancy classification) and to consider the probability of Area occupancy (Baldwin, 2018).
5. Estimates of occupancy model parameters were obtained in a Bayesian framework, and uncertainties were carried through to the calculation of performance measures. This contrasts MacKenzie's (2016) approach which was based on *reasonable values* for parameters.

Several scenarios representing Areas of differing size and assumptions regarding the coverage of survey stations were examined. For each scenario, a set of survey protocols were applied that varied the number of survey visits in each of two years and the number of visits with presence detections required to categorize an Area as occupied. Two performance measures – the False Omission Rate (FOR) and the False Discovery Rate (FDR) – were used to evaluate the performance of the different protocols for each scenario. The FOR is the probability that an Area is occupied given that it was classified as unoccupied, and the FDR is the probability that an Area is not occupied given that it was classified as occupied. We include tabular and graphical summaries of the trade-off between protocol design, sampling effort, and both the FOR and FDR.

A stated goal of this work was to consider Areas larger than a current-protocol Site. However, due to a lack of information regarding which Sites belong to the same Area in the existing data, we are relying on an assumption of independence in occupancy status among Sites in the same Area to evaluate candidate protocols in these larger Areas. Given that there is some evidence of dependence among Sites in the same Area with respect to occupancy status, we are not confident in the estimates of performance for large Areas that assume independence. For a given protocol, dependence among sites will lead to a FOR that is below the target, and a FDR that is above the target.

We encourage future protocol surveys to collect and report information that will allow issues of spatial dependence and missing data (due to stopping at occupancy detection or otherwise) to be properly incorporated into future statistical analysis. Station sampling should be done according to typical spatial sampling procedures. A complete recording of Station locations, both sampled and unsampled, should be retained to evaluate future updates to the protocol. This includes both the locations and times of sampling, for survey visits that occurred and survey visits that did not.

Introduction

This report describes the work undertaken by the authors in collaboration with the Pacific Seabird Group (PSG) marbled murrelet (MAMU) Inland Survey Protocol (ISP) statistical subcommittee. The overarching objective as we see it is to provide the best possible evidence-based advice to the PSG's-ISP Working Group of the Marbled Murrelet Technical Committee for their revision of the MAMU survey protocol, subject to various constraints. We endeavor to present the set of assumptions underlying the work so that the results can be used appropriately to guide the protocol revision.

A simplified summary of the current (ca. 2003) protocol as practiced is as follows (Evans Mack et al, 2003):

- An area of interest that is the subject of an upcoming management action is defined. Potential MAMU habitat in the vicinity of the area of interest is determined. The survey area (*Area*) is the potential habitat within the area of interest in addition to the potential habitat within one-quarter mile (402m) of the boundary of the area of interest.
- Under the 2003 protocol "[a]n occupied site is where murrelets have been observed exhibiting subcanopy behaviors, which are behaviors that occur at or below the forest canopy and that strongly indicate that the site has some importance for breeding"; occupied sites also include nest sites. Observation of a single "occupied" behavior results in the Area being classified as occupied (Evans-Mack et al. 2003).
- The Area is subdivided into *Sites* that are no larger than about 150 acres (61 ha).
- Survey *Stations* are locations at which survey observations take place. They are chosen to provide coverage of the Site under an assumption of maximum detection distance of 200m from each Station. This typically results in 5 or 6 Stations per Site.
- Site visits are made for up to two years. If at any point an occupied detection is made, the Area is determined to be occupied and survey visits stop. The number of visits described below are minimum numbers of visits.
    - In the first year, a minimum of five Site visits are made to distinct Stations, if possible. If MAMU are observed to be present but not observed to be occupying the Site (presence detection), then additional visits are made to the Site to a total of nine visits.
    - In the second year, an additional five Site visits are made. If a presence detection was made in the first year or during the first five Site visits in the second year, then additional visits are made to the Site to a total of nine visits.

Herein we describe: (1) the analysis of data collected during MAMU surveys performed under the current protocol in order to estimate quantities of interest and their uncertainties; and (2) the evaluation of a set of candidate protocols using these estimates. Candidate protocols are evaluated using a set of performance metrics that quantify expected error rates were a given protocol implemented.

Discussions with the statistical subcommittee, and consultation with the full ISP Working Group, have resulted in the following baseline requirements for an updated protocol:

1. Evaluation and execution of the protocol should be done at the Area scale, not the Site scale.

2. The protocol surveys will be conducted over two years. An Area is defined to be occupied if it is occupied in at least one of the two years. This implies that the occupancy status of an Area can change from year one to year two.
3. Station spatial density should reflect an effective radius of 100m for detecting "occupied" behaviors; rather than the 200m radius used in the 2003 protocol. As a result, there will be four times the number of Stations per unit of area compared to the 2003 protocol.
4. Station sampling should be done according to typical spatial sampling procedures. A complete recording of Station locations, both sampled and unsampled, should be retained to evaluate future updates to the protocol.

Data

Records of MAMU surveys conducted in Oregon and Washington state since 2003 were obtained from Kim Nelson at Oregon State University, and include Washington records provided by the Washington Department of Fish and Wildlife from their database, Oregon records provided by Oregon Department of Forestry, and records from an Oregon database assembled by Kim Nelson and others for surveys on federally-managed lands and other ownerships. California had many fewer protocol-level surveys since 2003 than did Oregon or Washington, and no database existed for California surveys since 2003, thus California data were not included. These are the same data provided to MacKenzie (2016). The data contain a unique Site identifier and Station identifier for each survey visit, but no Area identifier. As described in MacKenzie (2016), many fields have a high proportion of missing values, especially those related to environmental conditions at the time of the survey sample and whether the protocol was followed.

We restricted analysis to records from those Sites that had surveys in the year 2003 or later, except those Sites that had surveys in years prior to 2003 and whose final survey was in 2003. This restriction was intended to exclude Sites that were surveyed according to the pre-2003 protocol. Only data from 2003-2014 were used in analysis. This resulted in 29,631 unique survey visits at 10,453 Stations in 3,170 Sites. We categorized the possible outcomes of a survey visit to a Station as follows:

1. No detection
2. Presence-only detection (from the PresenceDet data field)
3. Occupied detection (from the OccupiedDet or CirclingDet field)

We defined circling behavior to be an occupied detection, in contrast to MacKenzie (2016) who excluded circling from their analysis. This reflects decisions by the full ISP Working Group in 2018-19 to treat most circling as "occupied" behaviors in the new protocol.

Framework

Our objective is to evaluate a set of candidate protocols against one or more performance measures in order to determine which protocols in the set are expected to achieve performance targets. Figure 1 sketches the workflow. In order to select one or more protocols for recommendation, several inputs are required:

1. A set of candidate protocols to consider.
2. One or more performance measures.
3. For each performance measure, a criterion that defines acceptable performance.

4. Data collected during previous surveys.

In addition, a series of assumptions are required to define the occupancy model to be estimated from the existing data and the simulation of surveys under candidate protocols.

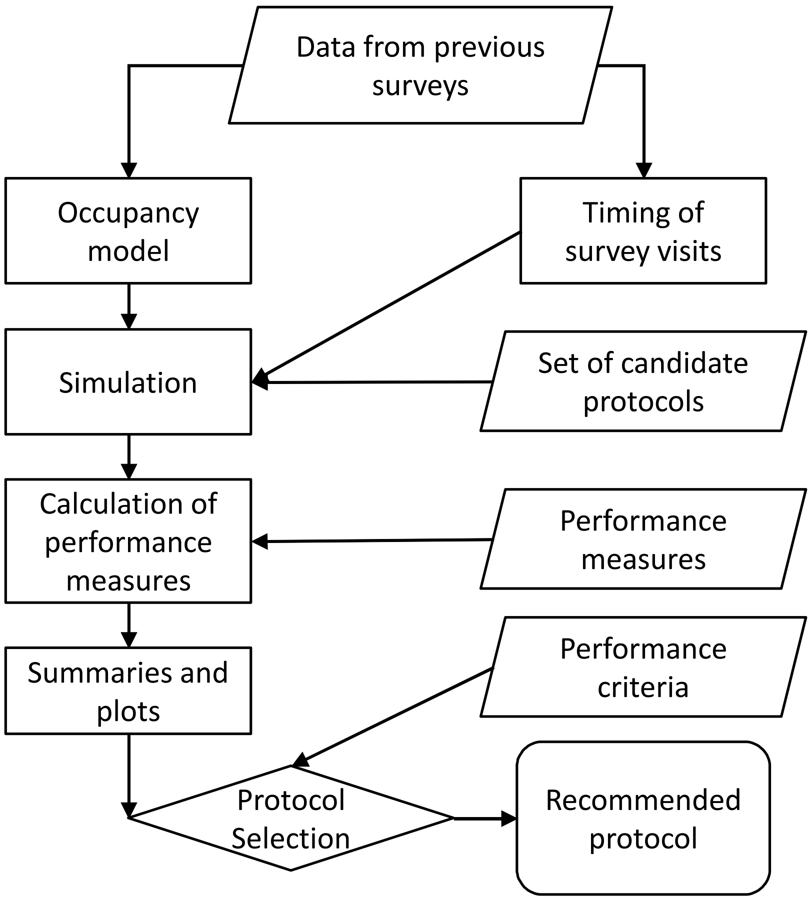


Figure 1: The framework for quantitative evaluation of candidate protocols. This report contains results for all components except for Protocol Selection, Performance criteria, and Recommended protocol.

Estimation of occupancy model parameters

As indicated in Figure 1, the evaluation of candidate protocols relies on the specification and fitting of an occupancy model in order to describe the data-generating process. A simplified version of the multi-scale occupancy model originally used by McKenzie (2016) is:

$$\begin{aligned} Z_i &\sim \mathrm{Bern}(\Psi) \\ V_{ij} &\sim \mathrm{Bern}(\theta Z_{ij}) \, , \\ Y_{ijk} &\sim \mathrm{Bern}(p_{ij} V_{ij}) \end{aligned}$$

where Z is the occupancy status of a Site, V is the occupancy status of a Station, Y are the data (was occupancy detected or not?), i is the Site, j is the Station, and k is the visit. This basic model set-up allows for differences in occupancy status among Stations within an occupied Site (sometimes referred to as "heterogeneity among survey stations"). Under consultation with the statistical subcommittee, we modified the model to include features that were believed to be important in describing MAMU occurrence and detection during protocol survey visits. We also modified the model to reduce complexity. These extensions were:

a. Occupancy probability Ψ differs by jurisdiction (Washington or Oregon)
b. Detection probability p is a smooth function of the day of the year at which the survey visit occurred, with an offset according to the jurisdiction
c. The occupancy state variable Z can change between the two years of the survey. The probability of a change of state depends on the jurisdiction.
d. The conditional Station-level occupancy probability θ differs by jurisdiction
e. The set of potential observations Y is expanded to include presence-only detections.

These modifications address two tasks outlined in the original Statement of Work:

1. The extension of the multi-scale model to a multi-year model.
2. The inclusion of presence detections (elsewhere called *multi-state*; Baldwin, 2018).

The full model specification is in the Appendix. We provide an overview of the extension to a multi-year model and the inclusion of presence detections next.

Extension to multi-year model

Calling t the calendar year, the state variable for the Site occupancy Z_{it} depends on the value of the Site occupancy status in the previous year in the following way:

Probability of new occupancy: $P(Z_{it} = 1 | Z_{i,t-1} = 0) = \psi_{i,01}$

Probability of no new occupancy: $P(Z_{it} = 0 | Z_{i,t-1} = 0) = \psi_{i,00} = 1 - \psi_{i,01}$

Probability of local extinction: $P(Z_{it} = 0 | Z_{i,t-1} = 1) = \psi_{i,10}$

Probability of maintaining occupancy: $P(Z_{it} = 1 | Z_{i,t-1} = 1) = \psi_{i,11} = 1 - \psi_{i,10}$

Extending this Site occupancy process out over many years, we can get the marginal or long-run probability of occupancy. It is: $P(Z_{i\cdot} = 1) = \Psi_i = \frac{\psi_{i,01}}{\psi_{i,01} + \psi_{i,10}}$,

and the complementary probability is $P(Z_{i\cdot} = 0) = 1 - \Psi_i$

We define the probability of occupancy in the first year of surveying a Site to be Ψ_i, after which the conditional probabilities of occupancy are used. The Ψ_i parameters of this simple model for the underlying occupancy process vary by jurisdiction, but the probability of new occupancy ψ_{01} does not. This modeling choice was made in consultation with the statistical subcommittee with the goal of limiting the number of parameters to estimate.

Inclusion of presence detections

Including presence detections as a possible survey visit outcome allows us to evaluate protocols that classify occupancy based on these presence detections. To our knowledge, this was first suggested by Baldwin (2018), in which it was described as "multi-state". We prefer not to use this terminology, to distinguish observations (none/presence-only/occupied) from the underlying state (unoccupied/occupied).

Define U_{ijk} to be the presence observation. That is, $U_{ijk} = 1$ if presence was observed and zero otherwise. If no occupancy is detected, but the Station is occupied, then $P(U_{ijk} = 1 | V_{ij} = 1, Y_{ijk} = 0) = q_1$. If no occupancy is detected, and the Station is not occupied, then $P(U_{ijk} = 1 | V_{ij} = 0, Y_{ijk} = 0) = q_2$. The usefulness of presence detections for categorizing Site occupancy relies on a difference between these two probabilities; if there is not a difference in the probability of a presence-only observation between occupied and unoccupied Stations, then it seems unlikely that presence-only observations could be used to differentiate occupied from unoccupied Stations, and ultimately occupied from unoccupied Areas.

To complete the mathematical specification, define a new survey outcome variable W_{ijk} which takes values:

$$W_{ijk} = \begin{cases} 0 & \text{if } U_{ijk} = 0 \text{ and } Y_{ijk} = 0 \\ 1 & \text{if } U_{ijk} = 1 \text{ and } Y_{ijk} = 0 \\ 2 & \text{if } Y_{ijk} = 1 \end{cases}.$$

A model (the likelihood) for W is

$$W_{ijk} \sim \text{Categorical}\left(V_{ij}(1 - p - q_1) + (1 - V_{ij})(1 - q_2), V_{ij}q_1 + (1 - V_{ij})q_2, V_{ij}p_{ij}\right)$$

A summary table of the probabilities of different survey observations is below:

	True state of occupancy	
Observation	Occupied: $V = 1$	Unoccupied: $V = 0$
Not observed: $W = 0$	$1 - p - q_1$	$1 - q_2$
Presence only: $W = 1$	q_1	q_2
Occupancy: $W = 2$	p	0

Model parameter inference

A Bayesian paradigm was used for inference of model parameter values. Details of priors for model parameters are presented in the Appendix. The posterior distribution of model parameters is not available in closed førm, so draws were obtained from the posterior distribution using the R package *nimble* version 0.7.1 (NIMBLE, 2019), which implements a hybrid Gibbs sampler for obtaining draws using Markov Chain Monte Carlo (MCMC). We used three MCMC chains each of total length 110,000, dropping the first 10,000 samples of each to avoid including draws that had not yet converged on the target distribution. The chains were thinned by 100, resulting in 1,000 samples in each, or 3,000 total samples. Visual inspection of the chains did not suggest a lack of convergence to the target, although mixing was slow for the parameter q_2. Parameter draws used in the evaluation of candidate protocols were further thinned to 200 total samples due to computer memory limitations. We expect this to be sufficient resolution to obtain approximate expected values and credible intervals for the performance measures.

Predictive model checking

One way to evaluate the ability of a statistical model to describe the data is to compare observed data to hypothetical data generated according to the model (Rubin, 1984; Gelman et al, 1996). However, in this case we can only partially describe the process that may have generated the observed data, because there is incomplete information about the full survey design. The protocol under which the data were generated specifies a data-dependent stopping rule. However, it can and has happened that survey visits that were planned were not in fact carried out, and the reason for this stopping is not available from the data in hand. Stopping for unknown reasons makes predictive model checking challenging because we can't specify what data should be missing.

To address this challenge, we restricted predictive model checking to those Sites in the data for which we were able to deduce the reason for stopping. In general, there was no information about which Sites were part of the same Area, so we were not able to identify stopping that occurred because of an occupancy detection at a different Site in the same Area. This results in many Sites being dropped from the model check; only 551 Sites matched the number of visits expected under the protocol according to Site occupancy detections alone (Figure 2). Using information from these 551 Sites, we generated 300 datasets from the predictive distribution of the occupancy model. We specified Sites with similar characteristics to those for which the stopping rule was evident (jurisdiction/state, day of year of visits, and median number of Stations), and applied the same protocol-specified stopping rule. The data generated using this procedure is not expected to match the observed data perfectly – for example, Sites with very few visits may tend to be over-represented in the data because occupancy detections early on at a Site will be kept but all other Sites in the same Area will be dropped. The proportion of Sites with occupancy detections and the proportion of Sites with presence detections match reasonably well with the observed proportions (Figure 3).

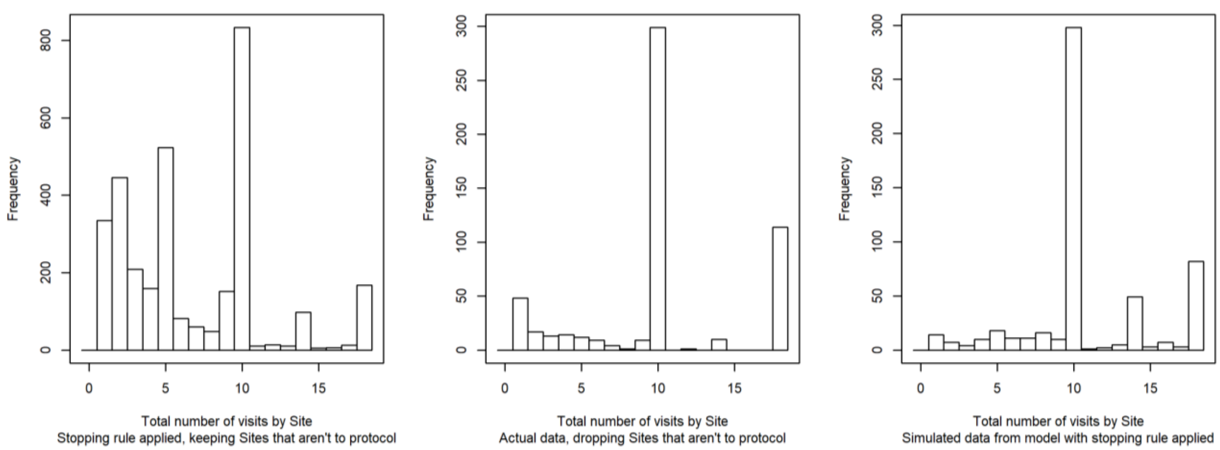


Figure 2: The distribution of the number of survey visits per Site. The left panel shows the total number of visits by Site after applying the 2003 protocol stopping rule. There are many Sites with fewer visits than would be expected. The middle panel drops Sites that were not obviously surveyed according to the protocol because they did not have an occupancy detection on the final visit, or because they did not perform enough surveys based on presence detections. The right panel is a single simulation from the

occupancy model coupled to the protocol stopping rule – model parameters were set to their expected values from the posterior distribution. The actual data appears to identify occupancy with fewer visits; this could be due to several factors such as surveys targeting the best habitat first, or surveys stopping at a Site because of an occupancy detection at another Site within the Area.

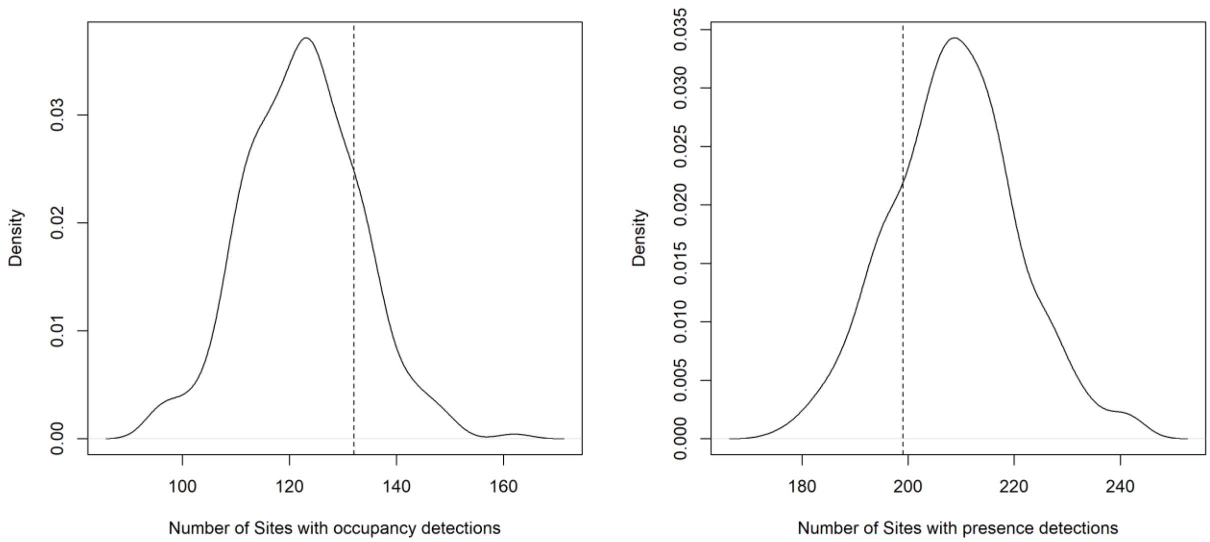


Figure 3: Posterior predictive check of the number of Sites with occupancy and presence detections. The distributions are from 300 simulated Sites drawn from the posterior predictive distribution with stopping rule applied. The vertical dashed line shows the value from the data for which the Site stopping rule was known to have matched the protocol stopping rule.

Evaluation of candidate protocols

Due to the complexities of the occupancy model arising from variation in probability of detection as a function of the day of year, variation in occupancy status, and other factors, we chose a simulation approach rather than an analytic approach to evaluate possible protocols. We simulated the true state of nature and resulting survey data for a number of Areas according to different scenarios, applied a set of survey protocols of interest, and summarized the performance of the protocols using predetermined performance measures.

Generating data from the model

We used the posterior distribution for model parameters described under *Estimation of quantities* to simulate data from hypothetical areas. Because the estimation model includes a description of the full data-generating process, we can simulate both the observations and true state of nature for the hypothetical areas, which allows us to estimate various measures that summarize the performance of each protocol in the set.

Outline of simulation

The simulation generates states of nature and observations for hypothetical MAMU survey areas as defined by a set of scenarios and survey protocols. Most of the simulation follows directly from the occupancy model. For each Area, two years are simulated. Areas were *simulated for each jurisdiction equally (Washington and Oregon). Areas can optionally be subdivided into strata that are assumed to be occupied independently. For a given scenario and survey protocol, the simulation proceeds in five steps:*

1. Generate occupancy status for each Area Stratum.
    - Depends on jurisdiction.
    - Depends on occupancy in the same Area Stratum in the previous year.
2. Generate the occupancy for each Station in each Area Stratum.
    - Depends on Area Stratum occupancy.
    - Depends on jurisdiction.
    - (Optional) Assume occupied Area Stratum has at least one occupied Station.
3. Generate sampling times.
    - In proportion to surveys in the existing data, for Sites with nine visits in a year.
4. Calculate occupancy detection probability.
    - Depends on jurisdiction.
    - Depends on sampling timing.
5. For each survey visit, generate an outcome: No MAMU detected, Presence only, or Occupied.
    - Stations are visited in random order.
    - All Stations are visited once before any Station is visited twice.
    - For stratified random sampling: Each stratum is visited once before any stratum is visited twice.

Scenarios

The scenarios define the characteristics of the Area under consideration. We considered six scenarios intended to explore the effects of Area size, Station occupancy in occupied Areas, and stratification in large Areas. The scenarios were:

1. A tiny Area with 3 Stations. Station occupancy is not assumed even if the Area is occupied. That is, it could be possible to position Stations in such a way that occupancy can't be detected, even if the Area is occupied.
2. A tiny Area with 3 Stations. At least one Station is occupied if the Area is occupied. That is, Stations provide coverage of the Area.
3. A small Area with 6 Stations. This size of Area is not uncommon, and would not have been out of place in the Areas surveyed under the current protocol.
4. An Area with 20 Stations. This size of Area is equivalent to the maximum Site size under the current protocol, about 150 acres (61ha).
5. An Area of about 450 acres (183ha), with 60 Stations, 3 Strata with independent occupancy, and simple random sampling. This and scenario 6 represent Areas substantially larger than 150 acres (61 ha), and thus requiring more survey effort than scenarios 1-4. These would be Survey Areas with multiple Sites under the 2003 protocol.
6. An Area of about 450 acres, with 60 Stations, 3 Strata with independent occupancy, and stratified sampling with sampling strata matching the underlying occupancy strata.
7. **(Additional Scenario added at the request of PSG).** An area of about 300 acres, with 40 Stations, 2 Strata with independent occupancy, and stratified sampling strata matching the underlying occupancy strata. **These results are in the appendix.**

The set of candidate protocols

Members of the set of candidate protocols can be differentiated by three attributes:

1. The amount of sampling effort applied. This is quantified as the number of Station visits per year, under the assumption that the same number of visits are to be made in each year, unless the survey is stopped due to a decision criterion being met. Because Areas of different sizes will have different numbers of Stations, the range of sampling effort considered under each scenario will differ.
2. The type of sampling to be done. In scenarios with Areas comprised of 20 or fewer Stations, this is always simple random sampling without replacement, so that all Stations are visited once in a season before any are sampled twice. In scenarios with Areas comprised of 40 or 60 Stations, this is either simple random sampling without replacement or stratified sampling of sub-Areas / strata that are 20 Stations each. Stratified sampling is also done without replacement. In addition, strata are sampled in turn (with an order that is randomly determined for each turn), so that each stratum is sampled once before any are sampled twice, each is sampled twice before any are sampled three times, and so on.
3. Occupancy determination. For all candidate protocols, a single occupancy detection on any Station visit will result in an occupancy determination for the Area. Some protocols will also use presence detections to determine occupancy, and will differ in the number of station visits with presence detections required for occupancy determination. Presence detections are recorded on a per-visit basis; multiple presence detections on a single visit to a single Station count as a single presence detection for the purposes of deciding Area occupancy.

Performance measures

We evaluated each candidate protocol in terms of four performance measures. These performance measures can be derived from the following decision table:

		Decision or claim	
		Not occupied	Occupied
True state of nature	Not occupied	True negative (TN)	False positive (FP)
	Occupied	False negative (FN)	True positive (TP)

The four performance measures are:

1. The False Negative Rate: $FNR = FN/(FN + TP)$. This measures the chance that an occupied Area is surveyed according to the protocol and is found to be unoccupied.
2. The False Positive Rate: $FPR = FP/(TN + FP)$. This measures the chance that an unoccupied Area is surveyed according to the protocol and is found to be occupied.
3. The False Omission Rate: $FOR = FN/(TN + FN)$. This measures the chance that an Area that is surveyed according to the protocol and found to be unoccupied is in fact occupied.
4. The False Discovery Rate: $FDR = FP/(FP + TP)$. The measures the chance that an Area that is surveyed according to the protocol and found to be occupied is in fact unoccupied.

The FNR and the FPR are conditional on the state of nature – they don't depend directly on the probability that a given Area is occupied. In our experience, they are not intuitive in the sense that they describe the probability of protocol decisions for given unknown states of nature, but in practice a particular Area is surveyed and a decision is made regarding occupancy. In this scenario, what is known is the outcome of the protocol and what is unknown is the state of nature, but the FNR and FPR work the other way around. Under the FNR and FPR the state of nature is treated as known and the decision is treated as uncertain. The FNR and FPR can be interpreted as rates of decisions made over many surveyed Areas, rather than a particular Area of interest. Analysis done in support of the current (2003) protocol and by McKenzie (2016) used the FNR to evaluate candidate protocols, and it was assumed that the FPR was zero in all cases because occupancy detections can only occur at occupied Stations.

The FOR and FDR are conditional on the decision made by following the protocol – they begin with a pre-survey probability of Area occupancy and update this probability in light of the decision made by following the protocol. In our experience, it is much easier to interpret these rates compared to the FNR and FPR. After the survey protocol is followed and a decision is made about occupancy, the FOR and FDR quantify the probability that the decision was incorrect. We note that these performance measures depend directly on the probability of occupancy. Consequently, the FOR and FDR of a fixed protocol will differ for populations with different underlying rates of occupancy. The statistical subcommittee agreed with our recommendation in favor of the FOR and FDR as more direct and intuitive measures of performance that address the primary quantity of interest: occupancy of the Area under survey.

Despite being intuitive, the terms False Omission Rate and False Discovery Rate are technical and do not lend themselves to lay interpretation. Helpful alternative terms are as follows:

- *The probability of occupancy* if the survey concludes no occupancy (False Omission Rate)
- *The probability of no occupancy* if the survey concludes occupancy (False Detection Rate)

Repeated simulation was used to estimate the proportion of Areas that land in each category in the decision table (TN, FP, FN, TP), while accounting for uncertainty in the model parameters. For each of 200 draws from the posterior distribution of model parameters, and for each scenario, and for each candidate protocol, either 300 or 100 Areas per jurisdiction were simulated according the scenario: Scenarios 1-4 were evaluated using 300 Areas; Scenarios 5-6 were evaluated using 100 Areas (difference due to computer memory limitations). Expected values for each of the four performance measures (FNR, FPR, FOR, FDR) were then computed as well as 50% and 90% credible intervals, equally weighting the two jurisdictions, for each scenario and candidate protocol. We also report results for each jurisdiction separately in the Appendix. We defer any recommendation of protocol to the statistical subcommittee.[1]

[1] In our discussions, the statistical subcommittee targeted a threshold for performance of a candidate survey protocol consistent with no more than a 5% probability of occupancy when a survey concludes no occupancy (FOR). Further, they decided that this performance threshold should be met with 95% confidence – that is, when considering uncertainty arising from occupancy model estimates, no more than 5% of the FOR credible region should exceed the threshold. While taking uncertainty into account is laudable, we note that tail probabilities can be challenging to quantify and should be interpreted carefully. We also emphasize that the FDR represents a potentially (continued next page…)

Results

Occupancy model

Mean values and percentiles from the posterior distribution for each parameter in the occupancy model are presented below (Table 1). For the model definition, see the Appendix.

Table 1: Occupancy model posterior probability summaries, for each parameter without reference to other parameters. The WA subscript refers to Washington and the OR subscript refers to Oregon. The 2.5% and 97.5% percentiles form a 95% credible interval for each parameter, and the 50th percentile is the median.

			Percentiles of posterior distribution				
Parameter	Short Definition	Mean	2.5%	25%	50%	75%	97.5%
Ψ_{OR}	Prob of Site occupancy: Oregon	0.266	0.244	0.258	0.266	0.274	0.289
Ψ_{WA}	Prob of Site occupancy: Washington	0.271	0.226	0.254	0.270	0.287	0.321
$\psi_{OR,10}$	Prob of local extinction: Oregon	0.106	0.065	0.090	0.105	0.120	0.152
$\psi_{WA,10}$	Prob of local extinction: Washington	0.104	0.062	0.087	0.102	0.118	0.154
ψ_{01}	Prob of new occupancy	0.038	0.024	0.033	0.038	0.043	0.053
θ_{OR}	Prob of Station occupancy given Site occupancy: Oregon	0.673	0.627	0.656	0.673	0.689	0.722
θ_{WA}	Prob of Station occupancy given Site occupancy: Washington	0.725	0.623	0.689	0.725	0.760	0.826
q_1	Prob of Presence-only detection given Station occupancy	0.273	0.257	0.267	0.272	0.278	0.289
q_2	Prob of Presence-only detection given no Station occupancy	0.016	0.013	0.015	0.015	0.016	0.018
β_{WA}	Prob of occupancy detection offset for Washington relative or Oregon	-0.304	-0.529	-0.379	-0.305	-0.228	-0.077
β_1	Coefficients of spline function on probability of occupancy detection (smooth function of day-of-year) for Oregon	-2.311	-2.965	-2.540	-2.311	-2.082	-1.683
β_2		-1.702	-2.379	-1.933	-1.696	-1.467	-1.089
β_3		-2.365	-2.993	-2.587	-2.363	-2.150	-1.729
β_4		-2.196	-2.691	-2.369	-2.192	-2.021	-1.712
β_5		-1.707	-2.125	-1.846	-1.705	-1.566	-1.300
β_6		-0.806	-1.251	-0.961	-0.806	-0.650	-0.348
β_7		-1.686	-2.262	-1.883	-1.682	-1.487	-1.087
β_8		-1.167	-1.875	-1.395	-1.162	-0.937	-0.487

The occupancy detection was modeled as a smooth function of the day of year. The posterior expected function is plotted below (Figure 4), along with 95 percent point-wise credible regions for each jurisdiction. The smooth curves are defined by the values of the β parameters.

(continued…) costly incorrect decision for resource owners, and encourage a thoughtful approach to the consideration of FDR, in particular given the tradeoff between FOR and FDR for protocols that use presence detections to classify occupancy. This report is intended to be agnostic toward a specific threshold on FOR or FDR, and the use of a 5% target in the following sections is for illustration purposes only and is not meant as a recommendation for a revised protocol.

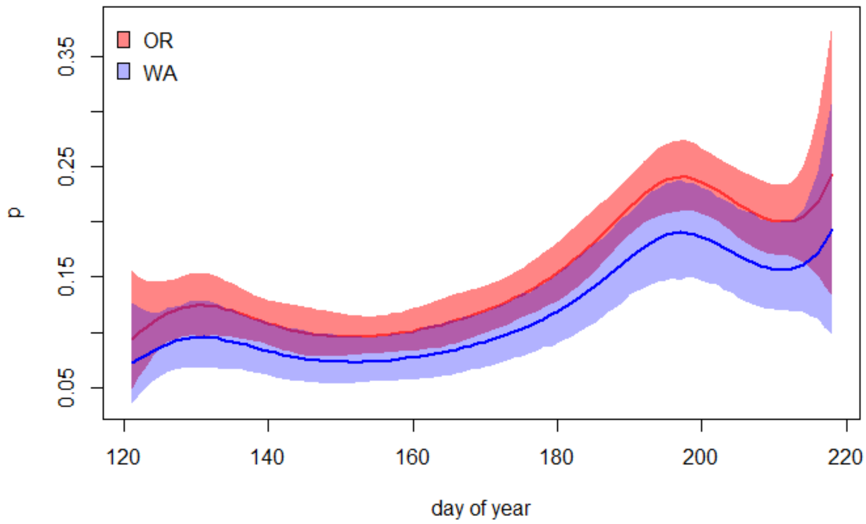


Figure 4: Posterior distribution of the detection probability p as a function of the day of year. The mean of the posterior distribution is plotted as a solid line, and shaded regions show the point-wise 95 percent credible regions for each jurisdiction.

Performance measures

Here we present results in terms of the FOR and FDR for different presence detection thresholds, number of station visits per year, and scenarios. Plotted are the expected (mean) posterior values of the measures of performance as solid lines, with pointwise 50% and 90% credible regions as darker and lighter regions, respectively. These credible regions are bounded by the 25th and 75th percentile (in the case of the 50% credible regions), and the 5th and 95th percentiles (in the case of the 90% credible regions). These performance measures are defined for the entire Area.

Comparisons of interest are:

- Performance between scenarios 1 and 2. In scenario 2, we assume that at least one Station is occupied if the Area is occupied. In scenario 1 we make no such assumption.
- Performance between scenarios 5 and 6. In scenario 5, we sample a large area using simple random sampling, whereas in scenario 6 we sample a large area using stratified sampling.
- Performance between scenarios 1, 3, 4, and 5 or 6 or 7. What is the relationship between the number of Stations in an Area (i.e. its size) and the amount of effort required to achieve defined performance criteria?
- Performance of different presence thresholds for determining occupancy, and the relationship between the threshold, the size of the Area, and the amount of survey effort required to achieve defined performance criteria.

Presence detections not used

When presence detections are not used, by assumption there can be no false occupancy determinations because occupancy can only be detected at occupied Stations. Comparing FOR across scenarios (Figure 5), there is no more than a slight difference in performance across scenarios 1-4. Not surprisingly, the larger Areas in scenarios 5 and 6 differ because they represent a different underlying occupancy structure; in scenarios 5 and 6, the Areas are comprised of three strata, each with their own independent occupancy status, and the Area is considered occupied if any of the three strata are occupied. Given that the marginal probability of occupancy for each stratum is ~ 0.27, the probability that one or more strata are occupied is $1 - (1 - 0.27)^3 \approx 0.61$. However, the probability of selecting an occupied stratum when choosing a Station to sample is unchanged, resulting in increased FOR.

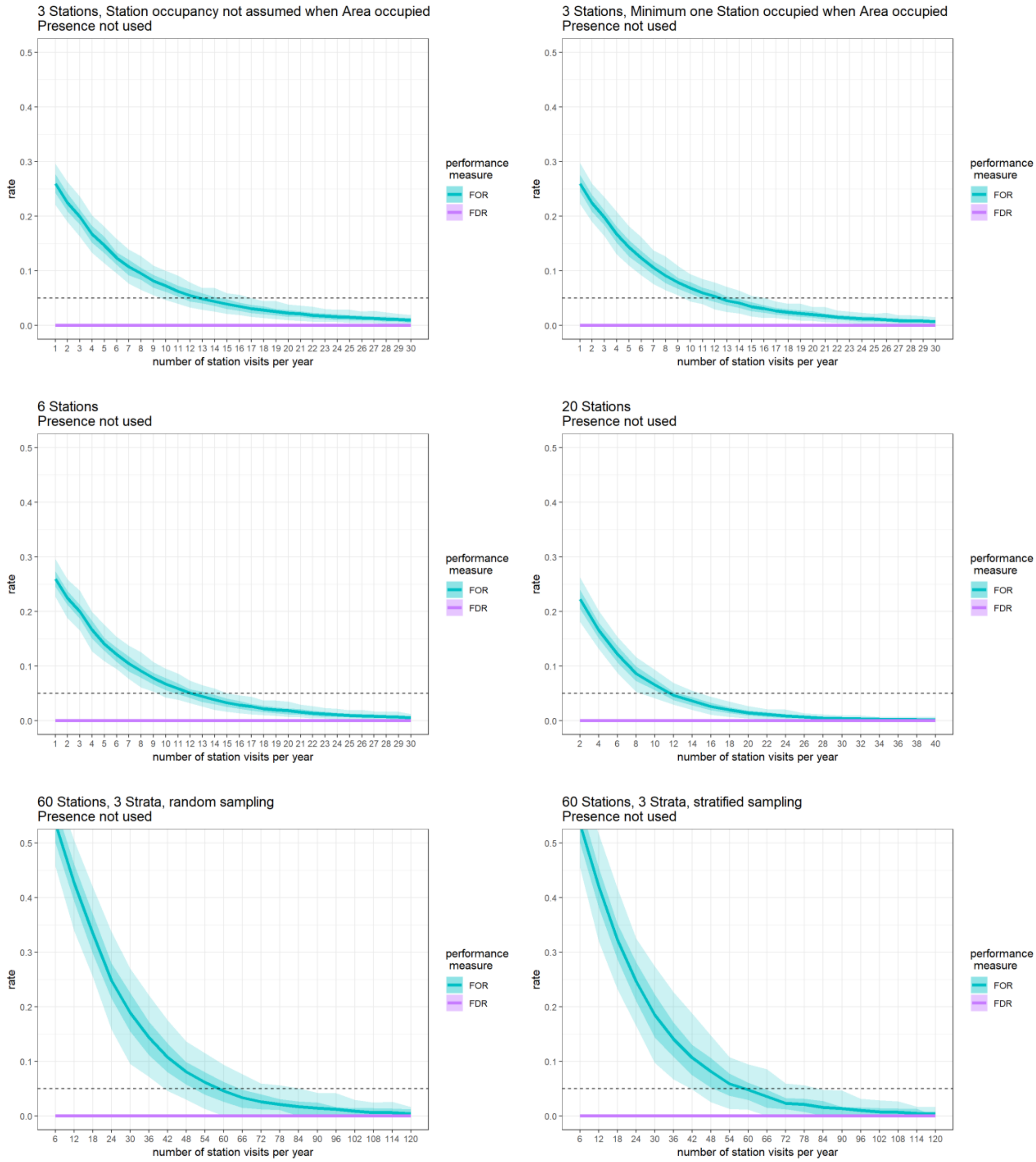


Figure 5: False Occupancy Rate and False Detection Rate when Area occupancy classification does not depend on presence detections, for each of six scenarios (1-6 left to right, top to bottom). Solid lines are posterior means, dark shaded regions are 50% credible regions, light shaded regions are 95% credible regions. The dashed reference line at 0.05 was based on discussions with the statistical subcommittee.

Single presence detection determines occupancy

Moving to a decision rule in which a single Station visit with a presence detection determines Area occupancy, we see a large reduction in the FOR – the probability of an Area that was determined to be not occupied is in fact occupied is much lower (Figure 6). This is a consequence of the labelling of Areas with one or more presence detections as occupied; it becomes much more unlikely that a visit to an occupied Area will have neither an occupancy detection nor a presence detection. However, this increased sensitivity to occupancy comes at the price of a likely unacceptably large FDR – the probability that an Area that was determined to be occupied but is in fact not occupied is no longer zero but rather appreciable, and in many cases much larger than the FOR.

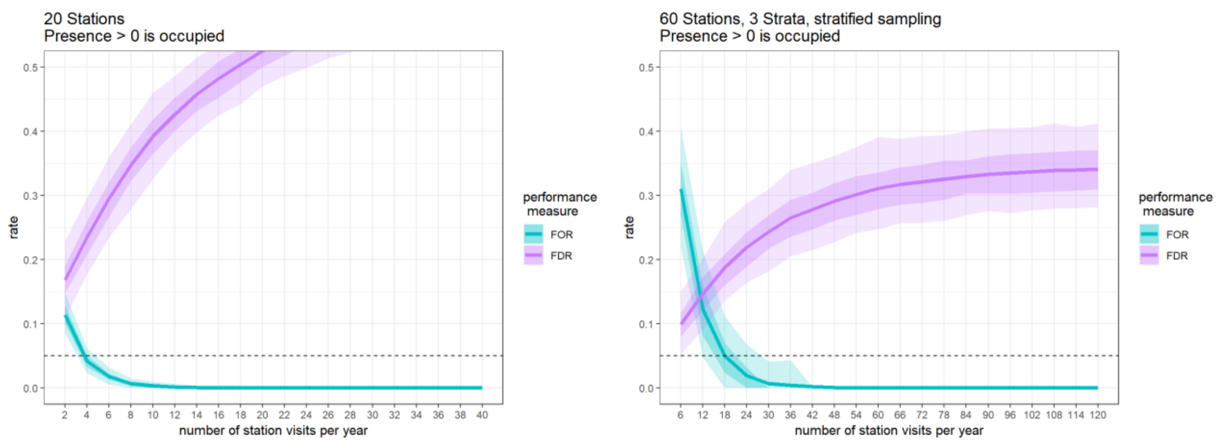


Figure 6: False Occupancy Rate and False Detection Rate when one or more visits with presence observed would classify an Area as occupied. There were no noticeable differences among scenarios 1-4 and among scenarios 5-6; the left figure shows scenario 4 and the right figure shows scenario 6. Solid lines are posterior means, dark shaded regions are 50% credible regions, light shaded regions are 95% credible regions. The dashed reference line at 0.05 was added based on discussions with the statistical subcommittee.

Two presence detections determine occupancy

Moving to a decision rule in which two Station visits with presence detected determines Area occupancy, there is an increase in the FOR and a decrease in the FDR (Figure 7) for a given number of station visits. In the case of Scenario 4, for example, there is a level of sampling effort (6-7 Station visits per year) for which both the FOR and FDR are expected to be below 5% probability. However, given the uncertainty in the performance of such a protocol resulting from uncertainty in the occupancy model parameters – as depicted by the shaded regions around the performance measure average curves – it is entirely possible that such a survey protocol would not meet a 5% threshold for either performance measure.

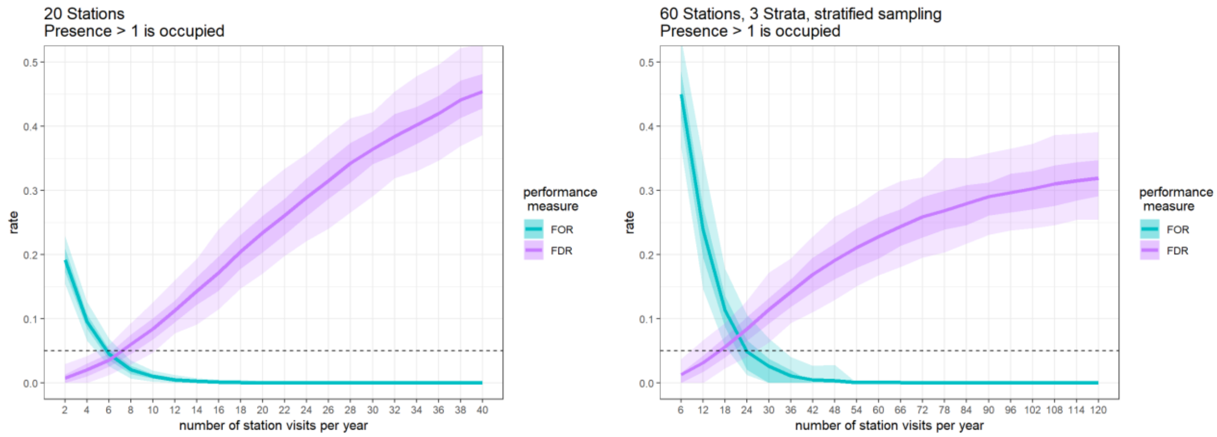


Figure 7: False Occupancy Rate and False Detection Rate when two or more visits with presence observed would classify an Area as occupied. There were no noticeable differences among scenarios 1-4 and among scenarios 5-6; the left figure shows scenario 4 and the right figure shows scenario 6. Solid lines are posterior means, dark shaded regions are 50% credible regions, light shaded regions are 95% credible regions. The dashed reference line at 0.05 was added based on discussions with the statistical subcommittee.

Three presence detections determine occupancy

Increasing the number of presence detections that determine Area occupancy to three or more achieves a FOR of 5% with an amount of sampling that is well below that required when presence detections are ignored (Figure 8). For example, under scenario 4, twelve survey visits per year would be required to achieve a FOR of 5% if presence detections were not used (Figure 5, middle-right); only eight survey visits per year are required to achieve a FOR of 5% here. The reduction in survey effort required comes at the cost of an increase in the FDR, to somewhere between 0-1.5% with 95% probability.

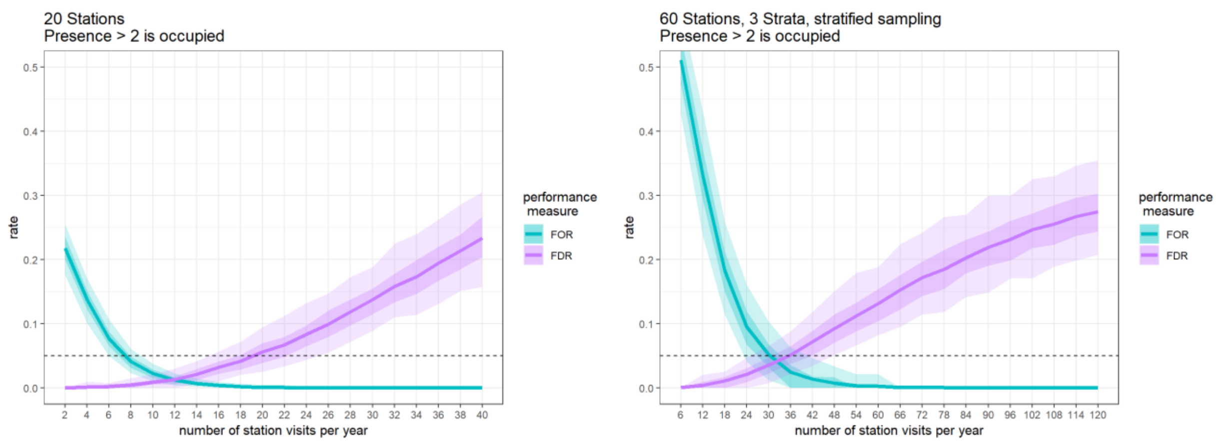


Figure 8: False Occupancy Rate and False Detection Rate when three or more visits with presence observed would classify an Area as occupied. There were no noticeable differences among scenarios 1-4 and among scenarios 5-6; the left figure shows scenario 4 and the right figure shows scenario 6. Solid lines are posterior means, dark shaded regions are 50% credible regions, light shaded regions are 95% credible regions. The dashed reference line at 0.05 was added based on discussions with the statistical subcommittee.

Four presence detections determine occupancy

Despite the appreciable reduction in survey effort required to meet the FOR target when three presence detections determine occupancy, an FDR of up to 2% with 95% probability may be too costly for landowners. Moving up to four presence detections determining Area occupancy is a potential compromise for Areas such as those in scenarios 1-4 (Figure 9). For example, under scenario 4, we can expect to achieve a FOR of 5% by visiting 9 times per year, and the corresponding FDR is not more than 0.6% with 95% probability.

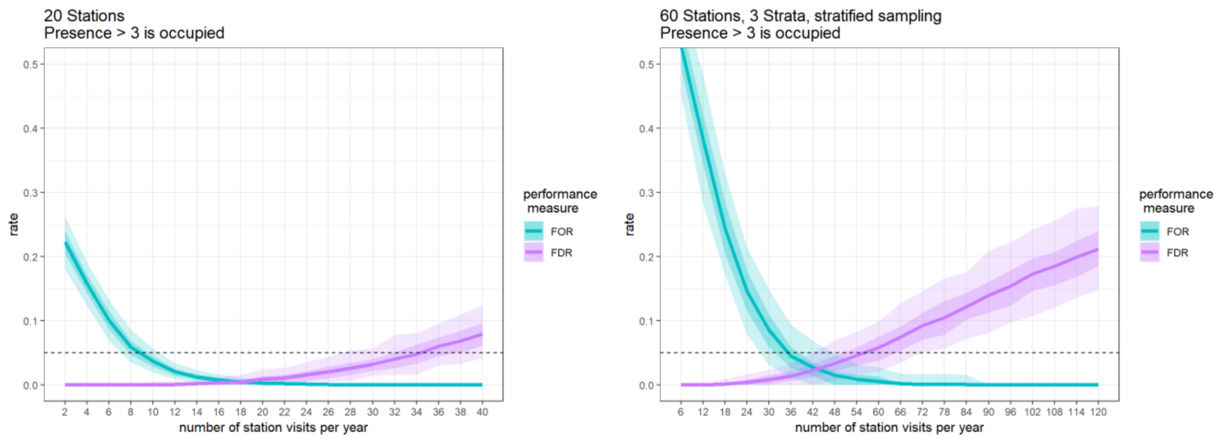


Figure 9: False Occupancy Rate and False Detection Rate when four or more visits with presence observed would classify an Area as occupied. There were no noticeable differences among scenarios 1-4 and among scenarios 5-6; the left figure shows scenario 4 and the right figure shows scenario 6. Solid lines are posterior means, dark shaded regions are 50% credible regions, light shaded regions are 95% credible regions. The dashed reference line at 0.05 was added based on discussions with the statistical subcommittee.

Scenarios 5-6 and Areas larger than a traditional Site

Given that the plausibility of cases presented by scenarios 5, 6, and 7 depend largely on the assumptions of distinct strata with independent occupancy status, it is difficult to evaluate a protocol for cases in which the Area is much larger than the size of a Site under the current protocol. On the one hand, as the size of an Area is increased it will almost surely contain a marbled murrelet. However, there is insufficient information available to determine how the probability of murrelet occupancy increases with increasing size of Area. Thus, the performance of candidate protocols under scenarios 5, 6 and 7 are exploratory at best, and protocol recommendations will need to be based on information other than that available to this report.

Scenarios 5 and 6 describe Areas comprised of three strata of about the size of the current protocol maximum Site size. Each stratum is assumed to behave as a current protocol Site, and the occupancy of each stratum is independent of the rest – i.e., if we knew the occupancy status of one of the strata, we assume that this does not alter our knowledge about the occupancy status of the other two strata in the same Area. This is just one of many possible assumptions that could be made. The Appendix section *Occupancy among Sites in an Area* describes an attempt to estimate the degree of dependence in occupancy status among Sites within an Area, for a subset of the data from Oregon. Results suggest some dependence among Sites within an Area.

Assuming independence among positively dependent strata within an Area will result in lower FOR and higher FDR than if the occupancy status of the strata were truly independent.

Keeping this warning in mind, we can approximate the performance of surveys performed on larger Areas by carrying out surveys in each Site-sized stratum and assuming independence in occupancy status among the strata. Under an assumption of independence among strata, the relationship between stratum FOR and area FOR is $b = 1 - (1 - a)^{1/n}$, where a is the area FOR, b is the stratum FOR, and there are n strata in the Area.

Consider the case of an Area with three strata, as in scenarios 5 or 6, and suppose the target FOR is $a = 0.05$. In that case, we would achieve the Area FOR if the stratum FOR is $b = 1 - (1 - 0.05)^{1/3} = 1 - 0.983 = 0.017$. Surveys in each stratum could be conducted to achieve this lower stratum-level FOR. Presence thresholds, if used, would apply to each stratum rather than across the Area. It appears that this approach lines up closely with the simulation results for Scenario 6 for the mean FOR, although there is a slight difference for the 95th percentile FOR.

Area FDR could also be calculated assuming independence in the same way. However, whereas the Area FOR would be an overestimate of the actual FOR, the Area FDR would be an underestimate of the actual FDR if the strata occupancy status are positively dependent.

Additional results

Additional results, including tables, figures, and estimated performance measures for each jurisdiction separately, are available in the Appendix.

Data collection and reporting for future surveys

We recommend the following data collection and reporting for future surveys. These recommendations are based purely on considerations related to statistical inference using the survey data to inform future protocols. We recommend collection and reporting:

- The Area to be surveyed
- The location of the survey stations in the Area
- The planned survey dates for each station in the Area
- The actual survey dates for each station in the Area
- Weather or other conditions that would affect the presence or behavior of occupying MAMU or the detection of MAMU that are present
- The reason for termination of the survey
- Survey visits that were not made due to occupancy detection (stopping rule) or for some other reason need to be reported

Given the stated goal of implementing a spatial sampling approach, this information will be critical to future occupancy modelling using these data.

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Appendix

Model definition

$$Z_{i,t} \sim \text{Bern}(\Psi^*_{i,t})$$

$$V_{ij,t} \sim \text{Bern}(\theta_{S_i} Z_{i,t})$$

$$W_{ijk,t} \sim \text{Categorical}(p^*_{ijk,t})$$

$$\Psi^*_{i,t} = \begin{cases} \psi_{01} \text{ if } Z_{i,t-1} = 0 \\ \psi_{S_i,11} \text{ if } Z_{i,t-1} = 1 \\ \Psi_{S_i} \text{ if } Z_{i,t-1} = \emptyset \end{cases}$$

$$S_i = \begin{cases} 1 & \text{Oregon} \\ 2 & \text{Washington} \end{cases}$$

$$p^*_{ijk,t} = [V_{ij,t}(1 - p_{ijk,t} - q_1) + (1 - V_{ij,t})(1 - q_2), V_{ij,t} q_1 + (1 - V_{ij,t}) q_2, V_{ij,t} p_{ijk,t}]$$

$$\text{logit}(p_{ijk,t}) = [X_{D_{ijk,t}}]\beta + I(S_i = 2)\beta_{WA}$$

$$q_1 \sim \text{Beta}(1,1)$$

$$q_2 \sim \text{Beta}(1,1)$$

$$\psi_{01} \sim \text{Beta}(1,1)$$

$$\Psi_S \sim \text{Beta}(1,1) \text{ for } S \in \{1,2\}$$

$$\theta_S \sim \text{Beta}(1,1) \text{ for } S \in \{1,2\}$$

$$\beta_l \sim \text{N}(0,10^2) \text{ for } l \in \{1,2,\ldots,v\}$$

$$\beta_{WA} \sim \text{N}(0,1)$$

Additional identities

$$\psi_{S,11} = 1 - \psi_{S,10}$$

$$\psi_{S,10} = \psi_{S,01}\left(\frac{1 - \Psi_S}{\Psi_S}\right)$$

The index i is for Sites, the index j is for Stations within Sites, the index k is for repeated visits to a Station, and the index t is for the year. The data are the $W_{ijk,t}$, which is a four-dimensional array that is almost entirely empty due to many Sites having only one or two years of data during the period from 2003-2015. In addition, a few Sites have a large number of Stations, and a few Stations have a large number of visits, which caused MacKenzie (2016) to truncate the data array in order to use existing analysis software. We coded the model using a bugs language for R called *nimble*, which allows for dynamic indexing, allowing us to minimize the in-memory footprint of W by treating it as a ragged array.

This required constructing indexing vectors to identify Site by year combinations, Station by year combinations, and Site by previous year combinations (to implement the dynamic model for Z).

The matrix X is a B-spline basis for a cubic spline that allows the occupancy detection probability to vary smoothly as a function of the day of year. We used a spline basis with 8 degrees of freedom, evaluated at each day of the season. The notation $[X_{D_{ijk,t}}]$ indicates a row vector extracted from the basis. The row corresponds to the day of the season D on which the survey visit was made to Site i, Station j, visit k, in year t.

Nimble code for model

```
# Put a dummy -1 in for the last Z. This will be for site/year combinations that
#   don't have a previous year.
#   prev_siteyear for these cases is set to Nsiteyears + 1 in the input constants,
#   so that the Z is drawn using the marginal probability of occupancy.
Z[Nsiteyears+1] <- -1

for( i in 1:Nsiteyears ){
    # There are three cases here:
    # Z = -1 (marginal probability of occupancy) ==> prob = Psi
    # Z =  0 (transition from unoccupied)     ==> prob = psi_01
    # Z =  1 (maintain occupancy)    ==> prob = 1 - psi_10 = 1 - psi_01*(1-Psi)/Psi
    Z[i] ~ dbern( prob = (1-abs(Z[prev_siteyear[i]]))*psi_01 +
                    abs(Z[prev_siteyear[i]])*( ((Z[prev_siteyear[i]]+1)/2)*
                              ( 1 - psi_01*( ( 1 - Psi[state[i]] )/Psi[state[i]] ) ) +
                        ((1-Z[prev_siteyear[i]])/2)*Psi[state[i]] ) )
}

for( j in 1:Nstationyears ){
    V[j] ~ dbern( prob = theta[state[siteyear[j]]]*Z[siteyear[j]] )
}

for( k in 1:Nobs ){
    logit( p[k] ) <- inprod( beta_DOY[], bsplineDOY[k,] ) + state_WA[k]*beta_pWA
    pp[1:3,k] <- nimC( V[stationyear[k]]*(1-p[k]-q1) + (1-V[stationyear[k]])*(1-q2),
V[stationyear[k]]*q1 + (1-V[stationyear[k]])*q2, p[k]*V[stationyear[k]] )
    W[k] ~ dcat( prob = pp[1:3,k] )
}


# remaining priors
q1 ~ dbeta(1,1)
q2 ~ dbeta(1,1)
beta_pWA ~ dnorm( mean = 0, sd = 1 )
psi_01 ~ dbeta(1,1)

for( l in 1:Nstates ){
  theta[l] ~ dbeta(1, 1)
  Psi[l] ~ dbeta(1, 1)
  psi_10[l] <- psi_01*( ( 1 - Psi[l] )/Psi[l] )
}

for( m in 1:df_beta_DOY ){
  beta_DOY[m] ~ dnorm(mean = 0, sd = 10)
}
```

Occupancy among Sites in an Area

I used the additional Area information from Oregon Department of Forestry, Bureau of Land Management, US Forest Service, and Oregon State to attempt to identify dependence of occupancy among Sites in the same Area and quantify the amount of dependence if possible. Figure A-1 shows the distribution of the number of Sites per Area in the data examined.

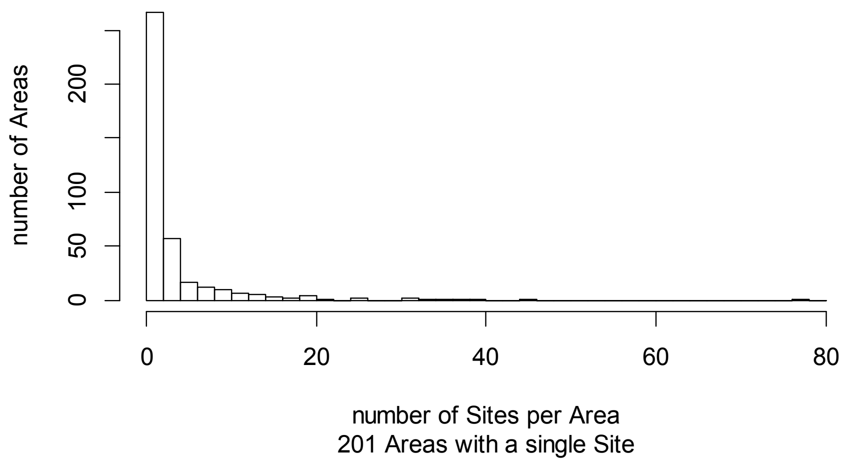

Figure A-1: The distribution of the number of Sites per Area for Sites with this information available.

For each Area, I determined the proportion of Sites that had an occupied behavior detected (Figure A-2, top panel), as well as the proportion of Sites that had a presence behavior detected (Figure A-2, bottom panel). The stopping rule makes it difficult to interpret these results. For instance, of 103 Areas with occupancy detections, 70 Areas had only one Site with occupancy detected. About half of these Areas were single-Site Areas, but it is not known whether these Areas included additional Sites that were not sampled due to the stopping rule.

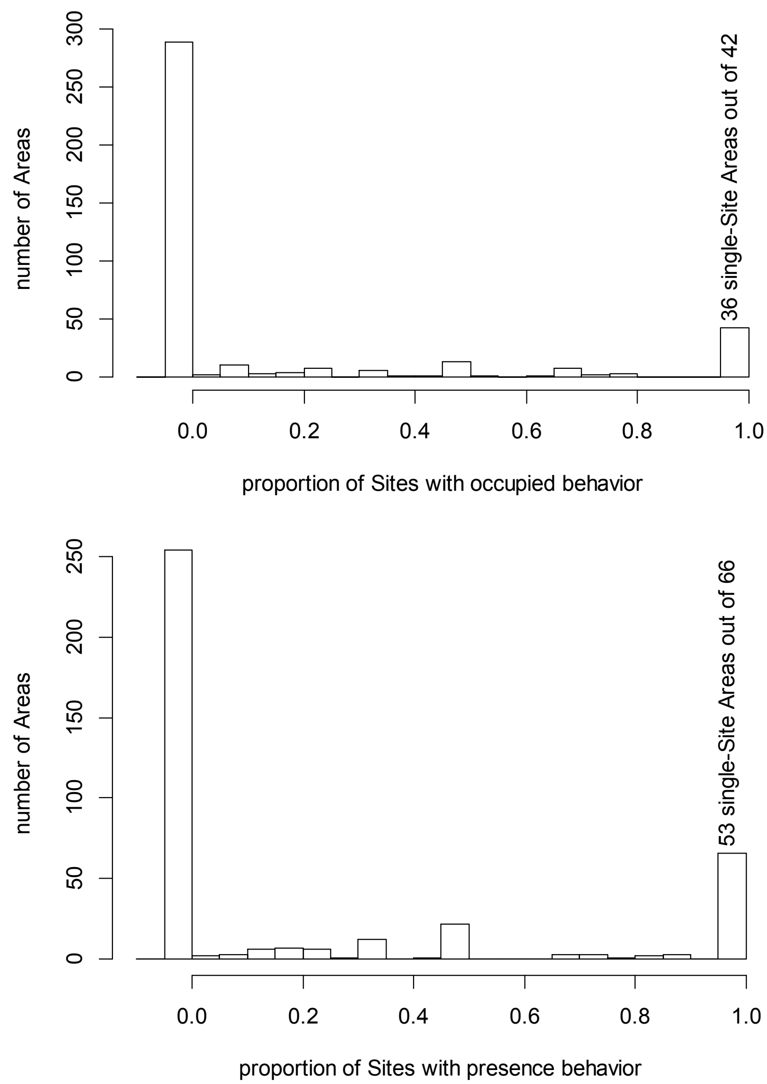

Figure A-2: Distribution of the proportion of Sites with occupied detections (top panel) and presence detections (bottom panel) by Area. In each case, most of the Areas with 100% had a single Site.

Ignoring the possible effects of the stopping rule and variation in detection probability, we would expect that the distribution of the number of Sites with occupancy (or presence) in any Area follows a binomial distribution. Table A-13 tabulates the number of Sites with occupancy or presence and the total number of Sites for each Area. There are not many very large Areas (with many Sites). There appears to be more variability than would be expected if the occupancy or presence status of Sites within an Area were independent.

One way to model the dependence among Sites is using a beta-binomial distribution for the number of Sites determined to be occupied (or have presence) in each Area, with the caveats above about ignoring effects of the stopping rule, and also under the assumption that occupancy is always detected for a Site that is occupied. Under these assumptions, we find that the correlation among Sites is positive; For occupancy, the estimates are: $\mu = 0.16, \rho = 0.36\ (0.27, 0.47)$; For presence, the estimates are: $\mu = 0.23, \rho = 0.41\ (0.33, 0.50)$. These estimates for ρ include approximate 95% confidence intervals. For illustration, we show the case of $\rho = 0.41$ alongside the independent case and the case where all Sites are identical, for an occupied Area with three Strata (Figure A-3).

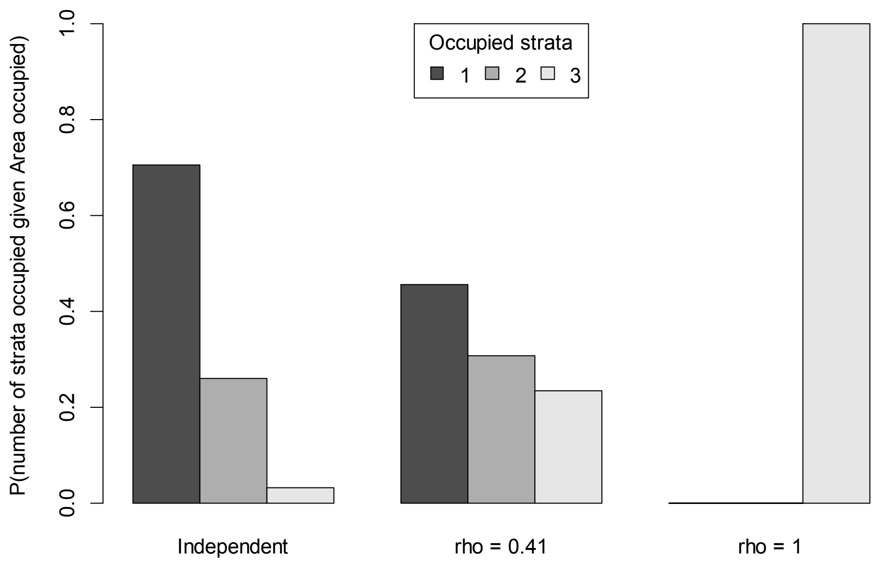

Figure A-3: Distribution of the number of occupied strata for an occupied 3-stratum Area, under three hypothetical values of the covariance parameter ρ.

Table A-13: The distribution of the number of Sites with Occupancy (top) and the number of Sites with Presence (bottom) for Sites within the same Area.

Sites with Occupancy (rows) × Number of Sites in Area (columns)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**25**	**26**	**31**	**32**	**33**	**36**	**38**	**39**	**46**	**77**
0	165	53	22	12	2	8	6	1	2	2	0	2	1	0	1	1	1	1	2	1	1	0	1	1	1	1	1	0	0	0
1	36	7	5	5	1	2	1	0	2	1	2	1	2	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
2		5	7	4	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3			0	2	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4				0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
8								0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9									0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10										1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20																			0	0	0	1	0	0	0	0	0	0	0	0
21																				0	0	0	0	0	0	0	0	1	0	0

Sites with Presence (rows) × Number of Sites in Area (columns)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**25**	**26**	**31**	**32**	**33**	**36**	**38**	**39**	**46**	**77**
0	148	46	20	8	2	3	5	1	3	3	1	2	2	0	0	2	1	1	2	1	0	0	0	0	0	1	1	0	1	0
1	53	13	7	6	1	3	2	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
2		6	3	4	0	3	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
3			4	3	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
4				2	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
5					1	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
6						0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7							0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8								0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9									0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
18																		0	0	0	0	0	0	0	0	0	0	1	0	0

APPENDIX C: DESCRIPTION OF MURRELET EGGS AND EGGSHELL FRAGMENTS

Compiled by Steve Singer

Background

Marbled Murrelet eggshells are not removed from the nest by the adults, but are often knocked to the ground from activity by the chick and adults on the nest. Finding these eggshells on the ground are an indication of a nearby nest tree (often found at or near the base of the nest tree). We are including this Appendix in the protocol as there is a chance that surveyors hiking to and from their survey stations could come across some eggshells. The following details will help them identify any murrelet eggshells.

Size and Shape

Marbled Murrelet eggs are subelliptical in shape with sizes ranging from 57.0-63.0 mm in length, 35.0-39.5 mm in width, and 36-41 g in mass (Nelson 1997). One reported measurement of eggshell thickness was 0.21 mm at the waist (Kiff 1981). Surface texture is usually smooth and non-glossy.

Color and Markings

Egg background color is olive-green, lime green, or greenish-yellow, and more precisely corresponds to colors of 2.5 GY 8/3, 2.5 GY 8/4, 7.5 Y 8/4, 7.5 Y 8.5/4, and rarely, 6.5 GY 8/3 (Munsell Color 1976; see Table C-1). Eggs are variably marked with irregular spots and splotches that are brownish, blackish, grayish, purplish, or sepia-like in color (Figure C-1). Spots and splotches may be 8 mm in their longest dimension (Becking 1991), although most are smaller than 2 mm in diameter.

It is not yet known if there is any geographic variation in egg color or markings. Some published descriptions have failed to match eggshell color with known color standards, thereby limiting their usefulness. Those that have done so have used Ridgway (1912), Smithe (1974, 1975, 1976), or the Munsell Book of Color (Munsell Color 1976). Of these color standards, only the latter has enough described colors to provide an exact match for all egg colors based on unfaded color swatches. A comparison of different color standards used to describe Marbled Murrelet eggshell colors is provided in Table C-1.

Figure C-1: *Intact Marbled Murrelet eggs found on Long Island, Pacific County, WA. Housed at the Burke Museum, Seattle, WA* http://staff.washington.edu/puffinus/brachyramphus-marmoratus/

Table C-1: *Background Marbled Murrelet egg color as defined by different color notation standards.*

Ridgeway (1912)	Smithe (1974, 1975, 1976)	Munsell Book of Color (Anon. 1976)
"pale glass green"[a]	No equivalent	2.5 GY 8/3
"pale chalcedony yellow"	No equivalent	7.5 Y 8/4 7.5 Y 8.5/4
"pale dull green-yellow"	No equivalent, but somewhat lighter than #59 "lime green" and more yellow than #162 D "opaline green"	2.5 GY 8/4 2.5 GY 8.5/4
"pale turtle green"[b]	#162 D "opaline green"	6.5 GY 8/3

[a] Sources: descriptive articles in References, also unpublished data.
[b] Uncommon eggshell color described in Singer et al. 1991.

Recommendations on Describing Eggshell Fragments

Eggshell fragments are often found in murrelet nests or on the ground below. Their condition can be useful in determining the fate of the nest if not otherwise known. Important information to collect on eggshells includes the following:

- Number, size, and shape of fragments and location where found;
- Background color based on Munsell Book of Color (but note that shell fragments weather toward brown relatively quickly under acid conditions of coniferous forests);
- Number, size, and shape of spots and splotches and color description based on Munsell Book of Color;
- Texture and thickness of the eggshell; and
- Presence of any other egg or nestling materials associated with the eggshell fragments, such as shell membrane, albumen, yolk, blood, feathers, or feather sheaths.

It is not permissible to keep eggshell fragments without the proper federal, state, or provincial permits. Eggshells should be donated to museums and scientists with the proper permits in your area.

Copies of the Munsell Book of Color are available in the library of any college or university with an Arts Department or can be ordered from Gretag MacBeth, 617 Little Britain Road, New Windsor, New York, 12553. Their web site is at http://munsell.com.

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APPENDIX D: WASHINGTON DEPARTMENT OF FISH AND WILDLIFE MARBLED MURRELET CIRCLING ASSESSMENT

18 July 2003
S. Desimone and J. Buchanan
[updated August 2014]

Background

Revision of the 2003 Pacific Seabird Group (PSG) protocol for the Marbled Murrelet has prompted the Washington Department of Fish and Wildlife (WDFW) to examine specific parts of rule language for possible changes. The Forest Practices Rules state that low circling behavior (curving flight between 1.0 and 2.0 canopy heights) of murrelets at a survey station indicates occupied behavior, and classifies the survey stand as occupied (WAC 222-16-010 occupied Marbled Murrelet site (1)(e)). Landowners, however, are concerned that low circling behavior, including minor deviations from linear flight, by murrelets at a survey station may result in a stand being incorrectly classified as occupied. To address these concerns, WDFW committed to an evaluation of the circling data, which included assessing the relationship between low circling and subcanopy behavior and the magnitude of change in flight direction during detections.

Methods

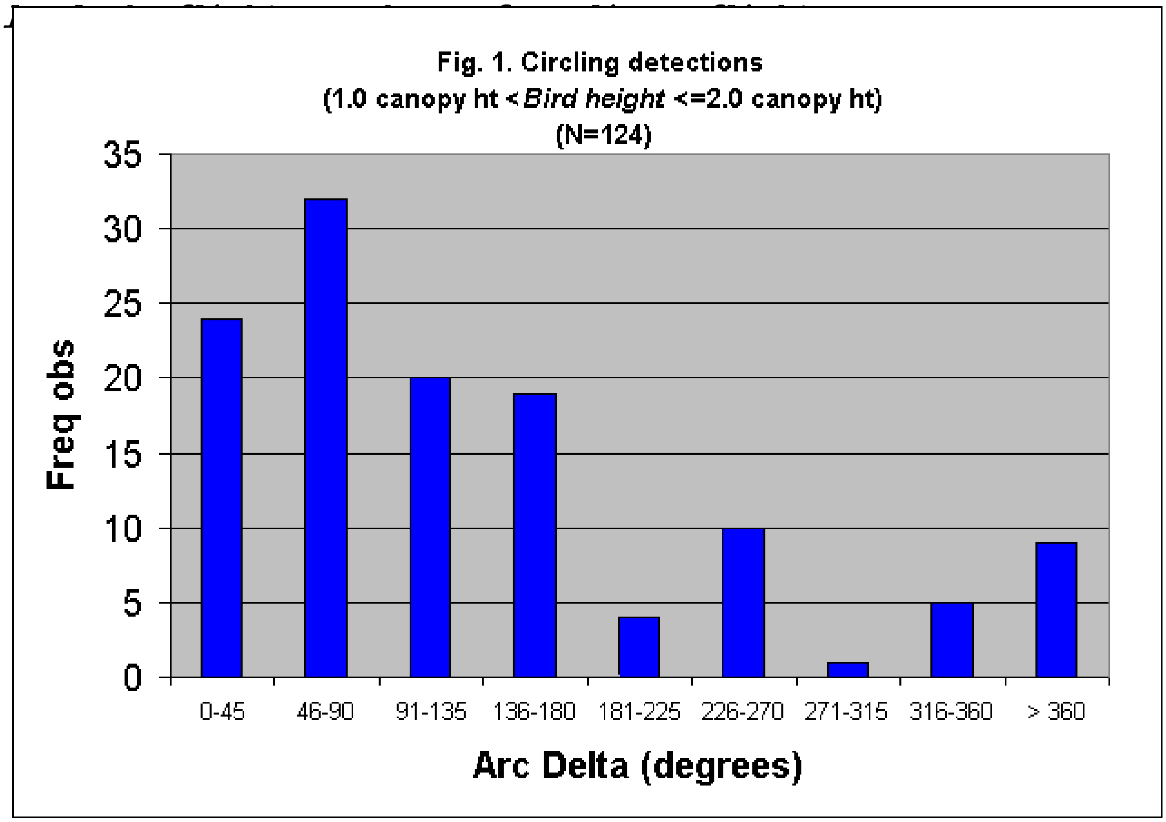
Data were compiled from copies of original survey data forms (which included maps and/ or aerial photographs) supplied by the landowners or their consultants and are contained in WDFW's Marbled Murrelet Survey Database. The circling database consisted of known occupied detection records (n = 182) from surveys conducted on private forestlands in Washington. Murrelet detections occurring at the site were classified as circling only, circling plus subcanopy behavior, and subcanopy behavior only. Many survey areas did not receive the full complement of surveys. For example, if an occupancy behavior (including circling) was detected during the survey season, subsequent protocol surveys were not conducted in some cases. This resulted in some unequal survey effort and prevented us from making more extensive comparisons with the survey data.

We examined the extent to which circling (i.e., the arc change) and other occupied behavior occurred during a survey. The arc change is the change in flight arc (degrees) of murrelet(s) tracked from the observer's initial detection of flight direction to the final detected flight path direction (Evans Mack et al. 2003). Arc change was determined by information on the data sheets and the arc drawn on the aerial photograph and/or map by the surveyor.

Results

We identified 88 sites on private forest lands that were determined to be occupied in 1 of the 3 categories: 10 (11%) were circling only, 30 (34%) were circling plus subcanopy, and 48 (55%) were subcanopy only. There were 124 observations of curvilinear flight of murrelets between 1 and 2 canopy heights. The frequency distribution of these circling detections according to the amount of arc change was left-skewed (Figure D-1).

Figure D-1: *Frequency distribution of all circling (bird height >1.0 canopy and ≤2 canopy heights) detections (n =124) on private forest*



Examining only the 0-45° category, there were 24 detections at 16 sites for which we had arc change data. Of these, 88% of the circling detections were associated with subcanopy behavior (Table D-1). Similarly, 89% (14/16) of the sites in the 0-45° category where circling was observed also had subcanopy behavior (Table D-2). Ninety-four percent (15/16) of occupied sites with at least one detection in the 0-45° category had ≥1 additional detection of >45° and/or subcanopy behavior detections at the site (Table D-2).

Table D-1: *Percent of circling (i.e., 1.0 canopy< bird height ≤ 2.0 canopy) observations (n =124) that were associated with subcanopy behavior.*

Arc change (degrees)	**Percent**
0-45	88
46-90	81
91-135	80
136-180	100
>180	97

Table D-2: *Occupied sites that had at least one arc direction change of ≤45° of circling (1.0 canopy< bird height ≤ 2.0 canopy) detected (n=16). Sites not meeting both criteria (bold) have zero values in both columns.*

WDFW reference (Site ID)	# of additional detections of Arc delta ≥45	Subcanopy detections
930590	7	8
970689	2	22
960060	13	9
970341	2	6
980501	0	6
970346	9	35
200080	1	20
983095	2	0
992447	**0**	**0**
962425	4	44
962639	0	33
945762	1	5
952158	7	13
952166	4	14
941386	5	13
941376	4	16

Discussion and Conclusions

Given the low probability of ground-based observers visually detecting true numbers of murrelets in occupied forest stands, as is indicated by radar studies (*e.g*., Cooper and Blaha 2002), some detections of murrelets in the forest environment will consist only of low circling above the canopy (*or of detections that result only in presence*). The fact that about one-third of occupied sites had both low circling and sub-canopy behavior, coupled with the issue of low detection rates mentioned above, leads us to conclude that low circling, on its own accord, continues to be a valid indicator of site occupancy. Such sites account for 11% of the occupied locations on private forest lands in Washington. Circling is defined as “Bird(s) seen circling over the forest at >1.0 canopy height. This behavior includes flight paths that deviate from a straight line, such as full, quarter and half circles, angular turns, etc.” (Evans Mack et al. 2003). This is an appropriate definition for forest practices rules and has been consistently applied in interpreting survey results.

In evaluating the survey data, we were unable to find any instances of slight deviations from linear flights that appeared problematic. In only two instances did we find a flight direction change of less than 45^{o} (i.e., 22.5^{o}) and in one of these cases the flight was associated with subcanopy behavior. Of 16 sites with at least one direction change ≤45^{o}, 15 were associated with other circling detections of >45^{o} and/or subcanopy behavior, and 14 of 16 sites had just other subcanopy behavior. This information indicates a high association between such flights and actual occupancy.

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APPENDIX E: MARBLED MURRELET VOCALIZATIONS

Reviewed by William Ritchie[10]

Familiarity with murrelet vocalizations is essential for anyone planning to conduct a protocol survey. The majority of murrelet detections are auditory (Paton and Ralph 1988, Hamer and Cummins 1990, Nelson 1990), especially at interior forest survey stations with limited visibility. Marbled Murrelet vocalization recordings are currently being collected and analyzed to characterize the different calls. Presently there are four recognized vocalization categories: (1) *Keer* calls, (2) Whistle calls, (3) Groan/grunt calls (formally known as alternate calls), and (4) Fledgling begging calls (Nelson and Peck 1995, Nelson 1997, Dechesne 1998). These categories of vocalizations can include a variety of variable call combinations. To date there have been no identified sexual differences, call functions, or geographic variability in murrelet vocalizations. However, in time we may be able to associate vocalizations with behavior.

The most distinctive and commonly heard vocalization is the *Keer* call. The frequency range for this call is 2,000 to 5,000 Hz, with a mean frequency of about 3,500 Hz. There are typically 2 or 3 elements to the *Keer* call, with the initial note of the call reaching a maximum at 5,000 Hz (see sonograms in Nelson 1997 and Dechesne 1998). *Keer* calls are intermediate in length at about 300-350 milliseconds. This call can be described as a piercing, high pitched "gull-like" call that phonetically sounds like *Keer-Keer*. Whistle calls generally consist of a short broadband initial segment followed by a narrow-band mid-frequency note of longer duration than the *Keer*, and without the repeating series of calls. This type includes the whistle-like *Kee*, single note calls similar to the initial segment of a *Keer* call, and the "soft- que" call, a long plaintive sounding ("*eeeh-eeeh*") whistle. Groan/grunt (alternate) calls can be heard frequently at inland locations, at sea, or while the adults are present at the nest during feeding visits. These vocalizations are similar to the raspy, nasal-sounding calls given by other alcids at breeding colonies. Many times a groan call is part of a *Keer* call sequence, or given in reply to another vocalizing murrelet. Long series of calls given by the same bird sometimes grade from *Keer* to groans without an abrupt change (Dechesne 1998). Adults bringing fish to the nestling often give a muted grunt call sounding like "*rrUH-rrUH*". The fledgling food begging call is a continuous series of soft, high-pitched "*peep*"s, sometimes heard when an adult arrives at or near the nest to feed the chick. In most cases vocalizations at the nest are not audible from the ground.

There are two additional auditory detections that may be heard at inland locations. These are not vocalizations, but sounds produced by air passing over the feathers of a murrelet in flight. The first is a jet sound, which can be heard when a murrelet is in a steep descent or when it is ascending following such a dive. This loud, slightly wavering, whooshing sound is a bit like a jet

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plane rapidly passing overhead. It is rarely heard and often occurs near or above nesting areas. The second, the sound of the murrelet's wing beat, has a wide frequency range, resulting in a rapidly alternating sound. These sounds have been described as similar to that of a rope being twirled rapidly in the air or a hand saw blade being shaken (Nelson 1997). Though the detection of murrelet wing sounds is often associated with below canopy flight, it also originates from murrelets flying above the canopy.

Once a surveyor learns the basic calls, they should develop their ability to identify similar-sounding vocalizations from other forest birds. This will help identify murrelet calls at locations with background noise and differentiate distant murrelet calls from other similar-sounding calls.

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APPENDIX F: SUMMARY OF DENSITY OF PLATFORM TREES SAMPLED AROUND MARBLED MURRELET NEST OR OCCUPIED SITES FROM AVAILABLE LITERATURE AND UNPUBLISHED STUDIES

Compiled by Martin G. Raphael, Pacific Northwest Research Station. February 24, 2023

In this document we define nesting habitat as any stand (with crowns extending to height of platform trees) with 1 or more platform trees. This density of platform trees is a minimum and we believe it is useful to characterize the frequency distribution of platform tree density to give a fuller appreciation of how density varies. Characteristics of murrelet nesting habitat vary across the species' range in Washington, Oregon and California and are thus difficult to summarize in a simple way. These characteristics generally include older coniferous forest with high canopy cover, tall and large-diameter trees, and complex canopy structure, but can also include young stands with scattered remnant platform trees. Raphael et al. (2016) and Lorenz et al. (2021) showed that probability of nesting increased as stand height, tree diameter, and canopy cover increased. Occurrence of nesting platforms is a key feature of murrelet nesting habitat on all ownerships. Without platforms and platform trees, murrelets have no place to nest; they don't build their nests and instead rely on the substrate or structure of branches (usually 10 cm (4 in) or more in diameter) to support their single egg during egg laying and incubation. From data published by Raphael et al. (2016), obtained from a random sample of plots on Federal lands (all agencies) in Washington, Oregon and California, we can compute the probability of a tree having 1 or more suitable platforms (i.e., the probability of a tree being a platform tree) as a function of tree diameter and species (Table F-1).

Table F-1: *Mean probability of a tree having 1 or more platforms as a function of tree species and size (diameter at breast height [DBH]) from data on Federal lands in Washington, Oregon and California.*[a]

		Mean probability of platforms by DBH class (cm)				
Common name	**Scientific name**	**50-75**	**75-100**	**100-125**	**125-150**	**≥ 150**
Douglas-fir	*Pseudotsuga menziesii* (Mirb.)	0.07	0.33	0.68	0.88	0.97
Redwood	*Sequoia sempervirens*	0.04	0.12	0.37	0.57	0.85
Sitka spruce	*Picea sitchensis* (Bong.) Carrier	0.16	0.50	0.68	0.97	0.95
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.	0.25	0.63	0.86	0.94	0.97
Western redcedar	*Thuja plicata* Donn ex D. Don	0.07	0.25	0.37	0.56	0.75
Other conifers		0.14	0.34	0.63	0.85	0.83

[a]Potential platforms defined as horizontal limbs 10 cm (4 in) or larger in diameter. Data modified from Raphael et al. (2016).

Nests occur in platform trees, and areas of greater platform tree density (PTD) are generally more likely to support nests and so we summarized available data describing estimated numbers of platform trees in occupied sites. Available data show that murrelets have been observed using areas with a wide range of PTD at the plot scale (Table F-2), but the minimum is one platform tree in a stand, hence the definition of habitat in Chapters 1 and 2. The PTD at the nest plot scale is not the only relevant factor determining nesting habitat. Murrelets most frequently nest in areas much larger than the size of a nest plot (using multiple nest trees over time) and depend on a larger forested area to support successful nesting (see Chapter 1 about the importance of large, contiguous stands, predation rates, and co-occurrence of murrelets in a given stand).

The data in Table F-2 are from plot-based measurements, primarily from Provincial and Federal Lands, of platform tree density around known nest trees and from stands determined to be occupied by murrelets using on-the-ground surveys. Murrelet nest areas are much larger than the size of a plot around a nest tree. These data represent information from available studies that were measured on a subset of all land ownerships, forest cover types, and scales. Some of these data were collected in only one small plot per stand and thus do not represent platform tree density at the stand scale (densities will be much lower at the stand scale given that most stands are heterogeneous and platform trees are not evenly distributed throughout a stand). Generally, if samples were taken at random, and sample sizes were sufficient, the plot data will presumably be representative of the larger stand, however not all of these data were collected in this manner. Furthermore, we make no assertion to how these data relate to reproductive success.

Table F-2: *Available platform tree density at nest and occupied sites, based on ground measurements, from British Columbia south to California.*

						Platform trees per acre				
Location and Ownership	**Reference**	**Site type**	**Habitat type**	**Plot size**	**# per Plot**	**Mean**	**SD**	**Min**	**Max**	**n**
BC: Provincial Lands	Manley 1999	Nest	Old-growth (≥250 years)	25m-radius plot centered on nest tree	1 in most cases	13.0	8.5	2.0	26.7	32
BC: Provincial Lands	Silvergieter and Lank 2011	Nest	Old-growth (≥200 years)	25m-radius plot centered on nest tree	1 in most cases	22.1	3.2	10.1	51.4	59
WA: Federal Lands	Wilk et al. 2016	Nest	Older-aged forests (≥80 years)	25m-radius plot centered on nest tree	1 in most cases	25.6	17.4	NA	NA	20
WA: Federal Lands	Huff et al. 2006; Raphael unpubl. data	Occupied	Older-aged forests (≥80 years)	25m-radius plots	8-10	21.1	10.7	2.4	51.6	34

						Platform trees per acre				
Location and Ownership	**Reference**	**Site type**	**Habitat type**	**Plot size**	**# per Plot**	**Mean**	**SD**	**Min**	**Max**	**n**
WA: Private Lands	Hamer et al. 2008	Occupied	Young forests (<80 years)with remnant platform trees	25m-radius plots	3-9	4.7	2.1	1.8	9.9	17
OR: Clatsop and Tillamook State Forests	Nelson and Wilson 2002	Nest	Older-aged forests (≥65 years) with remnant platform trees	25m-radius plot centered on nest tree	1 in most cases	25.6	20.5	4.0	78.9	22
OR: Elliott State Forest	Nelson and Wilson 2002	Nest	Older-aged forests (≥65 years) with remnant platform trees	25m-radius plot centered on nest tree	1 in most cases	15.0	9.5	4.0	38.4	10
OR: Federal Lands	Huff et al. 2006; Raphael unpubl. data	Occupied	Older-aged forests (≥80 years)	25m-radius plots	8-10	12.6	7.2	2.8	35.2	38

						Platform trees per acre				
Location and Ownership	**Reference**	**Site type**	**Habitat type**	**Plot size**	**# per Plot**	**Mean**	**SD**	**Min**	**Max**	**n**
OR: Private Lands	Nelson, unpubl. data	Occupied	Young forests (<65 years) with remnant platform trees	25m-radius plots	1 in most cases	5.9	4.0	0	16.0	139
CA: Federal Lands	Huff et al. 2006; Raphael unpubl. data	Occupied	Older-aged forests (≥80 years)	25m-radius plots	8-10	19.8	5.7	9.5	31.5	18

In the sections that follow, we expand on two of the studies listed in Table F-2 where data for each plot or set of plots is available.

Huff et al. (2006) data from plots on Federal lands in Washington, Oregon, California

Details on the density of platform trees in occupied and unoccupied sites are summarized from the study described in Huff et al (2006). In this study observers randomly selected up to 20 occupied and 20 unoccupied sites on Federal lands (including both USFS and BLM) in each of the three states, Washington, Oregon and California. Actual number of sites varied from that target, with a total of 87 occupied and 82 unoccupied sites selected. Within each site, observers measured dbh of trees ≥50.8 cm (20 in) in 25-m plots, and measured trees ≥25.4 cm (10 in) but <50.8 cm (20 in) dbh in a nested 13-m plot within each 25-m plot. Crews recorded species, DBH, and platform count for each tree. The total number of trees tallied was 33,392. Of those, 9,334 had 1 or more platforms. For this analysis Raphael computed the density of platform trees in each site (Figure F-1) and then computed means and other summary statistics from the data (Tables F-3, F-4). Occupied sites had significantly greater density of platform trees than unoccupied sites, as illustrated in Figure F-2.

Figure F-1: *Frequency distribution of density of platform trees per acre from occupied (n = 90) and unoccupied (n = 94) sites on Federal lands in Washington, Oregon, and California (from Raphael unpublished data).*

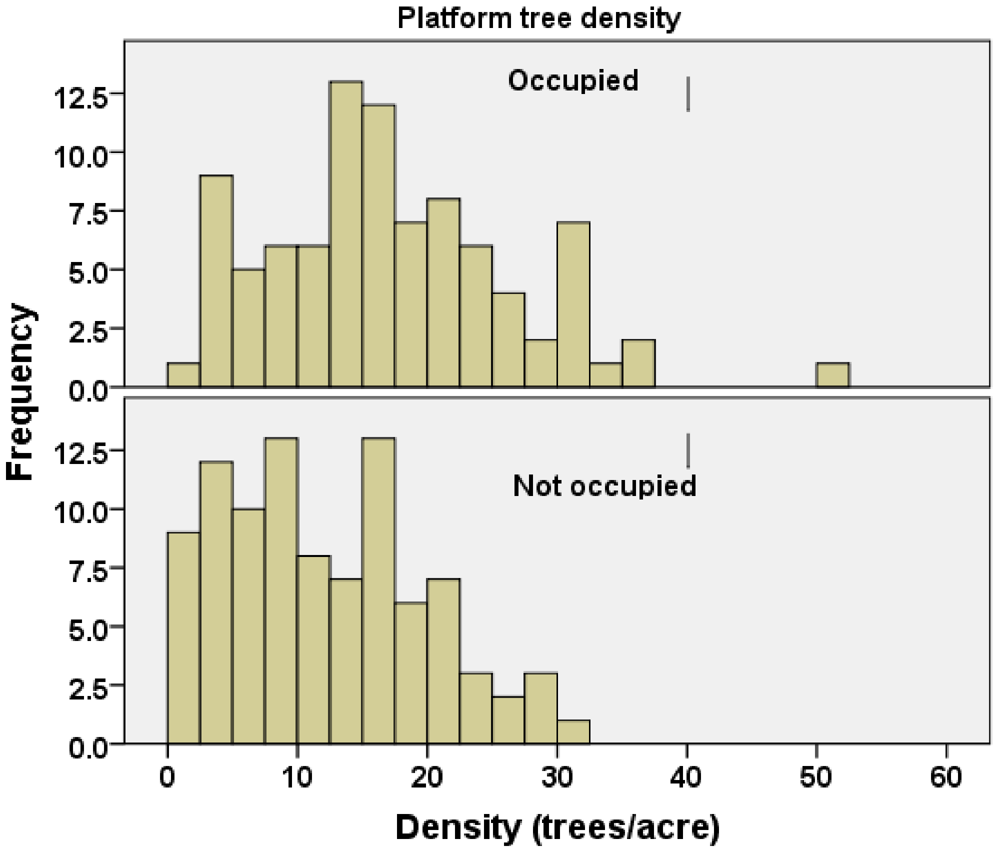
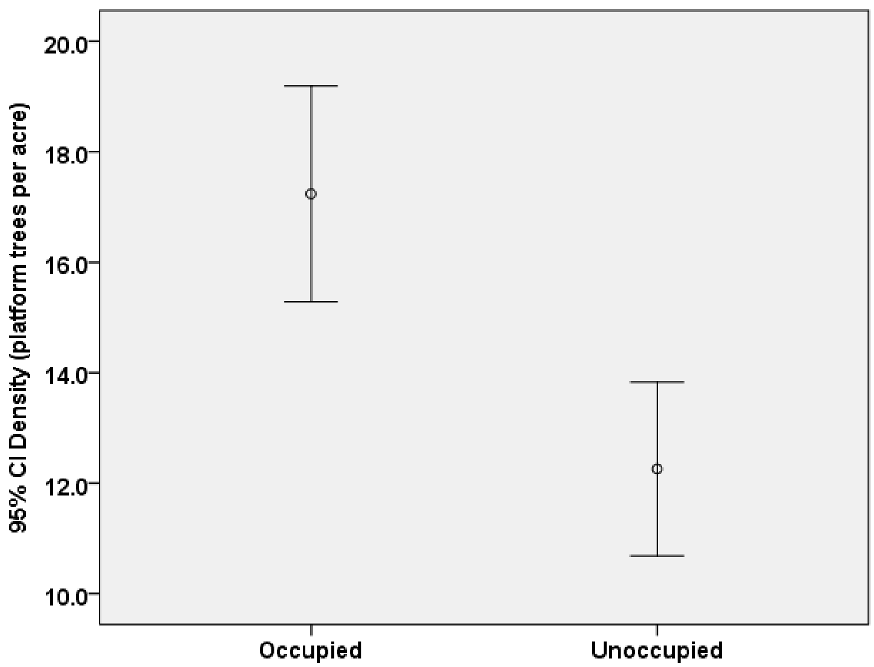


Table F-3: *Summary statistics from occupied and unoccupied sites on Federal lands in Washington, Oregon, and California (Huff et al. 2006, Raphael unpublished data).*

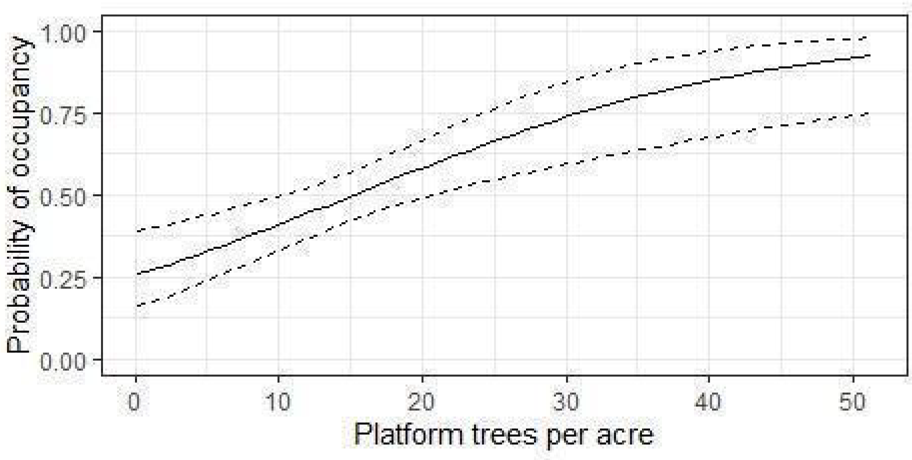
Platform Trees/Acre						
Occupy	**Mean**	**N**	**Std. Deviation**	**Minimum**	**Maximum**	**5th Percentile**
Occupied	17.2	90	9.32	2.4	51.6	3.2
Unoccupied	12.3	94	7.68	.3	30.8	1.8
Total	14.7	184	8.86	.3	51.6	2.2

Figure F-2: *Means (and 95% confidence intervals) of platform tree density per acre for occupied (n = 90) and unoccupied (n = 94) sites from Federal lands in Washington, Oregon, and California.*



Raphael (unpublished data) performed a logistic regression on these data. In this case the response variable is whether a site was occupied (coded as 1) or unoccupied (coded as 0). The independent variable was density of platform trees on each site. The results (Figure F-3) show how probability of occupancy increases as density of platform trees increases.

Figure F-3: *Predicted probability of occupancy as a function of platform tree density (Raphael unpublished data). Dashed lines indicate 95% confidence intervals.*

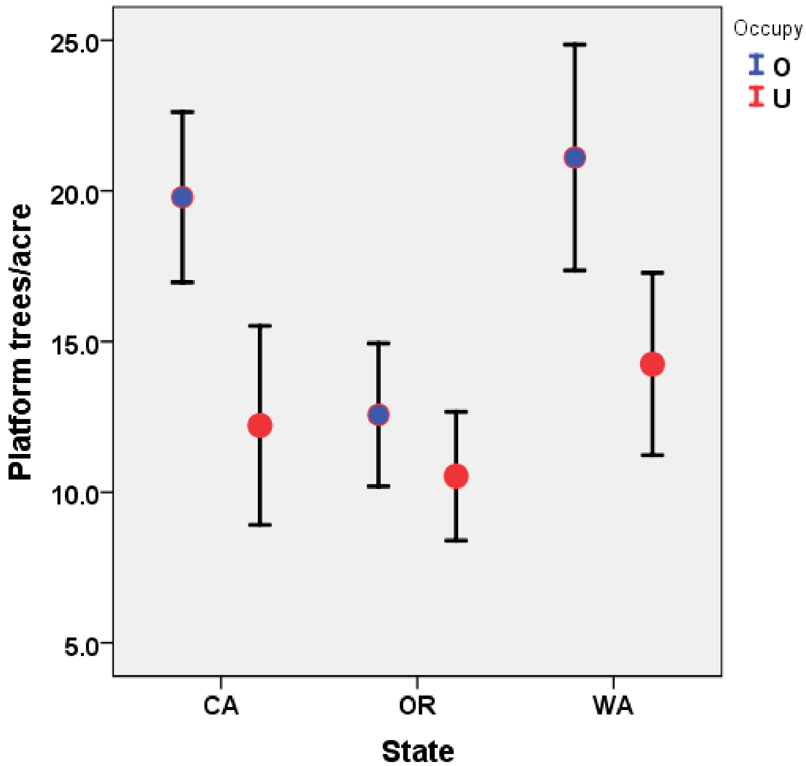


Mean density of platform trees per acre varied by state (Table F-4). Mean density was similar in Washington and California and was lower in Oregon. The 5^{th} percentile values in Table F-4 represent the cutoff value which included 95% of the platform density values in that sample.

Table F-4: *Summary statistics for platform tree density (per acre) from occupied sites on Federal lands in Washington, Oregon, and California (Raphael unpublished data).*

State	Mean	N	Std. Deviation	Minimum	Maximum	5^{th} Percentile
CA	19.8	18	5.68	9.5	31.5	9.5
OR	12.6	38	7.21	2.8	35.2	3.0
WA	21.1	34	10.74	2.4	51.6	2.6
Total	17.2	90	9.32	2.4		3.2

Figure F-4: *Means (and 95% confidence intervals) of platform tree density (per acre) on Federal lands on occupied (O) sites and unoccupied (U) sites in Washington, Oregon, and California (Raphael unpublished data).*



Nelson data from private lands in Oregon

Nelson (unpublished data) conducted two projects to describe murrelet habitat on private lands on the central Oregon coast (Florence to Pacific City) between 2010 and 2020. Plots were randomly placed in known occupied sites by randomly selecting UTM coordinates in these stands. Occupied sites were determined by the landowners, who hired crews to conduct PSG protocol surveys. Nelson resurveyed many of the occupied sites and found no errors in designation.

Occupied sites were suitable habitat, i.e., stands with platform trees. These were not current timber sales (although all included past management of a variety of types). Many included platform trees spread throughout the stands and, in some sites, they were also small concentrations of platform trees along riparian corridors. Dwarf mistletoe was common in some stands, which created platforms wherever western hemlock trees were located. Randomly locating the plots allowed us to describe the range of conditions in occupied sites on these lands.

Crews went out on the ground and placed 25-m-radius plots at the UTM coordinates. One plot was located in each "stand". The word "stand" is in quotes because some sites marked as stands were actually parts of a stand, so if the lines were redrawn using ridges, riparian areas, etc. there would have been more than one plot in some of the stands. Once the plot was located on the ground, it was centered on the closest tree (platform tree if available). Crews measured a variety of variables in each plot; all trees ≥10cm (4 in) DBH were measured and searched for platforms (PSG definition: ≥10cm (4 in) in diameter and ≥10m (33 ft) in height). The results for platform density are summarized in Table F-2 and Figure F-5. Vegetation measurement methods were exactly the same as used in Nelson and Wilson (2001) and in Raphael's data presented for the 20/20 plots (see above).

The frequency distribution from the individual plots is summarized in Figure F-5. Note that there are 10 plots with 0 platform trees in this dataset. This is an artifact of having randomly sampled small plots. These stands had platform trees but those trees were missed in the random samples. Table F-5 shows that densities of platform trees are very low on these private lands and that the 1st and 5th percentile values are zero. These represent the cutoff values for 95% of the platform density values in the sample.

Figure F-5: *Frequency distribution of measurements of platform tree density sampled from single 25-m radius plots in murrelet occupied stands on private industrial land in Oregon (from Nelson unpublished data).*

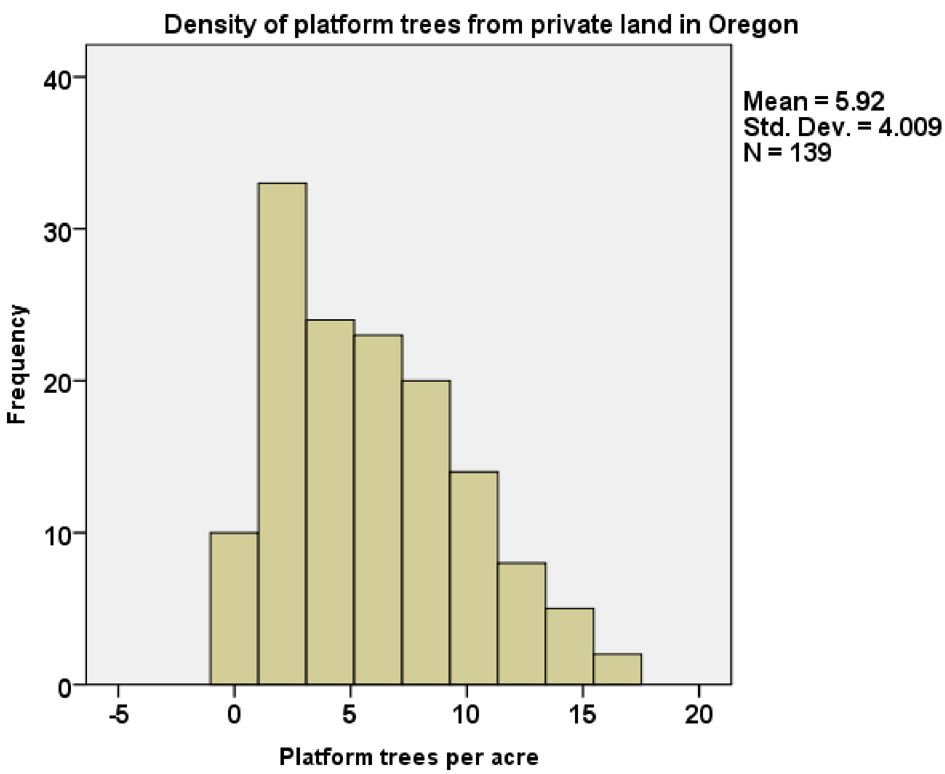


Table F-5: *Summary statistics from occupied sites on private lands in Oregon (Nelson unpublished data).*

Density of Platform Trees	N	Mean	SD	Min	Max	5%	1%
Per Ac	139	5.9	4.0	0	16.5	0	0

Platform tree density obtained from Northwest Forest Plan monitoring

As part of the Northwest Forest Plan (NWFP) monitoring program (Raphael et al. 2016, Lorenz et al. 2021) we created a database of estimated platform tree density for every 30 m (98.4 ft) pixel over the murrelet range in the NWFP area. These estimates were made using the so-called GNN database (Ohmann and Gregory 2002), which was built by modeling from Landsat spectral signatures for each pixel. GNN matches Landsat spectral data at known plots to each pixel. A disadvantage of these data is that they are subject to modeling errors, which are quantified to some extent by accuracy assessments that are published along with the models. Estimating platform density using GNN data requires several sequential models, thus errors may be compounded to an extent difficult to assess. Remotely sensed imagery is typically more well suited to look at general patterns rather than smaller spatial extent analysis. Still, these data are useful for describing more general patterns and relative magnitude of platform tree density (PTD) across ownerships and geographic areas.

To estimate PTD, Raphael and Duarte (unpublished report) used GNN variables for conifer tree diameter and species (e.g., TPH_PSME_50_75, which is trees per hectare of Douglas-fir in diameter class 50 cm (19.7 in) to 75 cm (29.5 in) DBH) to get a count of number of trees in each diameter class and species (as summarized in Table 1). For this analysis we considered any conifer tree greater than 100 cm (39.4 in) dbh as most likely to have platforms. We converted density to units of trees per acre. Note that our use of trees ≥100cm (39.4 in) DBH excludes trees of smaller diameter that may also have platforms and so our estimates here will be lower than estimates computed using the full range of tree diameters (as shown in Table F-1).

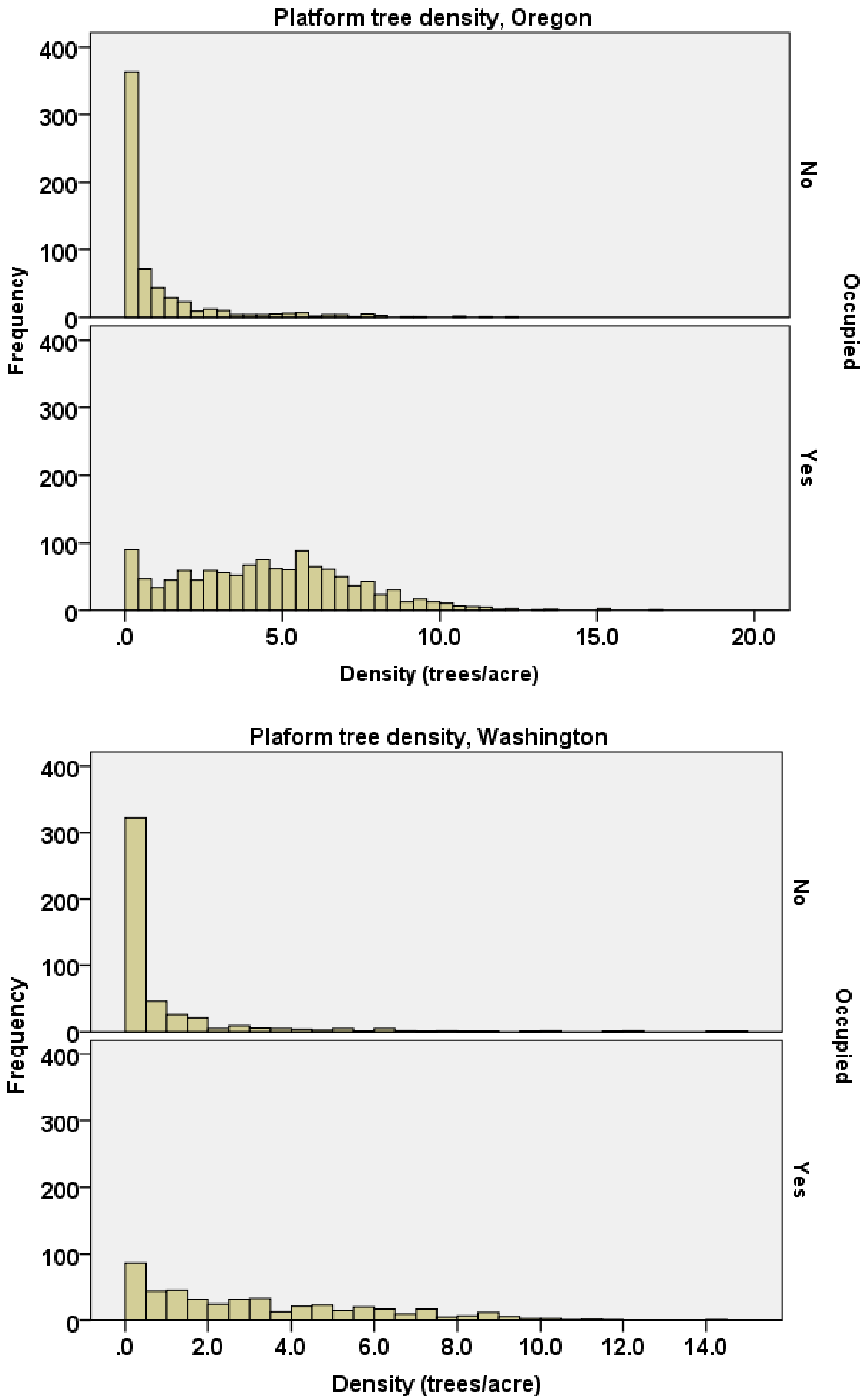
To summarize PTD in occupied and unoccupied sites, Raphael and Duarte took advantage of the large sample of occupied survey sites that they have obtained in Oregon and Washington (n = 616 in Oregon and n = 473 in Washington) in 1993–1997. Occupancy data were restricted to this set of years because it was close (in time) to the habitat data that were readily available (see below). Each unique occupancy location was only used once in this exercise. For Oregon, this was easily done because the data are stored in GIS by forest stand. For Washington, data are not organized by forest stand, but are instead organized based on general areas and subareas within the larger area. For Washington data, Raphael and Duarte attempted to maximize independence among occupied locations by using one location (chosen at random) from each subarea within each area. We also generated an equal number of random locations for each state to make comparisons. It is important to note that locations for murrelet surveys, and hence the occupied sites, were not randomly selected. These surveys were generally conducted in preparation for timber sales, and those locations may not be representative of the landscape as a whole.

Raphael and Duarte zeroed out habitat pixels that were disturbed or not habitat capable, which is the same procedure used for the periodic NWFP murrelet habitat reports. They created a 2.6 ha (6.4 ac) circle around the occupied locations (Washington), the centroids of the occupied stands (Oregon), and the pseudo-absent (randomly generated) locations. They then calculated the average of the pixel values within the 2.6 ha (6.4 ac) circle to calculate the mean conifer trees per acre in diameter class ≥100 cm (39.4 in) DBH within that circular buffer. They summarized these data using the mean, SD, and 5th percentile by land use type (i.e., Federal, non-Federal (state + private), state, and private).

Table F-6: *Mean conifer trees in diameter class ≥100 cm (39.4 in) DBH per acre at Oregon and Washington locations.*

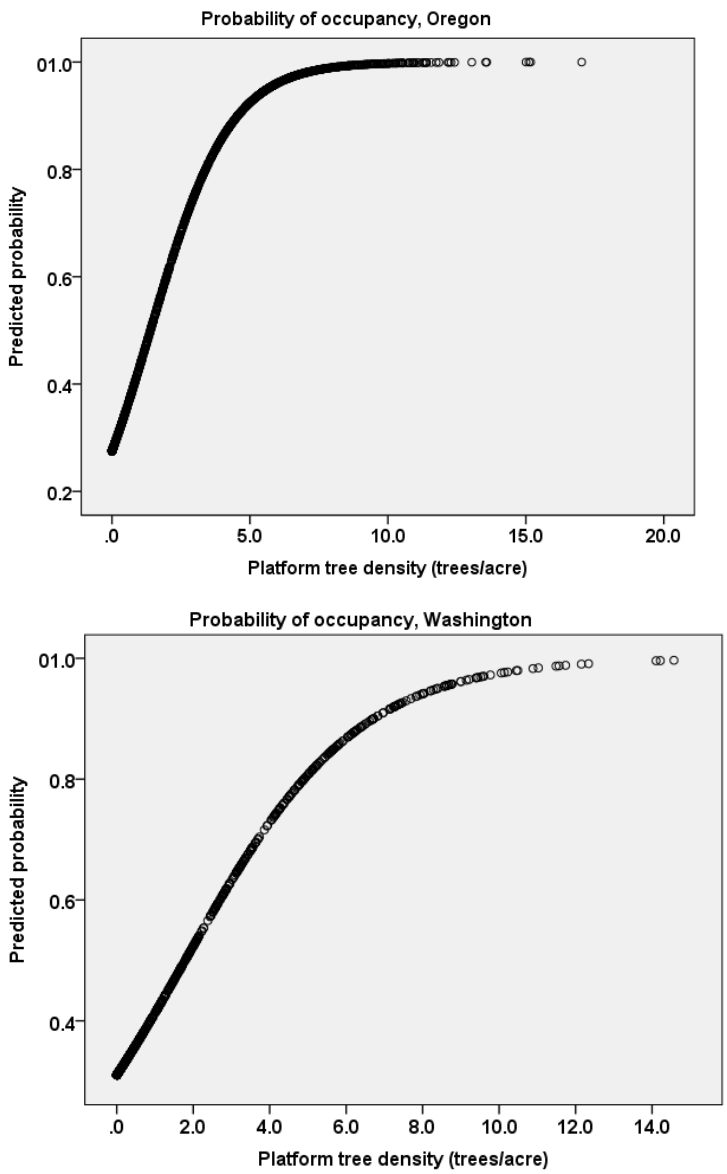
		Oregon				**Washington**			
Land use type	**Location type**	**Mean**	**SD**	**5th percentile**	***n***	**Mean**	**SD**	**5th percentile**	***n***
Federal	Random	2.41	2.79	0.01	164	2.44	3.23	0.00	135
Non-Federal (State+Private)	Random	0.52	0.99	0.00	452	0.34	0.70	0.00	338
Private	Random	0.45	0.80	0.00	393	0.27	0.52	0.00	269
State	Random	0.97	1.75	0.00	59	0.63	1.13	0.00	69
All lands	Random	1.02	1.86	0.00	616	0.93	2.05	0.00	473
Federal	Occupied	5.30	3.21	0.49	379	2.63	2.52	0.03	104
Non-Federal (State+Private)	Occupied	3.82	2.93	0.04	237	3.38	2.84	0.06	369
Private	Occupied	1.73	1.96	0.05	17	1.89	2.08	0.03	77
State	Occupied	3.98	2.94	0.04	220	3.77	2.89	0.10	292
All lands	Occupied	4.57	2.80	0.23	1232	3.21	2.70	0.37	473

Figure F-6: *Frequency distribution of density of platform trees from occupied and unoccupied (random) sites on all lands in Oregon and Washington. Data derived from GNN using counts of trees with DBH ≥ 100 cm (39.4 in) as a proxy for platform trees (from Lorenz et al. 2022; Raphael unpublished data).*



Raphael (unpublished data) performed a logistic regression on these data. In this case the response variable is whether a site was occupied (coded as 1) or a random (coded as 0). The independent variable was density of conifer trees ≥100 cm (39.4 in) dbh on each site. The results (Figure F-7) show how probability of occupancy increases as density of platform trees increases.

Figure F-7: *Predicted probability of occupancy as a function of platform tree density in Oregon and Washington (Data derived from GNN (Lorenz et al. 2022, Raphael unpublished data).*



To estimate the tradeoffs in sampling effort that might be required under varying thresholds of PTD, Raphael and Duarte used the pseudo absence locations from the previous exercise and tabulated conifer trees in diameter class >100 cm (39.4 in) DBH density at each of those random points. They then computed what proportion of those random points had a density equal to or greater than the specified PTD threshold.

Raphael and Duarte plotted different levels of murrelet habitat protection (minimum conifer trees in diameter class ≥100 cm (39.4 in) DBH density that would trigger a requirement to survey) against proportion of random points by each state (Figures F-8, F-9). They used the proportion of random points as a proxy to the total proportion of the landscape that would be eligible for sampling. Note that these results apply to all lands without regard to land ownership. In each figure, the numbers along each point specify the number of conifer trees in diameter class ≥100 cm (39.4 in) DBH per acre. For example, the point labeled “1” represents the proportion of stations (random and occupied) that have at least 1 conifer tree in diameter class ≥100 cm (39.4 in) DBH per acre. Again, the strength of using remotely sensed data is to evaluate general patterns and relationships. Thus, the actual values should not be interpreted with respect to the biology of Marbled Murrelets or used to determine habitat to survey.

Figure F-8: *Relationship between platform tree density (stems per acre) and area meeting that threshold, broken down by landowner in Washington. The Y-axis is based on the frequency distribution of occupied sites that have a given density of platform trees within a 2.6 ha (6.4-ac) circle surrounding the center of the occupied site. The X-axis is the proportion of the greater landscape that has that same density. Each dot represents a given density of platform trees. For example, the reddish dot labeled with "1" represents a PTD of 1 tree/acre. About 75% of the occupied sites were estimated to have that density or greater. At the same time, a density of 1 tree/acre covers about 24% of the available landscape.*

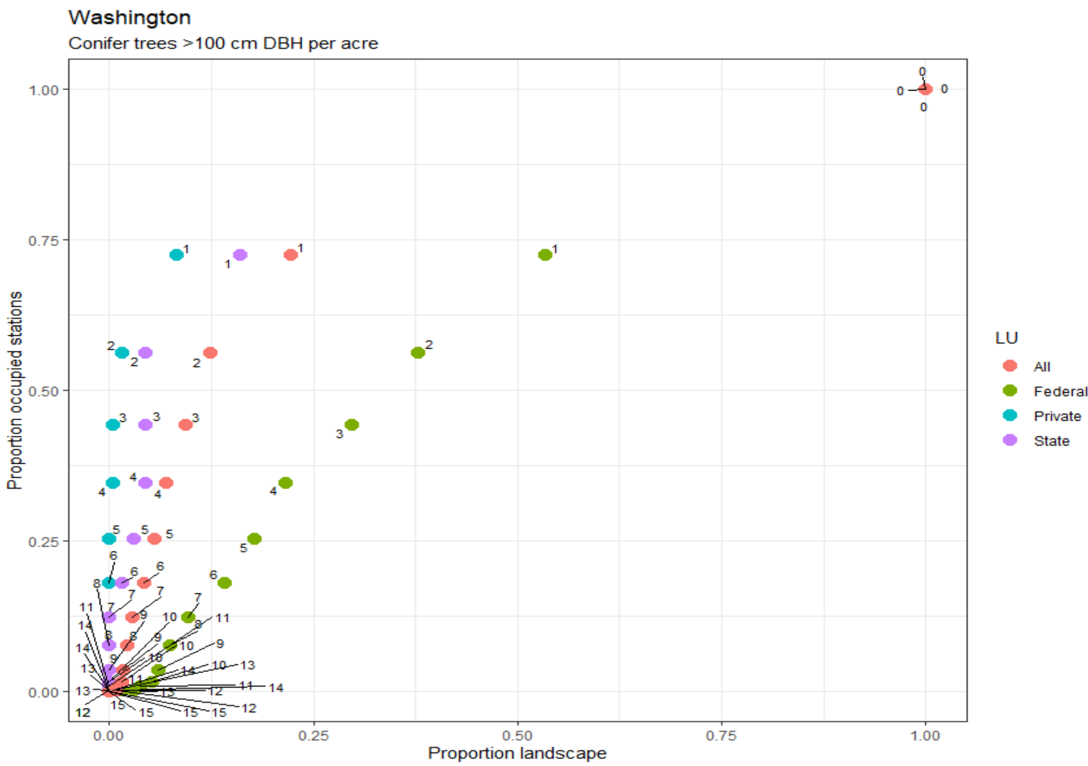
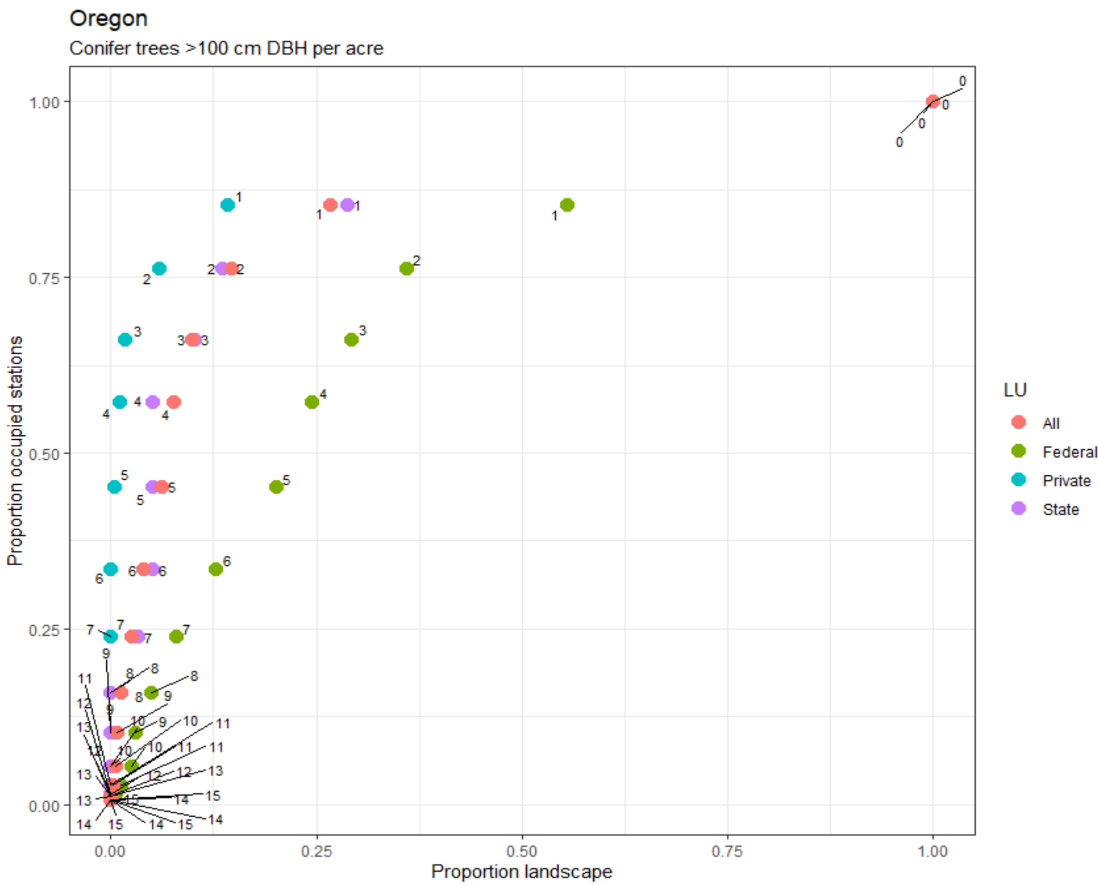


Figure F-9: *Relationship between platform tree density (stems per acre) and area meeting that threshold, broken down by landowner in Washington. See figure 6 for interpretation of this figure.*



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APPENDIX G: FOREST BIRD AND MAMMAL SPECIES POTENTIALLY MISIDENTIFIED AS MARBLED MURRELETS AND POTENTIAL MURRELET PREDATORS

The following species have been identified as sources of potential confusion if present during a Marbled Murrelet forest survey. They may be misidentified by sight, sound, or both by an inexperienced observer. Observers should be able to identify the species on this list to ensure the accuracy of the survey data reported. Marbled Murrelet flight is characterized by rapid, constant wing beats, whereas other forest birds have slower but constant flight patterns or alternate between flapping and gliding. See Appendix E for a detailed description of murrelet sounds. Species are identified by Common Name/A.O.U. code (birds).

Potentially Misidentified

Heard and Seen

Common Nighthawk (CONI)
Varied Thrush (VATH)
American Robin (AMRO)
European Starling (EUST)

Heard

Killdeer (KILL)
Bald Eagle (BAEA)
Red-shouldered Hawk (RSHA)
Red-tailed Hawk (RTHA)
Osprey (OSPR)
Northern Flicker (NOFL)
Red-breasted Sapsucker (RBSA)
Hairy Woodpecker (HAWO)
Olive-sided Flycatcher (OSFL)
Western Wood-Pewee (WWPE)
Steller’s Jay (STJA)
Gray Jay (GRJA)
Swainson's Thrush (SWTH)
Hermit Thrush (HETH)
Hutton's Vireo (HUVI)
Black-headed Grosbeak (BHGR)
Song Sparrow (SOSP)
Western Tanager (WETA)
Evening Grosbeak (EVGR)

Mammal: Douglas squirrel

Seen

Wood Duck (WODU)
Harlequin Duck (HADU)
Common Merganser (COME)
Spotted Sandpiper (SPSA)
Band-tailed Pigeon (BTPI)
Mourning Dove (MODO)
Black Swift (BLSW)
Vaux's Swift (VASW)
Tree Swallow (TRSW)
Violet-green Swallow (VGSW)
American Dipper (AMDI)

Mammal: Bat spp.

Potential Marbled Murrelet Predators

The following is a list of potential predators of adult Marbled Murrelets or their nests (eggs or young). The presence of these predators during the survey should be recorded in the notes section on the survey data form.

Bald Eagle (BAEA)
Sharp-shinned Hawk (SSHA)
Cooper's Hawk (COHA)
Northern Goshawk (NOGO)
Red-shouldered Hawk (RSHA)
Red-tailed Hawk (RTHA)
Peregrine Falcon (PEFA)
Great Horned Owl (GHOW)

Barred Owl (BAOW)
Northern Spotted Owl (SPOW)
Steller's Jay (STJA)
Gray Jay (GRJA)
American Crow (AMCR)
Northwestern Crow (NWCR)
Common Raven (CORA)

Douglas squirrel
Red squirrel
Northern flying squirrel
Forest deer mice (Peromyscus spp.)
Chipmunks (Neotamias spp.)
Woodrats (Neotoma spp.)
Pacific Marten
Fisher

APPENDIX H: INFORMATION AVAILABLE FOR ALASKA AND BRITISH COLUMBIA FOR MODIFICATION OF THIS PROTOCOL

Based on a recent review of past survey data and current knowledge, surveys for management applications should be conducted during the following periods: 15 April to 5 August in California (Carter and Erickson 1988, O'Donnell et al. 1995); 24 April to 5 August in Oregon and Washington, 1 May to 31 July in British Columbia (BC; Cragg et al. 2016); and 15 May to 5 August in southeastern and south-central Alaska (Kuletz et al. 1994, but see Brown et al. 1999 for a potentially earlier start in southeastern Alaska).

The survey period in California, Oregon, Washington is defined as at least a two-hour period from 45 minutes before to 75 minutes after official sunrise or for 15 minutes after the last detection, whichever is longer. In southern BC, surveys start 60 minutes pre-sunrise and end 60 minutes post-sunrise; in northern BC, including Haida Gwaii, surveys begin 75 minutes before sunrise and end 45 minutes post-sunrise. Surveys are continued until 15 min past last detection in each case. A combination of passive acoustics and AV surveys on Kodiak Island showed vocal activity beginning 90 minutes pre-sunrise and extending 1 hour after sunrise (See fig 3 in Cragg et al. 2016). See the BC Resource Inventory Standards Committee protocol for more information: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/mamu_ml20.pdf

In southeastern Alaska, survey visits should begin at least 60 minutes before sunrise (Brown et al. 1999), and in south-central Alaska, survey visits should begin 90 minutes before official sunrise (Kuletz et al. 1994). Nautical Almanac sunrise tables can be obtained at https://nrc.canada.ca/en/research-development/products-services/software-applications/sun-calculator/ for British Columbia and https://www.esrl.noaa.gov/gmd/grad/solcalc/ for British Columbia and Alaska.

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APPENDIX I: MARBLED MURRELET OBSERVER TRAINING PROTOCOL FOR FOREST SURVEYS

Updated by the Marbled Murrelet Inland Survey Protocol Team, Pacific Seabird Group, Marbled Murrelet Technical Committee

March 2023

Introduction

Presented here is a protocol to train and evaluate potential observers. The training program ensures the trainees can reliably discriminate the calls of murrelets from other species of birds and visually discriminate murrelets in flight from other similar looking birds. The training will also teach observers to accurately record observations on standardized data forms. Included in the training is an evaluation process that provides a standardized method for determining if an individual's abilities will yield reliable and dependable survey data.

Training for **first and second year** murrelet surveyors must include all of the following steps: (1) a hearing test submitted to the instructor prior to training in the first year (see Appendix K); (2) a seminar on murrelet biology and forest survey protocol; (3) field training, with a minimum of three survey mornings, from a qualified instructor; and (4) a field exam with a qualified evaluator. Instructor and evaluator qualifications are described at the end of this Appendix. Trainees should take the field exam after they understand the protocol and are proficient in survey techniques. Once a trainee completes these steps and passes the field exam, they are qualified to conduct murrelet forest surveys.

After 2 years of survey experience that includes murrelet detections on multiple surveys, it is recommended that annual training in subsequent years should include steps (3) and (4) as listed above, except with only one to two practice survey mornings in the field required prior to the field exam. Surveyors who do not perform murrelet surveys regularly should also include step (2) in their annual evaluation. After 5 consecutive years of survey experience that includes murrelet detections on multiple surveys, training in subsequent years should include steps (1) and (3), with step (4) occurring every other year, except with only one to two practice survey mornings in the field required prior to the field exam. Regardless of experience, it is important that surveyors re-familiarize themselves **each year** with the calls and techniques needed to conduct accurate murrelet surveys. Digital recordings of the variety of vocalizations of Marbled Murrelets are available on the PSG website for download (https://pacificseabirdgroup.org/psg-publications/technical-publications/). We also recommend that to help maintain their skills, surveyors who do not encounter murrelets by mid-season should visit a location with moderate activity levels at least one time during the season. This mid-season refresher would best prepare a surveyor for the increased activity levels that typically occur in July.

Training Requirement

Training is necessary for observers conducting surveys on forest birds (Kepler and Scott 1981), including Marbled Murrelets. Intensive training and annual review and evaluation in detecting and identifying Marbled Murrelets and their vocalizations is required, as they are exceedingly cryptic and can be easily missed in a forested setting or misidentified as other species. The training procedure includes an intensive instructional period with a minimum of three training mornings, followed by a fourth morning of performance evaluation or field examination. Training should only be conducted at a location with high activity levels (in excess of 25 detections per morning) to expose trainees to a wide range of vocalizations and activity during the morning. Surveyors should only be trained by PSG endorsed training programs (https://pacificseabirdgroup.org/psg-publications/technical-publications/). All trainees are required to have their hearing tested by a professional and have adequate vision (*Appendix J*).

Observer Qualifications

Our experience indicates that most individuals with adequate sight and hearing abilities are capable of being trained to recognize Marbled Murrelets following the PSG protocol. However, the quality and reliability of observations is greatly enhanced if surveyors possess basic bird identification skills, or, preferably, already have the ability to identify the common birds of the west coast by sight and sound. Surveys at locations with low or zero murrelet abundance require a higher degree of competence and documentation (Hunter and LeValley 1996). In addition, it is preferred that surveyors have field experience in the Pacific Northwest and in steep forested terrain. Given the expense of sorting out false positive detections, land managers should be willing to hire experienced surveyors to ensure that the data gathered are of the highest quality possible.

Seminar

A seminar on the biology of the Marbled Murrelet should include the following: species description, breeding chronology, flight behavior, habits, habitat and nest site description, and a summary of potential threats to the bird. A photo presentation or video including pictures of adults, juveniles, chicks, eggs, eggshell fragments, and some habitats used by murrelets should be included. A video of murrelets in flight over forests, illustrating a variety of flight patterns, should be incorporated. The seminar should provide information regarding the legal history and current status of the species. Questions from students should be answered regarding all aspects of the biology of the species.

The importance of adequate training and preparation for the evaluation should be emphasized at the seminar. Proper training will not only help observers to pass the evaluation, but also will improve the quality of data collected throughout the season.

The survey protocol should be thoroughly reviewed, and information presented on where to survey (habitat), when to survey (dates and times of survey), how to establish the survey stratum, how to establish and choose survey stations, and the number and size of the survey stations required to ensure adequate coverage of the habitat. Examples of how to establish survey stations should be presented with a discussion of how and where to strategically place stations within the survey stratum.

A complete description of how to record and interpret data and bird behavior should be included in all aspects of the training and reviewed annually.

Field Training

Field training should only be conducted at an area of relatively high murrelet activity, with an excess of 25 detections per morning, including visual detections. If this level of activity is not found in the local area, it is recommended that trainees be transported to an area of high murrelet activity. Currently, Northern California (i.e., Prairie Creek Redwoods State Park) is the only known location that reliably provides adequate murrelet activity prior to the onset of the survey season (15 April in California; 1 May in Oregon and Washington), however other locations may provide opportunities later in the season. Only PSG-endorsed instructors and evaluators should be used for training and evaluations (https://pacificseabirdgroup.org/psg-publications/technical-publications/).

Before the first day of training, trainees should become familiar with the most recent PSG survey protocol (PSG Technical Publication #6) and listen to a Marbled Murrelet vocalization recording with accompanying descriptions. An outline of the daily objectives for the training and equipment for surveys should be obtained from the instructor prior to the training session. Equipment needed for the training includes: a voice recorder, headlamp, extra batteries, binoculars, compass, and a timepiece.

Outline of field training schedule

Day 1.--The first day of the field training begins 15 minutes before the protocol-prescribed survey time (or, one-hour before official sunrise), at an area that will not disturb nesting murrelets. Trainees can listen to recordings of murrelet vocalizations while the instructor identifies the types of murrelet calls. The instructor should discuss calls from other species which may cause confusion.

At the survey training location, trainees observe and listen for murrelets while the instructor points out the murrelets and their calls as well as those of other birds. The instructor can discuss

(1) murrelet behaviors in the forest and the importance of behaviors in identifying occupied areas; (2) the data sheet, including the types of data taken and priorities when recording information; (3) observation and recording techniques; and (4) calls and flight patterns of other birds that can cause misidentification problems.

The use of the Notes section on the data form should be encouraged. Interpretation of survey results will be enhanced by narrative notes that clarify the data. The instructor should discuss the importance of using binoculars to identify some species which can be confused with murrelets (e.g., swallows, swifts). It also should be noted that because the use of binoculars during a survey can cause the surveyor to miss murrelets, their use should be limited to species verification and not for prolonged scanning for murrelets. The instructor should encourage trainees to ask questions throughout the session and during a discussion period following the survey.

During the last portion of the survey period, the instructor can record a few detections to demonstrate suggested recording methods. At the close of the session, trainees are asked to practice recording before the next day's session by observing birds of any species flying overhead. By recording these birds, they will become more familiar with the data collection process and the order in which the information is recorded.

A classroom session on this day can be used to explain details of recording observations on the data forms and mapping detections, and to show videos and/or slides.

Day 2.--On this day, trainees practice identifying murrelet calls and observing behaviors during visual detections. The instructor should measure and mark distances and tree heights at the training location to help trainees sharpen their skills for estimating distance to, and height of, the birds. A 50-m or 100-m tape, or a laser rangefinder can be used to further help with distance estimates. Considerations of station placement at a survey stratum can be covered in the field on this day.

The instructor should record a few detections on an audio recorder, play back the recording, discuss the data with the trainees, and answer questions. Trainees can then record detections on their own while receiving assistance from the instructor. At the end of the morning's session, trainees should transcribe a portion of their data with the assistance of the instructor. This is an excellent way to see what data they are missing or recording incorrectly. Again, we suggest that trainees spend some time before the next session observing and recording birds of other species. Estimating height and distance also can be practiced on other birds.

Day 3.--All trainees can conduct a complete survey on this day, as the instructor circulates between trainees, helping with comments on accuracy and technique. At the end of the survey, recordings are transcribed, and any questions on data are clarified by the instructor. Trainees should be familiar with the techniques for conducting and recording a murrelet survey by the end of this day. It is helpful for the trainer to record and transcribe a segment of the morning’s activity for comparison to the trainee’s transcriptions.

Day 4.--A simultaneous survey and field exam, described below, will be conducted on this day of the training.

Evaluation Survey (Field Exam)

The evaluation survey should only be conducted by a qualified evaluator (see PSG's list of endorsed instructors and evaluators; https://pacificseabirdgroup.org/psg-publications/technical-publications/). Also see Qualified Instructors and Evaluators, below, for information on evaluator qualifications.

Evaluation is based on the results of a simultaneous survey conducted by the trainees and an evaluator. The number of participants per evaluation will be determined in part by the size of the site. More importantly, the evaluator must be able to watch the participants and their reactions to birds to assess their competence. We recommend that group size be limited to 15 or fewer trainees per evaluator.

Participants should arrive at the site early enough to allow time for instructions and still begin the survey at the appropriate time. During the survey, trainees are positioned approximately 5-8 m (16-26 feet) apart. This helps ensure that observers have essentially the same viewing field, such that similar numbers of birds can be detected by all observers but reduces the likelihood that they will cue in on detections by watching the evaluator or other observers or be distracted by others speaking into their recorders. Watches should be synchronized or a time check recorded on the recorders at the beginning of the survey. The evaluator may call out a time check during the survey, at which time all surveyors record the time on their tape.

In periods of low activity during the evaluation survey, the evaluator can record calls of other species, recording the same type of information as for a murrelet. These observations can then be checked against the trainees' recorded data to determine whether species are being correctly identified. The evaluator should record at least 10 to 20 observations of other species.

At the end of the survey the data should be transcribed onto data forms. After transcription, all of the data sheets are turned into the evaluator, who checks for completeness and tallies and evaluates the results for each participant.

Evaluation of Survey Results

To evaluate the results, we suggest that, for each 10-minute period of the survey, the number of detections of murrelets be tallied according to the following six categories: number heard, number seen, total number of detections, number of detections with occupied behaviors (visual detections of murrelets flying at or below the canopy), number detected within 200 m (656 feet) (or recorded as Loud or Moderate) of the observer, and those detected at greater distances (or recorded as Faint). If birds are both heard and seen, they are tallied once in each of the first two categories.

Each surveyor's results for three categories -- number heard, number seen, and number of occupied behaviors and/or total detections -- are compared with the evaluator's observations for each 10-minute period and for the entire survey. Two criteria of success are described below, one for areas with many birds, making it likely that some birds would be missed during peak activity, and another for areas with fewer detections.

Areas with many detections

At a location where the evaluator records 35 or more detections, reasonable measures of success for a surveyor are the following: if the participant records at least 60% of the number of observations in two of the three categories, and at least 50% in the remaining category, it can be considered that the participant has sufficient skill to determine the presence of murrelets in a forest stand. These figures are based on our experience in training people and comparing with expert surveyors. In these comparisons, the expert surveyors always detected in excess of 70% of the best observer. Further, any person detecting more than 60% of the birds in a stand with 35 or more detections would be unlikely to overlook so many birds that a nesting stand would be misclassified as unoccupied.

If a participant records more detections than the evaluator, their results should be reviewed carefully to determine if they counted non-murrelet targets (suggesting that they misidentified murrelets) or double-counted what should have been single detections. There should be some allowance for visual detections, because the evaluator can't see everything and must at times focus their attention on the surveyors. The number of audio detections should generally not greatly exceed the evaluator's total.

Areas with fewer detections

If the survey location generally has fewer murrelet detections and the evaluator records fewer than 25 detections during the simultaneous survey, a different measure of success can be used. A participant should record at least 70% of the number of observations in two of the first three categories, and at least 60% in the remaining category. Activity during an evaluation should consist of a mix of both auditory and visual detections. Evaluation surveys with fewer than 25 detections during a one-day evaluation, or 18 detections in each of two consecutive days of evaluation, are generally not acceptable. We recommend that detections should include vocalizations and at least six visual observations each day. If detections are fewer than 18 in each of two consecutive days, a third day of evaluation training may be needed.

At the discretion of the instructor and evaluator, the criteria listed above may be relaxed for trainees that meet one or more of the following conditions: (1) birds not heard by the trainees are usually in excess of 200 m (656 feet) (or recorded as Faint) from the evaluator; (2) occupied behaviors are in excess of 80% of the standard and agree with the evaluator; and (3) missed detections occur during very busy (greater than 10 detections) 10-minute periods when the presence of many birds may make individual detections difficult to define.

Qualified Instructors

Instructors should be highly qualified field ornithologists very familiar with not only murrelets, but also all other bird species (especially their calls and songs) at evaluation sites. Instructors should have a minimum of three years' survey experience from a variety of survey situations (both high and low detection areas) and in a range of forest stand types. PSG maintains a list of endorsed instructors on their website (https://pacificseabirdgroup.org/psg-publications/technical-publications/).

Instructors are responsible for the first three days of the training sessions as outlined above. Instructors should have a demonstrated ability to teach and interpret the survey protocol. As such, an instructor must be knowledgeable in the areas of murrelet ecology, general habitat associations, protocol interpretation, survey design, and regional management and regulatory requirements.

Instructors should complete extensive re-familiarization annually and meet the general requirements to include a complete review of changes in survey protocol, new information suggesting alternative interpretation of survey data, and an update from local regulatory agency staff, if available. If the instructor is to perform evaluations, training should include simultaneous surveys as outlined in the *Qualified Evaluators* section below.

Qualified Evaluators

Evaluators (who may also be instructors) are responsible for the evaluation survey. It is the Evaluator's data that is used for comparison during the simultaneous evaluation survey. Evaluators should also be highly qualified field ornithologists very familiar with not only murrelets, but also other bird species (especially their calls and songs) at evaluation sites, especially birds that could be misidentified as murrelets. Evaluators should have a minimum of five years' murrelet survey experience from a variety of survey situations (both high and low detection sites) and in a range of forest stand types. Simply attending an evaluator training is not enough to make one an evaluator. PSG provides a list of endorsed evaluators on their website (https://pacificseabirdgroup.org/psg-publications/technical-publications/).

Evaluators must be knowledgeable in murrelet ecology, protocol interpretation, and have the ability to survey consistently within 20% of other evaluators. Evaluators must be listed on the official PSG evaluator list (https://pacificseabirdgroup.org/psg-publications/technical-publications/) in order to be qualified to conduct evaluation surveys.

Evaluators should complete a re-familiarization session annually and meet the general murrelet surveyor requirements. The annual session should include a complete review of any changes in survey protocol, new information suggesting alternative interpretation of survey data, and an update from local regulatory agency staff, if available. It also should include simultaneous surveys with other evaluators on at least two survey mornings. Consistent results (within ~20%) between the evaluators during simultaneous surveys should be achieved before outside evaluations begin. A potential evaluator should spend at least 2 mornings conducting simultaneous surveys with a qualified and experienced evaluator and obtain the same 20% consistency. Failure to complete an annual evaluator re-familiarization session calls into question the quality of any independent evaluation process, the status of the surveyors who may be certified by an unqualified evaluator and ultimately may jeopardize survey results.

Lists of Qualified Surveyors, Instructors and Evaluators

A list of current qualified surveyors or the organizations they belong to should be kept by each evaluating organization and posted on the PSG website (https://pacificseabirdgroup.org/psg-publications/technical-publications/) each year in case it is requested by regulatory agencies (e.g., the U.S. Fish and Wildlife (USFWS) or state fish and wildlife agencies). This list should include the names of participants who passed the evaluation survey and those who passed the more rigorous requirements to become an evaluator (see above). PSG will maintain a list of those individuals who are qualified to be an instructor and/or evaluator according to the guidelines above. Those wishing to be added to the list of instructors or evaluators must provide a statement of qualifications to the MMTC coordinator/s for review (see https://pacificseabirdgroup.org/psg-committees/ for contact information).

Follow-up Training

When possible, and at the discretion of the survey crew leader, follow-up surveys should be conducted by crew leaders (typically experienced surveyors) with first year surveyors at their assigned survey stations after the initial training and evaluation. These surveys help to identify any deficiencies in survey technique which may develop once observers are conducting field work. Two types of follow-up surveys may be conducted: (1) at low-use areas, within 1-2 weeks after successful evaluation; and (2) a mid-season survey at any area with detections, especially for those who have not seen or heard murrelets during the early part of the survey season.

Follow-up surveys at low-use areas are important to verify that observers are (1) identifying single murrelets in areas with few observations; and (2) not confusing murrelet calls with the calls of other forest birds in their survey areas. Because most training and evaluations are done at high-use areas, it is imperative that crew leaders verify that observers know how to accurately conduct surveys at low-use areas. It is recommended that these follow-up surveys take place for at least one morning in areas with the greatest likelihood of murrelet activity. The crew leader should conduct a simultaneous survey, similar to the initial evaluation, to identify how the observers would benefit from additional instruction. If no low-use areas are available in your area, high-use areas can be used. In this case, the survey period could be split between the periods of peak murrelet activity and the non-peak times. The crew leader could then focus on the non-peak times and compare the numbers and types of observations recorded by the observers.

It is recommended that a mid-season refresher training occurs (ideally during late June) for those surveyors who have not had any detections. This should involve at least 1 day of survey at low- or high-use areas. Crew leaders should review the survey protocol and reevaluate the observers' survey skills. This also is an important time to answer questions that have developed over the survey season and to revitalize crew morale.

Literature Cited

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APPENDIX J: DATA FORMS AND INSTRUCTIONS
(revised March 2023)

The following members of the **Pacific Seabird Group's Marbled Murrelet Technical Committee, Inland Survey Protocol Team** contributed to reviewing and updating this appendix.

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Will Ritchie, *USFWS Willapa NWR*
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Survey Cover Page Instructions

Item #

1 Page Number of the total number of pages of data for the survey. This includes Cover Page, Survey Activity Table page(s), and Map page(s).

2 Total Detections: Total number of murrelet detections recorded during a survey visit. All detections should be assigned a detection number (Detect. #), including un-mappable detections. No other species observations should be included in this count.

3 Other Species of Concern: Circle **Y** (Yes) or **N** (No) to indicate if species of concern other than Marbled Murrelet were observed; refer to your state or provincial Fish and Wildlife agency Species of Concern list. Record details of observation(s) ***in the notes section*** ***at the end of the last page of the Survey Activity Page***. Do not assign a detection number to non-murrelet observations

4 Month, Day, Year: Date of survey visit. Use 2 digits for Month and Day, and four digits for Year (e.g., May 10, 2000 = 05/ 10/ 2000).

5 Ownership: Enter the name of the land owner or land manager where the station is located.

6 Area Name: Name of survey area being surveyed.

7 Stratum Name / Number: Stratum name and number from which survey visit is conducted. Each Survey Stratum should have a ***unique*** number or alphanumeric identifier.

8 Station ID: Station ID (number, letter, etc.) from which survey visit is conducted. Each survey station should have a ***unique*** alphanumeric identifier relative to a survey stratum.

9 Station Location: Location of station where survey visit was conducted.
UTM – Enter the UTM zone, coordinates, and map datum (e.g., NAD83) from the Station Information Form, unless the survey was conducted from a different location due to noise or other disturbances (explain in notes).

10 Observer Name(s): First name, middle initial, and last name of the observer(s).

11 Initials: Legible initials of observer's full name.

12 Affiliation: Agency, tribe, or company name.

13 Phone: Agency, tribe, or company telephone number including area code. This should be a contact that can be reached during and after the survey season in the event that questions arise regarding the survey data.

14 Sunrise Time: Official sunrise time derived from tables based on the date of the survey visit and the geographic area; See Table references below; do not use newspaper or tide table sources. Use 4-digit "24 Hour Time"(e.g., 5:18 A.M. = 0518, or 6:30 P.M. = 1830).

15 Source: Indicate the Sunrise/Sunset table used to determine the survey times. Sunrise tables are obtained from the U.S. Naval Observatory at web stratum: https://www.esrl.noaa.gov/gmd/grad/solcalc/

16 Begin Survey Time: Actual time survey visit is started using "24 Hour Time" described above. A morning visit should begin ***at least*** **45** minutes before official sunrise. If a survey visit actually begins later, also note the number of minutes late (e.g., "5 min. late").

17 End Visit Time: Actual time survey visit is completed using "24 Hour Time" described above. A morning visit typically ends **75** minutes ***after*** official sunrise; more time is added when murrelet detections occur within the last 15 minutes of a visit.

ENVIRONMENTAL CONDITIONS: Record conditions as observed at the survey station at the beginning and end of the survey visit; also note any significant changes in conditions that affect murrelet detectability as they occur throughout the survey visit. Enter duration of such conditions in the "Notes" column:

- Record any conditions that affect vertical visibility to 1 canopy height, horizontal visibility to 100 m (328 feet), and audibility to 200 m (656 feet). If these conditions exist for a cumulative total of greater than ***12 minutes*** during the survey visit, the visit should be rescheduled, unless occupied behavior is observed.

18 Time: Record times in 4-digit "24 Hour Time". Enter the time when the survey visit began and ended and indicate "Begin Survey " and "End Survey " in the Notes column. Also enter the time when significant weather or environmental conditions occur that affect murrelet detectability from the station.

19 Vertical Viewing: Visibility is best assessed when the sky lightens. Enter '**U**' for Unknown at the beginning of the survey if darkness prevents an accurate assessment but remember to update as soon as possible and whenever significant changes occur.

- Ceiling: This is the height of the ***primary*** cloud/fog ceiling layer relative to the canopy of the survey stratum as viewed from the station. Record the appropriate code: **UL** Unlimited (clear); **HI** > 2.0 canopy height; **MID** ≥ 1.5 to ≤ 2.0 canopy height; **LO** >1.0 to <1.5 canopy height; **SUB** ≤ 1.0 canopy height; **U** = Unknown; cannot see adequately to describe due to lack of light.

- There may be several layers of clouds visible simultaneously during a survey visit. For this protocol, the ceiling is the continuous primary cloud layer most closely associated, and in proximity to the forest canopy. Patchy ground fog may develop as the air temperature warms above water bodies or forests and can affect vertical viewing as well as horizontal. These types of conditions should be reported as fog in the Precipitation column of the survey form.

- Cloud Cover: Select the class code that best describes the amount of overhead cloud cover visible from the station.
- Codes: **0** = 0% (clear sky; no cloud cover); **1** = about 33% of sky covered; **2** = about 66% of sky covered; **3** = 100% of sky covered; **U** = Unknown; cannot see adequately to describe conditions due to lack of light.
- Visibility to 1x-canopy: From the survey station, note whether vertical visibility is unimpeded to 1x-canopy height. Codes: **Y** = Yes; **N** = No; **U** = Unknown; cannot see adequately to describe conditions due to lack of light.

20 Horizontal Visibility to 100 m: From the survey station, note whether horizontal visibility is unimpeded within 100 m (328 feet). Codes: **Y** =Yes; **N** = No; **U** = Unknown; cannot see adequately to describe conditions due to station placement.

21 Audibility to 200 m –Y/N: From the survey station, note whether audibility is unimpeded within a 200 m (656 feet) radius. Codes: **Y** = Yes; **N** = No

22 Noise: Record the appropriate code(s) to indicate noise conditions that ***affect ability to hear murrelet calls*** within a 200 m (656 feet) radius: **N** = None; **A** = Aircraft; **B** = Bird song/calls; **C** = Creek or other water drainage; **M** = Machinery (logging, mining, road construction, etc.); **P** = Precipitation: rain/hail; **T** = Tree drip; **V** = Vehicle (trucks, cars, etc.); **W** = Wind; **O** = Other (***explain in Notes column***). List more than one if applicable. Note the time and duration of any noise that impedes murrelet detectability

23 Precipitation: Select the appropriate codes to indicate precipitation intensity at the survey stratum as observed from the station. List only one code per column. Use the following codes in each of the type columns

Rain: **N** = None; **L** = Light (mist, drizzle, soft rain)); **M** = Moderate (obscuring rain); **H** = Heavy (intense rain).

Fog: **N** = None; **L** = Light (translucent haze, thin fog)); **M** = Moderate (obscuring fog); **H** = Heavy (dense fog)

Other: For other precipitation conditions use the following type and intensity codes: **N** = None; **HL** = Light hail; **HM** = Obscuring hail; **HH** = Intense hail; **SL** = Snow flurry; **SM** = Obscuring snows; **SH** = Intense snowstorms, Blizzard

24 Wind: Record the wind speed based on the Beaufort Wind Scale. Observe the effects of wind conditions on trees and vegetation visible ***at ground level at the station*** and record the appropriate code (0= <1 mph, calm; 1= 1-3 mph, leaves barely move; 2= 4-7 mph, leaves rustle and small twigs move; 3= 8-12 mph, leaves and small twigs in constant motion; 4= 13-18 mph, small branches move; 5= 19-24 mph, large

branches and small trees start to sway; 6= 25-31 mph, large branches in constant motion; 7= 32-38 mph, whole trees move; 8= 39-46 mph, twigs and small branches break).

- Moderate to high winds of Beaufort 4 (13-18 mph) and above generally affect audibility. A handheld wind meter can be helpful if one is available.
- If wind noise impedes audible detections of murrelets at a distance of ≤200 m for greater than a cumulative total of ***12 minutes*** the visit should be rescheduled, unless occupied behavior is observed.

25 Notes: Record "Begin Visit" and "End Visit" to correspond to appropriate times recorded. Note any other pertinent information that can help to better describe or explain the conditions during the survey visit as they pertain to detectability of murrelets.

26 Survey Visit to Protocol: Circle **Y** (Yes) or **N** (No) to indicate if the survey was conducted following the guidelines of the Pacific Seabird Group protocol. Include the name, affiliation and phone number of the person who is making this statement, often the crew or project leader. To answer this question will involve a review of the survey visit by someone affiliated with the survey effort, who should check the survey form for compliance with the protocol, and possibly speak with the observer. The review is not to be done by the observer. An affirmative response does not necessarily imply that the entire survey effort was acceptable or that regulating or evaluating agencies will find the survey to be valid. To aid with answering this question, the following checklist should be completed for each survey:

- Survey began on time (at least 45 minutes before sunrise)
- Survey continued uninterrupted for at least 2 hours
- Vertical visibility to 1x canopy height was not impeded for >12 minutes total
- Horizontal visibility to 100m was not impeded for >12 minutes total
- Audibility to 200m was not impeded for >12 minutes total

Survey Activity Page Instructions

Item #

1 Detections - Page Total: Enter the total number of ***murrelet detections***; **every** detection should have a detection number. This is the total number of detections per single-sided page.

2 Page Number of the total number of pages, including maps.

3 Initials: Initials of observers' full name, consistent with the cover page.

4 Month, Day, Year: Date of survey visit. Use 2 digits for Month, Day, and four digits for Year (e.g., May 10, 2000 = 05/ 10/ 2000).

5 Area Name: Name of survey area being surveyed.

6 Stratum Name / No.: stratum name or number from which survey visit is conducted. Each survey stratum should have a ***unique*** number or alphanumeric identifier.

7 Station Number: Station number from which survey visit is conducted. Each survey station should have a ***unique*** numeric identifier relative to a survey stratum.

8 Units of Measure: Indicate measurement used for all horizontal distances. Circle either **U.S.** or **Metric**.

SURVEY ACTIVITY: Record details of murrelet detections in this table. A detection is defined as the visual or auditory observation of one or more murrelets ***acting together*** in a similar manner and initially occurring ***at the same time***.

- A **5 Second Rule** is applied to distinguish between separate detections. It may be helpful to count "1 one thousand, 2 one thousand, etc."
  - If a murrelet detection is **auditory**, 5 seconds of silence must pass in order to classify the next murrelet sound as a new detection, unless the next detection is clearly made by a different, unassociated individual.
  - If a **visual detection** of a murrelet is lost from view for more than 5 seconds, the next sighting is a new detection, even if it is obviously the same bird(s).
- If two or more groups of murrelets coalesce into one larger group, record data on a separate line for each group and write, e.g., "detect. # 10 and detect. # 11 joined", in the Notes column. Assign each detection its own unique detection number. Refer to the definition of a detection above.
- If one group of murrelets split into two or more separate groups of birds, each new subgroup is still considered part of the original detection, but each is recorded on a separate line as follows. Prioritize the subgroup with the lowest canopy height first. If all subgroups are at the same canopy height, then prioritize circling behavior over non circling. Write, e.g., "detect. # 5 split", in the Notes column to link birds associated with the same detection. Assign the same detection number to both lines of data, since all the birds were initially part of the same group, and thus only constitute one detection. Each subgroup will have the same Time, and Initial Detection and Flight Directions, but likely will have differing Heights, Closest

Distances, and Depart and Final Directions. Thus, each subgroup will need a separate line to record all the relevant data.

9 Detection #: Each separate ***murrelet detection*** is sequentially numbered one per line as it occurred throughout the survey visit. When mapping the detections, use the detection numbers to cross reference the corresponding line entry. Number only the prioritized subgroup if a group of birds split, because the whole occurrence is considered one detection. Line out the Detect. # column for all associated subgroups. See the Survey Activity section above. Do NOT enter a detection number for any non-murrelet detections or other entries such as detections of other species or noting when the survey started and ended.

10 Time: Record the time in 4-digit "24 Hour Time" at the beginning and end of survey and for all murrelet detections .

- **U** (unknown) is entered if detection time was not recorded.

11 Initial Detection Direction: Record the direction where the murrelet is first detected ***relative to the observer***. The direction is recorded at a minimum of 45-degree increments (e.g., N = North; SW = Southwest; E = East).

- **U** (unknown) is entered if initial detection direction was not identified. Without this information, the detection cannot be mapped.
- If a bird is seen landing, perching, or flying into or out of a tree or stand of trees, a stationary detection is heard, or an area of concentrated activity is detected, an azimuth compass bearing for that location (e.g., "145" = 145 degrees) is preferred.

12 Type: Record the detection type using the following codes: **H** = Heard only [auditory sound(s) with no visual observation]; **S** = Seen only (visual observation with no auditory sounds); **B** = Both Seen and Heard (visual observation with accompanying auditory sounds).

13 Auditory: Call types have been assembled into call groups based on their sounds. Review recordings of Marbled Murrelet vocalizations and other sounds to assist with identification. Recordings of other forest bird calls/songs that may have similar sounding notes should also be reviewed periodically.

14 Vocal (vocalizations): Refer to Appendix E for a description of different murrelet calls.

15 K #/M: Record the number (1-5) of *Keer* calls heard for each detection. When more than 5 keers, record **M** (for multiple).

16 Other Vocs: If “Groan” (**G**) or “Whistle” (**O**) calls are heard, simply enter the associated code. More than one code may be entered. “**G**” = Groan group (longer, variable groans formerly known as alternate calls); and the “**O**” = Whistle group (longer, variable whistle). Birds most often grade their calls between two of these groups within a series or bout of calling.

17 Other (non-vocal sounds): In addition to the vocal sounds described above, there are two other auditory sounds attributed to marbled murrelets. These non-vocal sounds are Wing sounds or wing beats = “**W**”, and Jet sounds associated with aerial or power dives = “**J**”. Record all types heard for each detection.

OL (Overlapping vocal/non-vocal): Indicate **Y (Y**es) or **N (N**o) if overlapping calls/non-vocal sounds are heard as part of the detection. Overlapping calls are an indication that multiple birds are involved with a detection. This should not be confused with multiple calls that are not overlapping.

- A **solid line (——)** for "not applicable" is entered in columns that do not apply. Seen only detections do not include an auditory element, i.e., a visual detection with no vocalization or other auditory sounds.

18 # of Birds Seen: Enter the number of birds ***visually observed***.

- If 2 or more groups of murrelets join into 1 group, record data on a separate line for each group and write, e.g., "Detect. #X and Detect. #X1 joined", in the Notes column. Assign each detection its own unique detection number.
- If one group splits into a separate group of birds, then each subgroup is part of the original detection, and each is recorded on a separate line observing the prioritization procedures outlined above under the SURVEY ACTIVITY heading. Each subgroup will have the same Time and Initial Detection Direction. Assign the same detection number to both lines of data.
- A **solid line** (——) for "not applicable" is entered for heard only detections.

19 Behavior: Record the behavior type of the bird(s) according to the following codes:

C = Bird(s) seen circling over the forest at > 1.0 canopy height. This behavior includes flight paths that deviate from a straight line, such as full, quarter, and half circles, or angular turns ≥45 degrees.
B = Bird(s) seen circling at or below the forest canopy, i.e., ≤ 1.0 canopy height. This behavior includes flight paths that deviate from a straight line, such as full, quarter and half circles, or angular turns ≥45 degrees.
F = Bird(s) seen flying in a straight (≤ 45-degree) flight path over the forest at > 1.0 canopy height.
T = Bird(s) seen flying through in a straight flight path at or below the forest canopy, i.e., ≤ 1.0 canopy height.
L = Bird(s) seen landing in, perching, or departing from a tree. This is a rare event.
S = Bird(s) heard emitting ≥ 3 calls from a fixed point in a tree within 100 m (328 feet) of the observer. This is a very rare and unusual event.
U = Bird(s) behavior unknown, i.e., bird(s) seen but behavior not identified, or canopy height not quantified, or detection was heard only and was not stationary.

20 Initial Flight Direction: This is the direction that the murrelets are seen heading when initially detected, i.e., ***the direction the birds are traveling when first detected***. This information allows for accurate mapping of visual detections, and compliments the Bird Depart Direction data. Enter direction in a minimum of 45-degree increments (e.g., N = North; SW = Southwest, etc.).

- **U** (unknown) is entered for any auditory detections because flight directions are often difficult to correctly identify.

21 Initial Distance to Birds: Enter an estimated horizontal distance to the murrelet(s) when first detected. This information is useful for mapping flight paths.

22 Bird Height: This is determined from ***visual*** observations only. Enter an estimate of bird height in decimal units based on bird location ***relative to the height of the forest canopy***, i.e., the tallest trees within the survey area that are observable from the survey station. The height of the ***tallest observable tree within the station effective area*** is equivalent to a unit of 1.0 canopy height. If a bird was seen flying halfway beneath the height of the tallest observable tree, the bird height is "0.5 canopy heights." A bird seen flying over the canopy at one quarter the height of the tallest tree observed is at "1.25 canopy heights."

- If a detection is seen "at or below" canopy height, but an actual height was not determined, enter **< 1.0** canopy heights in the Notes section.
- If a bird is only seen flying straight or circling over a clear-cut or water adjacent to the survey stratum, project the height of the tallest tree observable to determine the bird's height. Indicate in Notes if the bird is only seen over these substrates.
- **U** (unknown) is entered if the bird(s) were seen but the height was not quantified.
- A **solid line** (**——**) for "not applicable" is entered for heard only detections.

23 Closest Distance to Bird(s) Seen: Record the closest horizontal distance from observer to the murrelet(s). A bird flying directly overhead is equivalent to a horizontal distance of zero. Distances are recorded only for ***visual*** detections. Most visual detections are within 100 m (328 feet). ***Indicate units of measurement*** at top of the column.

- For ***heard only*** detections, a **solid line "——"** is entered in the Closest Distance to Bird(s) Seen column

24 Loudness: For heard detections, enter one of the following codes, based on the intensity of the sound: **L** = Loud (typically 0-50m); **M** = Moderately loud (typically >50m to 150m); **F** = Faint/distant (typically >150m).

- Unless the observer has information to the contrary, for the purpose of mapping, "loud" detections will be mapped at 25 m (82 feet) from the observer; "moderately loud" detections will be mapped at 75 m (246 feet) from the observer; and "faint" detections will be mapped at 200 m (656 feet). Most detections are audible only within 200 m (656 feet). The observer should provide, in the Notes section, any additional information that helps interpret distance. E.g., a faint call heard up high directly overhead should not be mapped at 200 m.
- **U** (unknown) is entered if the distance is seen but not quantified.

25 Depart Flight Direction: The direction the murrelet was last detected heading, i.e., ***the direction the bird(s) was traveling when last detected***. Enter direction in a minimum of 45-degree increments (e.g., N = North; SW = Southwest, etc.).

- **U** (unknown) is entered for any auditory detections because flight directions are often difficult to correctly identify.

26 Final Detection Direction: The ***final*** direction the murrelet was detected ***relative to the observer***. The direction is recorded at a minimum of 45-degree increments (e.g., S = South; NE = Northeast; W = West).

- **U** (unknown) is entered if the final direction is not identified.

27 Notes/other species: Enter brief notes here. Indicate "Begin Survey" and "End Survey" and be sure to enter the corresponding time in the Time column. Alpha codes for other species can be obtained here: https://www.birdpop.org/docs/misc/Alpha_codes_eng.pdf. Use the *Additional Notes* section for more detail.

28 Additional Notes: Enter corresponding detection #. Additional information which can help to concisely describe and map a detection is entered here. For example: groups of birds that split or join other birds; unusual observed behavior; flight path directional information ("circled clockwise" or "counterclockwise"). Or if a dive is seen, record full details of the dive flightpath here. Include references to proximity of murrelet flights to outstanding features on the landscape that may be useful for accurate mapping of detections. Additional survey detections can also be entered here.

Mapping Murrelet Detections

To each survey form, attach a copy of a registered aerial photo, orthophoto (1:12,000), or a USGS or equivalent (for BC) topographic map showing the area/stratum surveyed. Be certain to indicate the corrected scale if the original scale was enlarged or reduced. Delineate the survey **area**/stratum boundary and identify the observer station location using a circle with a dot in the center (⨀). If plotting detections on aerial or orthophoto maps, use a topographic map to aid in determining the correct location to plot the detections with respect to the terrain.

Plot the murrelet detections using the directional information, Behavior, and Distance to Bird(s) data from the Survey Activity Table. Indicate the murrelet flight path and behavior (circling, straight flight path, stationary, etc.) relative to the station location using the symbols below. On 1:12,000 scale orthophoto maps, 1 mm = 12 m (39 ft); on 7.5 minute topographic maps the scale is 1:24,000, so 1 mm = 24 m (79 ft).

Audible detection: A dashed line with arrow head (⇢) indicates an audibly tracked flight path.

Visual detection: A solid line with arrow head (→) indicates a visually observed flight path.

Stationary or Unknown Bird Depart/Final Direction: A triangle with a dot in the center (◬) indicates a stationary detection, or a visual or audible detection without a Bird Depart or Final Direction.

- In the upper right-hand corner of each map page write the: (1) Page # of Total Page #; (2) the TRS or UTM coordinates; (3) survey stratum name; (4) station number; (5) observer's initials; and (6) date of the visit.

- Label each separate mapped detection with the corresponding Detection # from the first column on the Survey Activity page. At high activity areas, more than one map may be necessary. Indicate the Page # of Total Page # on each map.

- If you have multiple detections with the ***same behavior type*** in the ***same location***, record all applicable detection numbers in sequential order at that location. Use additional maps as needed to record all detections. Detections without an Initial Detection Direction may be un-mappable. All occupied behaviors may be mapped together and other detections separately if desired.

- Unless the observer has information to the contrary, for the purpose of mapping "heard only" detections: Loud (L) detections will be mapped at 25 m (82 feet) from the observer; Moderately loud (M) detections will be mapped at 75 m (246 feet) from the observer; and Faint (F) detections will be mapped at 200 m (656 feet). Most detections are audible only within 200 m (656 feet).

MARBLED MURRELET FOREST SURVEY FORM

Total Detections: ______

Species of Concern Y / N (circle one; details on last page)

State/Province (circle) AK BC WA OR CA

Ownership:_______________________________________

Month ____________ Day ________ Year ________

Area Name: ________________________________ Stratum Name/Number: _________________ Station Number: ______ _____ ___

Observer (s) Name: _______________________ Initials: _______ Affiliation: __________________ Phone: (_____)_________________

Station Location: - UTM zone: _______ E (x) coordinate: _________________________ N (y) coordinate: __________________________

Source: _______________________________ Datum: _________________________ Accuracy: __________________________

Official Sunrise Time: _____________ Source: ________________ Begin Survey Time: ___________ End Survey Time: _____________

ENVIRONMENTAL CONDITIONS:

revised: 12 / 2020

Time				Vertical Viewing			Horiz. Vis. to 100m (Y/N/U)	Audibility to 200m (Y/N)	Precipitation			Wind	Noise	Notes Remember to record duration of any conditions that affect survey validity
				Ceiling	Cloud Cover	Visibility to 1x Canopy			Rain	Fog	Other			

- **Ceiling: UL** Unlimited (clear); **HI** > 2.0 canopy height; **MID** > 1.5 to < 2.0 canopy height; **LO** >1.0 to <1.5 canopy height; **SUB** < 1.0 canopy height; U = Unknown (too dark to see)
- **Cloud Cover: 0** = 0%, **1** = 33%, **2** = 66%, **3** = 100%.
- **Vertical Visibility: N** = Impaired (detections may be missed due to conditions), **Y** = Unimpaired (conditions allow for reliable detection), **U** = Unknown.
- **Horizontal Visibility: N** = Impaired (detections may be missed due to conditions), **Y** = Unimpaired (conditions allow for reliable detection), **U** = Unknown.
- **Audibility: N** = Impaired (detections may be missed due to conditions), **Y** = Unimpaired (conditions allow for reliable detection).
- **Precipitation - Rain & Fog: N** = None, **L** = Light, **M** = Moderate, **H** = Heavy. **Other: H** = Hail, **S** = Snow. (Indicate intensity using same codes for rain & fog).
- **Wind: 0** = <1 mph (calm), **1** = 1-3 mph (leaves barely move), **2** = 4-7 mph (leaves rustle, sm. twigs move), **3** = 8-12 mph (leaves & sm. twigs in constant motion), **4** = 13-18 mph (sm. branches move), **5** = 19-24 mph (lg. branches & sm. trees start to sway), **6** = 25-31 mph (lg. branches in constant motion), **7** = 32-38 mph (whole trees move), **8** = 39-46 mph (twigs & sm. branches break).
- **Noise: N** = None, **A** = Aircraft, **B** = Bird song/calls, **C** = Creek/water drainage, **M** = Machinery, **P** = Rain/hail, **T** = Tree drip, **V** = Vehicle, **W** = Wind, = Other (explain in Notes).

Protocol Review

☐ Survey began on time (at least 45 minutes before sunrise)
☐ Survey continued uninterrupted for at least 2 hours
☐ Vertical visibility to 1x-canopy height was not impeded for >12 minutes
☐ Horizontal visibility to 100m was not impeded for >12 minutes
☐ Audibility to 200m was not impeded for >12 minutes

Survey Visit to Protocol?: (circle one) Yes / No

Protocol Reviewer Name__________________________

Protocol Reviewer Affiliation: ______________________

Protocol Review Date _______________

MARBLED MURRELET FOREST SURVEY FORM

Area Name ___________________________ Page ______ of ______

Observer (s) Initials: _______________

Stratum Name /No:________________________

Detections - This Side Page Total: _________

Units of Measure (circle one): U.S. / Metric

Station Number: _______________________

Month ________ Day ________ Year _______

SURVEY ACTIVITY: *Note Significant Weather Changes on Page 1*

Detection #	Time	Initial Detection Direction	Initial Distance to Birds Seen	Type	Auditory				# Birds Seen	Behavior	Initial Flight Direction	Bird Height Seen	Closest Distance to Birds Seen	Closest Distance to Birds Heard (Loudness) L = Loud: 0-50m M = Moderate: >50-150m F=Faint: >150m	Depart Flight Direction	Final Detection Direction	Notes
					Vocal Series		Other	Overlapping									
					K#/M	Other Voc	W/J	Y/N									
																	Start

Detection #	Additional Notes

TYPE: **He**ard; **S**een; **B**oth heard and seen. BEHAVIOR: **Un**known; Flyover (straight flight over canopy); **C**ircling above canopy; Fly **T**hrough (straight flight at or below canopy); Circling at or **B**elow canopy

Station Information Form Instructions (Optional)

The Station Information Form should be completed by the persons establishing stations on the ground prior to initiating surveys. Individuals establishing stations should be trained murrelet surveyors and should be trained and skilled in estimating horizontal and vertical distances and in estimating canopy cover. Laser rangefinders may be used for measuring heights and distances. For guidance with station-placement strategies refer to the protocol section *Survey Stations and their Placement* in Chapter 2 of the protocol.

1 Date: Date station was established or evaluated in the field. Use 2 digits for Month and Day, and four digits for Year (e.g., May 10, 2000 = 05/ 10/ 2000).

2 Name: First name, middle initial, and last name of the observer

3 Initials: Legible initials of observer's full name

4 Affiliation: Agency, tribe, or company name

5 Phone: Agency, tribe, or company telephone number including area code. This should be a contact that can be reached during and after the survey season in the event that questions arise.

6 State/Province: Circle the appropriate state or province

7 Area Name: Name of survey area

8 Stratum Name / Number: Enter the name or number of the survey stratum. Each survey stratum must have a ***unique*** number or alphanumeric identifier.

9 Station ID: Station ID (number, letter, etc.). Each survey station must have a ***unique*** alphanumeric identifier relative to a survey stratum.

10 Station Location:
UTM - Enter the UTM zone, and coordinates and map datum (e.g., NAD83) from a USGS or equivalent topographic map. Indicate the source used to determine the station location (e.g., type of map or GPS). If a GPS is used, indicate the accuracy or error value (FOM) when the position was taken, ***and*** what map datum (e.g., NAD 27 CONUS, WGS 84, etc.) the unit was set for. UTM coordinates may also be acquired using a UTM grid overlay (some compasses also have these) with a USGS topographic map.

11 Station Elevation: Using GIS, a USGS topographic map, or a properly calibrated altimeter or GPS, record the station elevation. Indicate whether the value is in feet or meters and indicate the source (GPS, altimeter, etc.).

12 Position on Slope: Select the code that best describes the station's position on slope. Codes: **B** = Canyon bottom or coastal plain, **L** = Lower 1/3, **M** = Middle 1/3, **U** = Upper 1/3, **R** = Ridgetop.

- To determine the position on the slope, use a topographic map to identify the ridgetop and valley bottom elevation at 90 degrees (perpendicular) from the contour where the station is located. Then subtract the lower value from the higher and divide by 3 to determine the position based on the station's elevation.

13 Station Placement: Circle whether survey station is located **Inside** or **Outside** the survey stratum. **Stations on the survey stratum boundary are considered Inside**.

- One station may adequately cover an area of up to 100 meters visually and up to 200 meters audibly. Station placement in dense forest with abundant understory and high overhead cover can limit visibility and mask sounds, thereby affecting the observer's ability to see and hear murrelet activity. Topography is also a factor to consider when establishing stations because rugged, steep terrain will affect the observer's range of detectability. In these situations, station density should be increased as needed to provide adequate survey coverage of the stratum being surveyed.

14 Distance from Survey Stratum Boundary: This measurement applies only to **Outside** stations. Indicate distance from the survey station to the survey stratum boundary. Stations are generally located $\leq$50 m (164 feet) from the edge of the survey stratum boundary.

15 Station Canopy Cover: Select (circle) the canopy cover class code that best describes overhead canopy cover at the survey station (approx. 25 m radius). Codes: 1 = 0 -25%, 2 = 26 -50%, 3 = 51 -75%, 4 = 76 - 100%. This can be derived as an ocular estimate of the area immediately adjacent (approx. 25 m radius) to the survey station or an actual measurement. These data can be useful in determining the visibility from a station. It's often easier to estimate ***openings*** in the canopy. The ***inverse*** value represents the amount of canopy cover. The value recorded must represent canopy ***cover***, so remember to translate openings to cover (%cover = 100% - %opening).

16 Canopy Height: Enter the height of the tallest tree within the station effective area. Indicate units of measure (feet/meters) and if height was measured or estimated (circle one).

17 Horizontal Visibility: provide an estimate of the approximate dimensions (length x width) of the canopy opening. Use ∞ (infinity) or >X (greater than x distance) for stations that are outside of the stand. For each 90-degree quadrant, enter the estimated average horizontal distance from the station to visual obstructions (i.e., trees, hillsides).

Marbled Murrelet Station Identification Form

Date: ________________ Observer (s) Name: ______________________________ Initials:_______

Affiliation: ___________________ Phone: (____)_______________ Email: ______________________

State / Province (circle): AK BC WA OR CA

Area Name: _____________________________ Stratum Name: __________________________________

Station ID (name/number): ____

Station Location

UTM zone: ____ E (x) coordinate: ______________ N (y) coordinate: _______________

Source: ___________________ Map Datum: __________________ Accuracy/Error:________________

Station Elevation: __________ Ft / M Elevation Source:_______________

Position on Slope (circle one): Bottom/Plain, Lower 1/3, Mid 1/3, Upper 1/3, Ridgetop

Station Placement (circle one): Inside Outside

Distance from Survey Site Boundary (if outside): _____________ feet / meters

---

Canopy

Station Canopy Cover (circle one): 1 = 0 to 25%; 2 = 26 to 50%; 3 = 51 to 75%; 4 = 76 to 100%

Canopy Height (tallest tree within station effective area): ______________ feet / meters; measured / estimated

---

Horizontal Visibility

Size of canopy opening: ________ X ________ feet / meters

Average distance to visual obstructions: NW_________; NE_________; SE_________; SW_________ ft / meters

---

Description of Roads to Station or Trailhead (Starting at a paved road, list roads, directions, estimated distances, mile markers, travel times, gates, or other helpful information; use additional pages if needed):

Description of Trail to Station (Include compass bearings, landmarks, distances, flagging color, or other helpful information; use additional pages if needed):

Approximate time required to hike to station from take-off point: __________

APPENDIX K: HEARING EXAMINATION FOR MARBLED MURRELET FOREST SURVEYS

Compiled by William Ritchie[11] and S. Kim Nelson[12]

Introduction

Given that a larger proportion of Marbled Murrelet detections are audible rather than visual, normal levels of hearing are required of all Marbled Murrelet survey personnel. Surveyors must have their hearing tested by a certified audiologist or physician prior to conducting protocol surveys. These standard tests are available at a reasonable price and offered at any clinic with an audiologist on staff.

In addition to having normal hearing, or corrected hearing that meets the test criteria, a prospective murrelet surveyor must attend a recognized training program and demonstrate a proficiency in their ability to conduct protocol Marbled Murrelet surveys under the guidelines set forth by the Pacific Seabird Group (See Appendix I). Individuals also should have normal or corrected vision.

Examination Procedure

Audiologists use specialized equipment calibrated to provide diagnostic pure-tone audiometric testing. An audiometer provides a measure of a person's ability to hear sounds of different frequencies and intensities. These tests are typically performed in sound-treated examination rooms in order to obtain accurate results. The results of the testing should report the patient's hearing thresholds at sound frequencies within the normal range of human hearing, between 250 Hz and 8,000 Hz. Upon completion, the audiologist or physician should provide the patient with an audiogram and confirmation of normal hearing ability. An audiogram represents the hearing thresholds in decibels (dB) and can be displayed graphically or as a list of values.

It is recommended that a hearing test be conducted prior to hiring individuals for murrelet survey work. Producing the results of an acceptable hearing test should be a condition of hire for everyone expected to conduct protocol murrelet forest surveys. Results of the hearing test must also be reviewed by the training evaluator before a surveyor can qualify as proficient. A person's hearing should be tested at a minimum of once every two years, or more frequently if they have been exposed to any loud noise. The Occupational Safety and Health Association (OSHA)

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defines loud noise to be of an intensity ≥85 dB for ≥8 hours in duration (e.g., small aircraft flights, chainsaw, gunshots, loud music, etc.). This is roughly equivalent to a situation where a normal level of conversation within three feet begins to become difficult to discern due to the intensity of the noise. When assessing previous exposure to loud noise, one should consider that as noise intensity levels increase, the duration time of exposure before reaching the critical threshold will decrease. OSHA recommends annual testing whenever an individual is exposed to these conditions.

Evaluating Test Results

A review of the audiogram is necessary to determine if an individual has an acceptable level of hearing to conduct murrelet surveys. Marbled Murrelet vocalizations and sounds associated with flight range between 2,000 Hz and 5,000 Hz. In order for a person to have an acceptable hearing test, they should have good hearing at all frequencies, but especially in this range. The American Medical Association and OSHA define good hearing as 0 to 25 dB in both ears. This means that at all frequencies within the normal range of human hearing, an individual's hearing thresholds should be 25 dB or less. Individuals with good hearing, or corrected hearing that meets the definition of 'good' hearing, are qualified to conduct protocol murrelet forest surveys upon successful completion of an approved survey training program.

Marginal hearing is defined as 0 to 25 dB in one ear, and a level not to exceed 60 dB in the other ear. If an individual with marginal hearing can demonstrate proficiency in their ability to detect Marbled Murrelets during the survey evaluation, given their impaired hearing, they can conduct protocol murrelet forest surveys. This determination is made at the discretion of the training evaluator. Evaluators must be assured of the surveyor's ability to identify murrelet vocalizations at distances greater than 200 meters (600 ft), and their ability to discern correct detection and flight directions.

Poor hearing is defined as greater than 25 dB in both ears. Individuals with poor hearing, including those who meet the definition of poor hearing with corrective devices, are not qualified to conduct protocol murrelet forest surveys.