# Marbled Murrelet
# Forest Habitat Relationships Studies

## Sampling Design
## Data Collection
## Analysis Method
## Model Results for
## Southwest Washington

January 14, 1999

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ABSTRACT

As part of its Habitat Conservation Plan (HCP), the Washington Department of Natural Resources (DNR) has in place a marbled murrelet interim conservation strategy. The interim strategy outlines steps for the collection of information needed to develop a long-term conservation strategy. The first phase of the interim "information-gathering" strategy implements, in each HCP planning unit, a marbled murrelet forest habitat relationships study, to determine the relative importance of distance from marine waters and forest structure on murrelet occupancy of DNR-managed lands. Application of models built from data collected during these studies defines the habitat types and identifies the forest stands that would be expected to contain 95% of the sites occupied by murrelets on DNR-managed lands. The second phase of the interim strategy implements murrelet surveys on all acres constituting these higher-quality habitat types.

For each habitat relationship study, 54 research sites, stratified by distance to marine waters and forest structure, are surveyed for 2 years to determine site status as occupied or unoccupied by murrelets. Habitat information collected at each research site characterizes forest conditions and nesting opportunities. Multiple logistic regression is used to select 2 probability models. The first model includes murrelet nesting variables, such as numbers of platforms, and is built only to examine the relationships of these variables to occupancy. The second model includes variables present in DNR's forest inventory. This model is applied to DNR-managed forest stands that are estimated to be within the scope of the sample of research sites. This model assigns each forest stand a probability of occupancy which is multiplied by the stand's size to predict the number of "occupied acres." The stands are sorted on probability to determine the probability threshold that includes 95% of the "occupied acres" in each HCP planning unit.

Of the 110 research sites in the South Coast and Columbia HCP planning units (1 extra site in each unit), 25 are occupied, 81 are unoccupied, and 4 were removed from the analyses. Data from these planning units were combined for the purpose of model building. Occupied sites are an average 8.6 miles from marine waters versus 33.4 miles for unoccupied sites ($P = 0.0002$). In

general, western hemlock, western redcedar, and sitka spruce variables are positively correlated with murrelet occupancy, while Douglas-fir variables are negatively correlated. Occupied sites have an average 7.5 western hemlock trees ≥32" per acre, versus only 1.9 for unoccupied sites ($P = 0.0001$). Platform variables are strongly correlated with murrelet occupancy. Occupied sites have an average 3.9 western hemlock platform trees per acre, versus an average 0.5 at unoccupied sites ($P = 0.0001$). The variables selected for the first model are distance from marine waters, western hemlock platform trees per acre, western hemlock trees ≥32" per acre, and western redcedar trees ≥32" per acre. The variables selected for the second model include distance from marine waters, western hemlock trees ≥32" per acre, western redcedar trees ≥22" per acre, and basal area of Douglas-fir trees ≥7" per acre.

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# INTRODUCTION

## Marbled Murrelet Biological and Political Status

Marbled murrelets (*Brachyramphus marmoratus*) are robin-sized seabirds of the family Alcidae. They populate the Pacific coast from Alaska to central California and forage in nearshore marine waters on small fish, such as sand lance (*Ammodytes hexapterus*) and Pacific herring (*Clupea harengus*), and on invertebrates (Burkett 1995). Although murrelets spend most of their lives at sea, throughout most of their breeding range, they nest inland in forests as far as 50 miles from shore (Hamer 1995). They most often nest in old-growth or late-successional forests on the large-diameter, upper branches of mature, coniferous trees (Ralph et al. 1995a). Deformities caused by mistletoe or wind also create nesting opportunities for murrelets, and moss or litter is usually present as substrate on the nest limb (Hamer and Nelson 1995).

There is evidence that marbled murrelet populations have been declining in some areas in recent years. The decline is attributed primarily to the loss of old-forest habitat, but also to increased nest predation from forest fragmentation and mortality caused by oil spills in the marine environment and net fisheries (Ralph et al. 1995a). In September 1992 the marbled murrelet was federally listed as threatened under the U.S. Endangered Species Act (U.S. Fish Wildl. Serv. 1992). This listing applies to the Washington, Oregon, and California populations. In the fall of 1993 the state of Washington also listed the marbled murrelet as threatened.

In 1994 the Washington Department of Natural Resources (DNR) initiated a series of marbled murrelet forest habitat relationships studies to better understand murrelet habitat use on DNR-managed forest lands. These studies were conceived to fulfill the first phase of an interim conservation strategy for marbled murrelets that would become an integral part of the agency's Habitat Conservation Plan (HCP) (Wash. Dep. Nat. Resour. 1997 [DNR 1997]).

## DNR's Habitat Conservation Plan

In January 1997 DNR signed a multi-species HCP with the U. S. Fish and Wildlife Service and the National Marine Fisheries Service (DNR 1997). This plan provides minimization of and mitigation for incidental take of the northern spotted owl (*Strix occidentalis caurina*) and the marbled murrelet and also conserves habitat for many unlisted species in western Washington, including several species of salmonids. For the marbled murrelet, DNR's goal is to implement a long-term conservation strategy; however, because murrelet habitat needs have not yet been clearly defined, attempts to develop such a strategy have been unsuccessful. Thus, DNR's HCP outlines an interim "information-gathering" strategy that will ultimately establish a long-term conservation strategy.

## Marbled Murrelet Interim Conservation Strategy

DNR's marbled murrelet interim conservation strategy provides protection for murrelet habitat on DNR-managed state trust lands while allowing DNR to participate in the collection of information needed to develop a long-term conservation strategy (DNR 1997:IV.39-42). Until the long-term strategy is implemented (Step 5), DNR is protecting all sites identified to be actually *occupied*[1] by murrelets and is also participating in cooperative regional research efforts. These research efforts explore such topics as marine survey methods, uses for radar surveys, nest requirements, and the effects of fragmentation and forest structure on nest predation. The following steps constitute DNR's marbled murrelet interim conservation strategy.

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[1]An *occupied* site, or a site with occupancy, is a stand of potential habitat where (1) an active or recent marbled murrelet nest has been discovered as evidenced by a fecal ring or eggshell fragments, (2) a chick or eggshell fragments have been discovered on the forest floor, or (3) murrelets have been observed exhibiting *subcanopy* behaviors (Ralph et al. 1994). *Subcanopy* behaviors include flying into, through, or out of the forest canopy as well as landing in trees. These behaviors suggest nesting is occurring in the stand.

Step 1. Defer harvest on any part of a suitable habitat block, defined as being ≥5 acres in size, containing an average of ≥2 potential nesting *platforms*[2] per acre, and being ≤50 miles from marine waters.

Step 2. Conduct a 2-year marbled murrelet forest habitat relationships study within each of the 6 HCP planning units within the murrelet's range (Fig. 1) to determine the relative importance of distance from marine waters and various forest structures to murrelet occupancy of forest stands.

Step 3. Based on analysis of data collected during the habitat relationships studies, define and identify marginal, or lower-quality, habitat types that would be expected to contain no more than 5% of the sites occupied by murrelets on DNR-managed lands within each planning unit. Make these habitat types available for harvest.

Step 4. In each planning unit, conduct murrelet surveys on all acreage constituting the higher-quality habitat types (expected to contain 95% of the occupied sites) in order to locate sites actually occupied by murrelets. Outside of Southwest Washington, release surveyed, unoccupied habitat for harvest if it is >0.5 miles from an occupied site *and* if, after harvest, ≥50% of the higher-quality murrelet habitat on DNR-managed lands in the Watershed Administrative Unit would remain.

Step 5. After Steps 1-4 are completed for each planning unit, using the information obtained from these studies and the other cooperative research efforts, develop a long-term conservation strategy for marbled murrelet habitat on DNR-managed forest lands.

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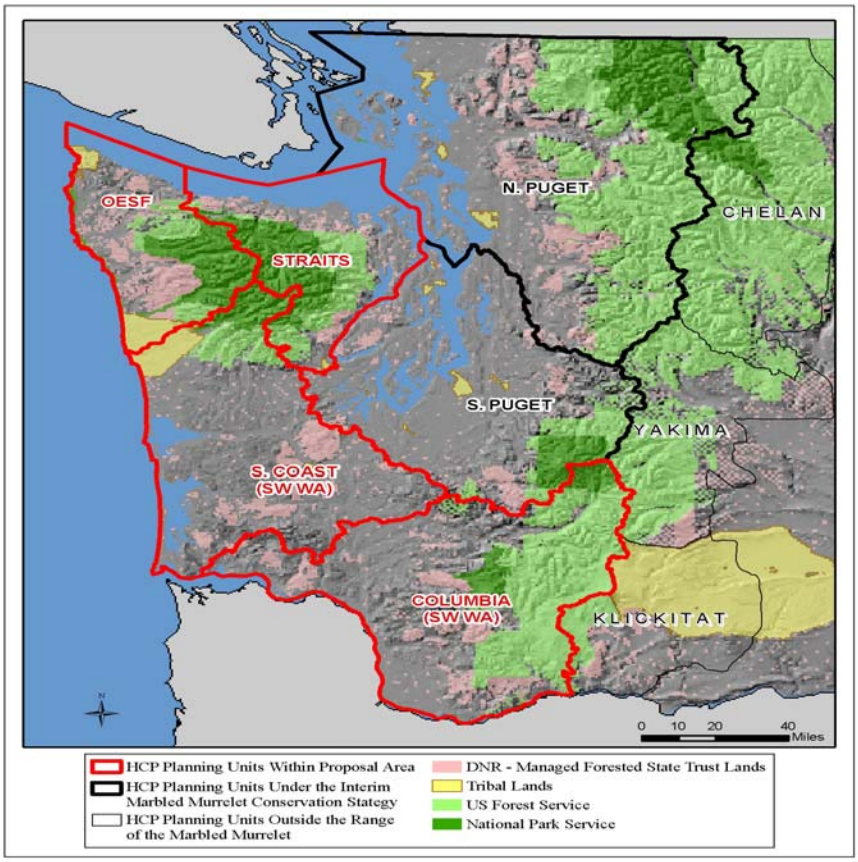
[2]A potential nesting *platform* is any horizontal limb, tree structure, or other deformity, such as a mistletoe broom, that is ≥50 feet (15.2 m) above ground and ≥7 inches (18 cm) in diameter (Hamer 1995). Platforms are counted only in conifer trees and only if located within the live crown. Structures are not judged for their perceived suitability or nonsuitability for murrelet nesting. Potential nesting platforms are hereafter referred to as platforms.

Figure 1. Boundaries of the 6 HCP planning units within the marbled murrelet's breeding range (DNR 1997: Map1.4). OESF = Olympic Experimental State Forest.

## Marbled Murrelet Forest Habitat Relationships Studies




The objective of the habitat relationships studies (Steps 2 and 3 above) is to determine, for each HCP planning unit, the influences of distance from marine waters and forest structure on marbled murrelet occupancy of forest stands (DNR 1997:III.43). Results are used to formulate a threshold definition of murrelet habitat for DNR-managed lands and to develop a long-term conservation strategy. The threshold habitat definition separates the lower-quality habitat types containing 5% of sites expected to be occupied from the higher-quality habitat types containing 95% of sites expected to be occupied on DNR-managed lands within each planning unit.

This report describes the design and implementation of DNR's marbled murrelet habitat relationships studies. In particular, it describes the sampling design, data collection methods, and analysis method for the formulation of the threshold murrelet habitat definitions. It also

presents results of the data collection, univariate analyses, and habitat model building for the 2 HCP planning units in Southwest Washington, the South Coast and Columbia planning units.

## METHODS

### Sampling Design

Within each HCP planning unit within the marbled murrelet's range, approximately 54 research sites are selected on DNR-managed forest lands (DNR 1997:III.43-44). Sites selected range in size from 15 to 120 acres. The sites are stratified by 2 factors, distance from marine waters and forest structure (a combination of forest age and platform density [Table 1]). Stratification by these factors ensures that the relevant ranges of distance from marine waters and forest structure are included in the sample of research sites. At each of the sites, 2 years of murrelet surveys are conducted to determine site status as occupied or unoccupied by murrelets, and habitat information is collected to characterize forest conditions and nesting opportunities.

Table 1. Target allocation of research sites for each planning unit by distance from marine waters and forest structure (DNR 1997:III.44).

| forest structure: forest age, platform density | distance from marine waters | | | |
|---|---|---|---|---|
| | near band | mid band | far band | total |
| old forest, ≥2 platforms/acre | 6 | 6 | 6 | 18 |
| young forest, ≥2 platforms/acre | 6 | 6 | 6 | 18 |
| young forest, <2 platforms/acre, ≥1 platform/site | 6 | 6 | 6 | 18 |
| total | 18 | 18 | 18 | 54 |

To stratify by distance from marine waters, 18 research sites are selected in each of 3 distance bands (near, mid, and far). Band width is based on the distribution of DNR-managed lands from marine waters, the first band containing the first third of DNR-managed lands within the planning unit ≤66 miles from marine waters, the second band containing the second third of DNR-managed lands within the planning unit ≤66 miles from marine waters, etc. Thus, actual band width differs within and among planning units.

To stratify by forest structure, within each distance band, 6 of the 18 research sites are selected in each of 3 classes: old forest habitat with an average density of ≥2 platforms per acre, young forest habitat with an average density of ≥2 platforms per acre, and young forest habitat with an average density of <2 and >0 platforms per acre (≥1 platform at the site). In the context of these relationships studies, old forest is defined as old-growth or mature forests where most of the co-dominant trees are >120 years old. Young forest is defined as sub-mature forests where most of the co-dominant trees are <120 years old. The average density of platforms is estimated from field inspection at the sites. The *scope of the sample* of research sites includes all lands within 66 miles of marine waters and within 1 of the 3 forest-structure classes, defined above.

Table 1 shows the target stratification of research sites by distance from marine waters and forest structure. Because it is often impossible to find all 6 research sites of a forest-structure class within a distance band on DNR-managed lands, these target numbers are often not realized. Because the distribution and extent of the 3 forest-structure classes are not known, selection of sites within the classes is not random, nor is selection of sites random within DNR-managed lands. However, sites are selected to be representative of forest structures in the planning unit. Nevertheless, biases, such as ease of access to the sites, probably do occur. To help assure research sites represent independent sampling units, research sites selected are ≥0.5 miles apart.

## Data Collection

### *Marbled Murrelet Survey Methods and Number of Visits*

Surveys at each site are conducted for 2 consecutive years following the guidelines of the Pacific Seabird Group's (PSG) protocol for conducting marbled murrelet forest surveys (Ralph et. al 1994, 1995b, 1996, 1997, 1998). Although the protocol has not been published in a scientifically peer-reviewed forum, it is widely accepted by industry, agency, and academic seabird biologists. For these habitat relationships studies, there are a few deviations from PSG recommendations in the way surveys are mapped and scheduled (DNR 1997:III.44-45).

Whereas the PSG protocol specifies a maximum *survey station*[3] coverage of 30 acres, survey stations for these studies are mapped with a target of 15-acre station coverage. The PSG recommendations specify that 4 visits should be conducted in each year at each site to determine murrelet *presence*[4] versus absence. They specify that 10 visits should be conducted at each site

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[3]*Survey stations* are the locations where observers stand when conducting survey visits; typically a site has from 2 to 5 survey stations (Ralph et al. 1994).

[4]A site with *presence* is a stand of potential habitat where there has been ≥1 murrelet *detection*. A murrelet *detection* is the sighting or hearing of 1 or more murrelets acting in a similar manner. If murrelets have been seen exhibiting *subcanopy* behaviors, the site is given the more significant classification of *occupied* (Ralph et al. 1994).

to determine occupancy versus non-occupancy, although unequivocal recommendations have not been given yet as to whether the 10 visits should occur in *each* of the 2 consecutive years for a total of 20 visits or *across* the 2 years for a total of only 10 visits. For these studies, occupancy versus non-occupancy is determined by conducting 6 visits in the first year and 10 visits in the second year for a total of 16 visits. Table 2 summarizes the survey visit prescriptions.

Table 2. Prescribed number of visits for each research site for both years (DNR 1997:III.45).

| year-1 status | year-2 status | number of year-1 visits | number of year-2 visits | total number of visits |
|---|---|---|---|---|
| no detections | no detections | 4 | 4 | 8 |
| no detections | presence | 4 | 10 | 14 |
| no detections | occupancy | 4 | 6-10[a] | 10-14[a] |
| presence | presence | 6 | 10 | 16 |
| presence | occupancy | 6 | 6-10[a] | 12-16[a] |
| occupancy | occupancy | 6 | 6 | 12 |

[a]The number of year-2 visits and total visits depends on when occupancy is determined in year 2.

*Marbled Murrelet Habitat Characterization Sampling and Methods*

The perimeter of each research site is digitized, and a Geographic Information System ([GIS] ARC/INFO®, Environmental Systems Research Institute, Inc., 380 New York Street, Redlands, CA 92373, USA) is used to determine geographic and topographic attributes for the site. These include elevation, percent slope, aspect, distance from marine waters, density of roads, and density of rivers and streams. Elevation and slope values for each research site are averages over every acre. Aspect is obtained for each acre of each site and categorized as either north, south, east, or west. The site is assigned the aspect with the highest frequency. For calculating distance to marine waters, included are the Pacific Ocean, Puget Sound, and the mouth of the Columbia River eastward to Rice Island. Density of roads and density of rivers and streams are calculated as linear feet per acre within the area of the research site plus a 300-foot buffer around the site.

At each research site, habitat information is collected to characterize forest conditions and nesting opportunities. Data are collected using either of 2 different sampling schemes. (1) 3 or 4 randomly placed, 0.5-acre, fixed-radius plots per research site (before 1996), or (2) systematically placed, variable-radius plots at intensities from 0.4 to 2.5 acres per plot (since 1996). The second sampling scheme, used in all but the South Coast and Columbia planning units, covers the extent of each research site more effectively. The bounds of each research site are determined by the extent of DNR-managed lands, survey station coverage, and the area of potential habitat.

For the first sampling scheme, habitat plots are randomly placed within each murrelet research site ≥330 feet (100 m) from clear-cuts, ≥165 feet (50 m) from significant changes in forest age, and ≥80 feet (25 m) from roads. The number of plots placed depends on the number of survey stations at the site — 3 plots for sites with 2 or 3 survey stations and 4 plots for sites with 4 or 5 survey stations. Trees with diameter at breast height (dbh) ≥20 inches (50 cm) are measured if they are ≤83.3 feet (25.2 m) from plot center (1/2-acre plot). Trees with dbh <20 inches and ≥4 inches (10 cm) are measured if they are ≤41.6 feet (12.6 m) from plot center (1/8-acre plot). All other data are collected at plot center.

For the second sampling scheme, variable-radius habitat plots are systematically placed within the entire extent of each research site. The density of plots placed depends on the expected density of trees with platforms and the expected density of trees with dbh ≥20 inches. Data are collected preliminarily from 3 to 5 1/3- to 1/2-acre, fixed-radius plots to determine the expected densities of platform trees and 20-inch trees at each site. Then, in an effort to capture more platform trees at sites with low expected densities of platform trees, the percentage of 20-inch trees targeted at sites is inversely related to the expected density of platform trees. Sites with lower expected densities of platform trees are prescribed a number of plots to target a higher percentage of the 20-inch trees at the site. For example, in a particular planning unit, a site with an expected density of 0.5 platform trees per acre was prescribed the number of plots required to target 19% of the 20-inch trees at the site, whereas a site with an expected density of 11 platform

trees per acre was prescribed the number of plots required to target only 10% of the 20-inch trees at the site. The percentage of 20-inch trees targeted at different sites ranges from 7 to 25%.

For each tree, technicians record up to 11 variables. These include tree species, dbh, tree height (fixed-radius plots only), condition of tree top, number of platforms, amount of moss cover on limbs, depth of moss on limbs, amount of lichen cover on limbs, abundance of infestation of hemlock dwarf mistletoe (*Arceuthobium tsugense*), amount of cover around and above platform limbs, and diameter of the largest platform.

Tree dbh is measured using either a diameter tape or a Biltmore stick. Tree height is measured only on fixed-radius plots and only for 3 trees per plot. Heights of other trees on the fixed-radius plots are estimated and placed into 1 of 7 height classes: 7-13 feet (2-4 m), 13-26 feet (4-8 m), 26-52 feet (8-16 m), 52-105 feet (16-32 m), 105-157 feet (32-48 m), 157-210 feet (48-64 m), and >210 feet (North 1993). Tree-top condition is recorded as broken or not broken.

Platforms are horizontal limbs or structures that are ≥50 feet (15.2 m) above ground and ≥7 inches (18 cm) in diameter (Hamer 1995). Platforms are counted only in conifer trees and only if located within the live crown. Only 1 platform is counted per limb even if several platforms are present on the limb. Platforms at angles >45° are not counted. Moss cover on limbs is included in the determination of the 7-inch-diameter criterion. Platforms are counted from only 1 vantage point, that where the tree crown is most visible. A platform count reflects only the platforms visible from this location even if platforms are seen from other vantage points; thus, a platform count is an *index* of platform abundance and not a total count of availability. Structures are not judged for their perceived suitability or nonsuitability for murrelet nesting.

Moss cover (including liverworts) is averaged from the large limbs of trees with platforms and is recorded in 5% intervals. Average moss depth on the large limbs of platform trees is visually estimated and placed into 1 of 4 categories: none-trace, trace-0.4 inches (1 cm), 0.4-1.6 inches (1-4 cm), and >1.6 inches. Lichen cover is averaged from the large limbs of platform trees and is

recorded in 5% intervals. The abundance of infestation of hemlock dwarf mistletoe is recorded for all western hemlock trees and is quantified by Hawksworth's 6-class dwarf mistletoe rating system (1977). The system rates trees from 1, low infestation, to 6, high infestation.

Platform cover is estimated using an index that measures the amount of side (horizontal) and top (vertical) cover around the platforms in a tree. The index is determined by rating side and top cover independently on a 0-1-2 scale and adding the ratings; thus, the platform cover index ranges from 0 to 4. Side cover must be within 7 feet (2 m), and top cover must be within 16 feet (5 m), to be considered. Platform cover indices are averaged for platforms in the tree. Codes used for side cover are 0) no cover other than the tree bole, 1) partial side cover, <50%, and 2) ample side cover, >50%. Codes used for top cover are 0) no top cover <16 feet, 1) some top cover, but it is either sparse or high (>7 feet) above the platform, and 2) ample top cover.

At each plot, technicians record an additional 3 variables. These include canopy cover, number of canopy layers, and openness of the canopy. Canopy-cover estimates are made using a concave spherical densiometer (Lemmon 1956). For the fixed-radius plots, 16 canopy-cover estimates are taken from the boundary of the 1/8-acre plot, 1 facing each of the 4 cardinal directions at each of the 4 cardinal points around the plot. For the variable-radius plots, 4 canopy-cover estimates are made from plot center, 1 facing each cardinal direction. The number of canopy layers is estimated visually by counting the number of discrete layers of tree crowns visible from the plot. The number of canopy layers is a measure of the vertical stratification in the plot, but it also corresponds to the number of predominant diameter classes of trees.

Openness of the canopy is judged with respect to ease of access to the site by adult murrelets and is recorded as (1) large openings in the canopy, low tree-stem density, and high height-class diversity make access easy; (2) moderate-sized openings in the canopy, moderate tree-stem density, and moderate height-class diversity make access reasonable; or (3) closed canopy, high tree-stem density, and low height-class diversity make access difficult.

## Model Building

Once the data are collected, analyses are conducted to build models of marbled murrelet habitat relationships. These analyses model the influence of the above geographic and forest variables on marbled murrelet occupancy of DNR-managed lands within each planning unit. For a forest stand of a particular geographic position and a particular forest structure and type, the models estimate the probability of that stand being occupied by murrelets.

### *Univariate Statistics*

All statistical tests are conducted using SAS® System software (SAS Institute Inc., SAS Campus Drive, Cary, NC 27513, USA). The data are divided into 2 groups, occupied and unoccupied research sites. For each independent variable, the sample size, mean, and standard error are calculated separately for each group. The data in each group are tested for normality using the Shapiro-Wilk test (Shapiro and Wilk 1965). If the data in either group are not normal, a nonparametric Wilcoxon rank-sum statistic is computed to test for a difference between the 2 groups (Wilcoxon 1945). If the data in both groups are normal, a variance ratio test ($F'$ test) determines whether the variances of the 2 groups are equal. If the variances are equal, a $t$-test is conducted to test for a difference between the 2 means. If the variances are not equal (the Behrens-Fisher problem), the Cochran and Cox approximate $t'$-test (Cochran and Cox 1957:100-102) tests for a difference between the 2 means. Lastly, univariate logistic regression (Hosmer and Lemeshow 1989) is conducted for each independent variable against the binary dependent variable, *status*, which has a value of 1 for occupied sites and 0 for unoccupied sites.

### *Multivariate Statistics*

Some independent variables are not available at all of the sites in the sample and, thus, have total sample sizes that are less than the total number of sites. For example, the quadratic mean diameter of sitka spruce trees cannot be calculated for a site where sitka spruce trees do not occur. Such variables are excluded from the multivariate model-building process. Variables

with Wald $X^2$ probabilities ($P$-values) >0.25 from univariate logistic regression are also excluded. All remaining variables are included in the multivariate model-building process.

Because the outcome variable of the research sites, *status*, is binary, occupied or unoccupied by murrelets, multiple logistic regression is the most appropriate method for modeling the relationship between *status* and the set of independent variables. The logistic regression model is favorable for this type of research because it assigns a predicted "probability" of occupancy to each research site analyzed, as well as to any site within the scope of the sample.

The logistic regression model is:

$$\text{probability of event} = \pi(x) = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2 \ldots}}{1+e^{\beta_0+\beta_1 x_1+\beta_2 x_2 \ldots}} = \frac{e^{g(x)}}{1+e^{g(x)}} .$$

The logit transformation of $\pi(x)$ defines the logit, $g(x)$, below. The logit has many of the desirable properties of a linear regression model (Hosmer and Lemeshow 1989).

$$\text{logit} = g(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0+\beta_1 x_1+\beta_2 x_2 \ldots$$

The objective of logistic regression modeling is to choose the independent variables ($x_1$, $x_2$, etc.) that best model a binary outcome variable (occupied or unoccupied) and to estimate the parameters, or coefficients ($\beta_0$, $\beta_1$, $\beta_2$, etc.) of those variables, in order to determine $\pi(x)$. The following paragraphs describe techniques used and statistics examined to search for and choose the best fitting, most parsimonious, yet biologically reasonable logistic model to describe the relationship between *status* and the set of independent variables.

Hundreds of multivariate models are generated using a "best-subsets" variable-selection procedure (based on the Score statistic). After this list of models is examined to learn how

variables interact and group themselves, some variables might be summarized differently, combined with other variables, or perhaps removed from consideration completely. These decisions are based on statistical and biological factors. After these variable changes are made, the "best-subsets" variable-selection procedure is employed again to generate more multivariate models. Models in which all the variables have coefficients significant at the 0.05 probability level, based on the Wald $X^2$ statistic, are evaluated for the following attributes: 1) joint, or overall, significance of the coefficients of the model variables, 2) predictive and classification ability of the model, and 3) goodness-of-fit of the model to the actual data.

The joint significance of the coefficients is determined with the likelihood ratio test statistic, -2 log likelihood (-2LogL); however, it is not wise to use -2LogL to compare different non-nested models. The Akaike Information Criterion (AIC) adjusts -2LogL for the number of terms in the model; thus, AIC emphasizes parsimony and is an excellent statistic to compare different models for the same data (Burnham and Anderson 1992). Smaller values of AIC indicate a more desirable model. Rescaled, or adjusted, logistic $R^2$ (Nagelkerke 1991) is also examined for each model.

Rank correlation indices are used to summarize the predictive ability of the model. Correlation indices such as Somer's D, Goodman-Kruskal gamma, and Kendall's tau-a are calculated from the numbers of concordant and discordant pairs of observations. A classification table is a convenient way to summarize results of a logistic model. The table is built by cross-classifying the outcome variable, *status*, with a dichotomous variable derived from comparing each estimated logistic probability to a defined probability cutpoint. Classification values examined for these models include the percentage of sites correctly classified at the 0.5 probability level. The percentage of unoccupied sites correctly classified, or specificity, is assessed at the 0.25 probability level, as is the percentage of sites classified as unoccupied that are actually occupied, false negatives. The percentage of occupied sites correctly classified, or sensitivity, is examined at the 0.75 probability level, as is the percentage of sites classified as occupied that are actually unoccupied, false positives. Of these classification values, the percentage of false negatives is the most critical when considering the classification of marbled murrelet habitat. If the same

data that are used to fit a model are used to derive the classification values for the model, the results are biased. Jackknifing, or cross validation (Hamer 1996), is a method often used to avoid this bias; however, it can be computationally intensive. SAS® creates a bias-adjusted classification table using a method that approximates the jackknifing technique but is much faster computationally.

The overall goodness-of-fit of logistic regression models is often assessed with the deviance and Pearson $X^2$ statistics; however, these statistics are not appropriate if the independent variables in the model are continuous, as they are for this research. The Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 1989) groups observations based on the percentiles of the estimated probabilities and then calculates a Pearson $X^2$ statistic to summarize the difference between the actual number and expected number of observations in each group. The statistic is compared to a $X^2$ distribution with degrees of freedom equal to the number of groups minus 2. To determine if any of any of the sites are overly influential to the fit of the models, logistic regression diagnostics (Pregibon 1981) are calculated and plotted against the estimated probabilities. A particularly informative diagnostic plot is that of $\Delta X^2$ versus the estimated probabilities with the size of the plotting symbol proportional to $\Delta B\text{-}hat_j$ (Hosmer and Lemeshow 1989). The diagnostic, $\Delta X^2$, is the change in the Pearson $X^2$ due to deleting an individual site. The diagnostic, $\Delta B\text{-}hat_j$, is the standardized change in the parameter estimates due to deleting an individual site.

Of the above statistics, overall significance of model coefficients as reflected in AIC and model classification accuracy, particularly percentage of false negatives, are the most influential in selecting a logistic model among the dozens examined. However, model selection is based not only on careful examination of the above statistics but also on prudent consideration of the biological processes involved and the practical consequences of model application.

## Threshold Habitat Definition

The major objective of this research is to formulate a threshold definition of murrelet habitat for DNR-managed lands within each planning unit. The threshold definition separates the lower-quality habitats containing 5% of sites expected to be occupied from the higher-quality habitats containing 95% of sites expected to be occupied. To derive this threshold, a logistic habitat model is selected in the process outlined above. This model estimates the probability that a forest stand is occupied by murrelets. This model is then applied to all the DNR-managed forest stands that are estimated to be within the scope of the sample of research sites. Thus, it is necessary that the independent variables of this logistic model be derivable from DNR's forest inventory. Unfortunately, many variables that other studies have found useful to predict murrelet occupancy, specifically, numbers of platforms and moss coverage of platform limbs, are not measured by DNR's inventory. Thus, 2 logistic habitat models are built. The first is termed the murrelet model and includes the above types of variables during the model-building process. This model is built to examine the relationships of these variables to murrelet occupancy, but it is not used to formulate the threshold habitat definition. The second model is the FRIS model after DNR's newest forest inventory system. It excludes the above types of variables from the model-building process and is the primary model used to formulate the threshold habitat definition.

### *DNR's Forest Inventory Systems*

DNR-managed forest lands are presently inventoried under either the Forest Resource Inventory System (FRIS) or the Land Use Land Cover (LULC) Inventory System. FRIS is the newest forest inventory system and is now available for over 60% of DNR's forest lands in western Washington. Initiated in 1991, FRIS systematically samples site-specific forest data within designated forest inventory units (FIU) to provide stand-level inventory information. An FIU is a contiguous forest community that is sufficiently uniform in topography and vegetative characteristics to be distinguishable from adjacent communities. Within each FIU, sample points measure general site and vegetative characteristics, including live and dead trees, plant

associations, ground vegetation, and down dead woody material. FIUs range from 5 to 300 acres with a mean of 60 to 70 acres. Sample points are systematically placed every 5 acres within average-sized FIUs. FIUs less than 25 acres contain the minimum 5 sample points, and FIUs greater than 150 acres contain the maximum 30 sample points. FRIS data are reliable and are appropriate for countless applications.

LULC is the historical inventory system and is available for the remaining 40% of DNR's forest lands in western Washington. In existence since the early 1980's, the LULC inventory includes forest stand information obtained in a variety of means, some more reliable than others. Some of the stands were systematically cruised according to written procedures or were sampled by field plots. However, for other stands, the LULC inventory contains data that were obtained by simple field inspection (windshield survey), photo interpretation, or summary of office records. The variety of inventory methods is a strong and distinct weakness of LULC data.

Because FRIS includes information about individual trees, data can easily be summarized by species and diameter class. The FRIS model that is selected for each planning unit includes variables that are species-specific and diameter-class-specific. In contrast, while information in the LULC inventory can be summarized by species, it cannot be summarized by diameter class. Thus, yet another probability model must be built. This model is termed the LULC model, and it is applied to the DNR-managed lands where FRIS data are not yet available. To build the LULC model, the FRIS model is applied to DNR-managed lands in the planning unit where FRIS data are available. The logit, $g(x)$, is determined for each FIU. Then, FRIS data are used to perform simple linear regression using the logit as the dependent variable and using variables similar to those that are available in the LULC inventory (e.g. diameter-nonspecific variables) as independent variables. So the LULC model is built from FRIS data summarized to resemble LULC inventory variables. This LULC model is then applied to the LULC-inventoried lands.

*Minimum Model Criteria*

Because it is not appropriate to apply the models to forest stands that are not within the scope of the sample of research sites used to build the model, determination must be made for each stand as to whether it meets the minimum criteria under which the data were collected. If a stand does not meet these criteria, it is assigned a probability of murrelet occupancy equal to 0. The 2 minimum criteria for a stand to be included in the sample of research sites (see page 4) are to be within 66 miles of marine waters and for the average density of potential nesting platforms to be >0 per acre (≥1 platform at the site). The first criterion, within 66 miles of marine waters, is easily determined for DNR's forest stands using GIS. The second criterion is not easily determined because data on numbers of platforms are not collected by DNR's forest inventory. Thus, surrogate criteria are used to approximate this criterion. Because it is known that all of the research sites have at least 1 platform, the data from the sites are used to select the surrogate criteria. The research sites are repeatedly sorted by the values of several forest variables and inspected for the smallest values of these variables. Minimum criteria are chosen based on the values that include the sample of research sites. These criteria, applied to all of DNR-managed forest stands, will undoubtedly miss some stands that do have ≥1 platform and will include many stands that do not have 1 platform. However, these surrogate criteria are the best approximation available to use. While not selected in the most analytical manner, these criteria should assure the model is applied only to those stands that are estimated to be within the scope of the sample of research sites. Separate minimum criteria are developed for the FRIS model using variables available in FRIS and for the LULC model using variables available in the LULC inventory.

*Calculation of Threshold Habitat Definition*

Once the models have been built and the surrogate minimum model criteria defined, calculation of the threshold habitat definition begins. All of the FRIS forest inventory units in the planning unit within 66 miles of marine waters are checked to determine whether they meet the FRIS minimum model criteria. If they do not meet the criteria, they are assigned a probability of

murrelet occupancy of 0. If they do meet the criteria, the FRIS logistic habitat model is applied to determine their probability of occupancy. The same is done for the LULC inventory units, using the LULC minimum model criteria and the LULC probability model. Once all the units have been assigned a probability of occupancy, the units are sorted by probability. Those probabilities are multiplied by the size of the unit to calculate the predicted "occupied acres." For example, if an inventory unit is 50 acres and has a 0.5 probability of occupancy, determined by the model, the unit would be predicted to have 25 "occupied acres." These "occupied acres" are summed to calculate the predicted total "occupied acres" in the planning unit. This number is multiplied by 5% to determine the murrelet habitat threshold probability for the planning unit. The threshold probability separates the lower-quality habitats containing 5% of sites expected to be occupied from the higher-quality habitats containing 95% of sites expected to be occupied. Table 3 demonstrates how this procedure works using a fabricated list of inventory units.

Table 3. Demonstration of how the threshold definition of murrelet habitat is calculated. The fabricated inventory units are sorted by probability of occupancy. "Occupied acres" are calculated by multiplying those probabilities by the size of the units. The total number of "occupied acres," 100, is multiplied by 5% to get 5 acres. These acres represent the lower-quality habitat types containing 5% of the sites expected to be occupied. The dashed line indicates that, for this example, the threshold habitat definition is a probability of occupancy between 0.04 and 0.08.

| inventory unit | FRIS or LULC inventory unit? | unit size in acres | meets FRIS minimum model criteria? | meets LULC minimum model criteria? | FRIS model probability of occupancy | LULC model probability of occupancy | probability of occupancy | "occupied acres" |
|---|---|---|---|---|---|---|---|---|
| 1 | FRIS | 40 | Yes | | 0.85 | | 0.85 | 34 |
| 2 | LULC | 75 | | Yes | | 0.44 | 0.44 | 33 |
| 3 | FRIS | 72 | Yes | | 0.25 | | 0.25 | 18 |
| 4 | LULC | 125 | | Yes | | 0.08 | 0.08 | 10 |
| 5 | FRIS | 50 | Yes | | 0.04 | | 0.04 | 2 |
| 6 | FRIS | 150 | Yes | | 0.02 | | 0.02 | 3 |

| inventory unit | FRIS or LULC inventory unit? | unit size in acres | meets FRIS minimum model criteria? | meets LULC minimum model criteria? | FRIS model probability of occupancy | LULC model probability of occupancy | probability of occupancy | "occupied acres" |
|---|---|---|---|---|---|---|---|---|
| 7 | FRIS | 65 | No | | | | 0.00 | 0 |
| 8 | FRIS | 43 | No | | | | 0.00 | 0 |
| 9 | LULC | 135 | | No | | | 0.00 | 0 |
| total | | | | | | | | 100 |

## RESULTS FOR SOUTHWEST WASHINGTON

This section presents results of the marbled murrelet habitat relationships studies in the 2 HCP planning units in Southwest Washington, the South Coast and Columbia planning units (Fig. 1). It describes the data-collection phase and the model-building phase and presents the final marbled murrelet habitat models for the planning units. Threshold habitat definitions for the 2 units are not presented here because they have not yet been calculated.

### Data Collection

In the South Coast planning unit, research site selection and data collection were conducted in 1994 and 1995 by the Washington Department of Fish and Wildlife. In the Columbia planning unit, site selection and data collection were conducted in 1995 and 1996 by DNR's Southwest Region.

Table 4 shows, for each of the 2 planning units, the distribution of research sites by forest structure and distance from marine waters, the number of sites determined to be occupied by marbled murrelets, and the width of the distance bands. Each distance band contains 1/3 of DNR-managed lands within the planning unit ≤66 miles from marine waters. Because of the

lack of some forest structures on DNR-managed lands within specific distance bands, for these planning units it was impossible to match the target allocation of research sites shown in Table 1.

Table 4. Allocation of research sites in the South Coast and Columbia planning units. The number on the left of the slash is the number of sites determined to be occupied by marbled murrelets. The number on the right of the slash is the total number of sites in that cell. Numbers in brackets are unoccupied sites removed from analyses because surveys were not done exactly according to the PSG protocol.

| | South Coast planning unit distance from marine waters (miles) | | | Columbia planning unit distance from marine waters (miles) | | | |
|---|---|---|---|---|---|---|---|
| forest structure: forest age, platform density | near band 0 - <10.6 | mid band 10.6 - 18.5 | far band 18.5 - 38 | near band 0 - <35.5 | mid band 35.5 - 55.8 | far band 55.8 - 66 | total |
| old forest, ≥2 platforms/acre | 5 / 6 | 2 / 2 | 0 / 0 | 6 / 9 [1] | 0 / 3 | 0 / 7 | 13 / 27 [1] |
| young forest, ≥2 platforms/acre | 3 / 6 | 2 / 4 | 0 / 2 | 4 / 8 [1] | 0 / 7 | 0 / 2 | 9 / 29 [1] |
| young forest, <2 platforms/acre ≥1 platform/site | 1 / 7 | 1 / 9 | 0 / 9 [1] | 1 / 12 [1] | 0 / 7 | 0 / 10 | 3 / 54 [2] |
| total | 9 / 19 | 5 / 15 | 0 / 11 [1] | 11 / 29 [3] | 0 / 17 | 0 / 19 | 25 / 110 [4] |

Numbers to the left of the slashes in Table 4 are the numbers of sites determined to be occupied by marbled murrelets after surveys were conducted for 2 consecutive years. Numbers in brackets are unoccupied sites that were removed from analyses because surveys were not done exactly according to the PSG protocol. For example, in 1 of the 2 survey years, the only survey visit to 1 of the survey stations was during unacceptable weather conditions; thus, survey coverage at that research site was inadequate in that year. No occupied sites were removed from analyses. The South Coast planning unit has 45 research sites — 30 unoccupied, 14 occupied, and 1 removed from analyses. The Columbia planning units has 65 sites — 51 unoccupied, 11 occupied, and 3 removed from analyses. For both of these planning units, habitat information was collected using 0.5-acre, fixed-radius plots, not variable-radius plots.

## Model Building

Because the South Coast and Columbia HCP planning units are both in Southwest Washington and because relatively few research sites in the units were determined to be occupied, data from the units were combined for the purpose of model building. However, threshold habitat definitions for the 2 planning units will still be calculated separately.

### *Univariate Statistics*

The 100 variables that were considered in these analyses are listed in Appendix A. Listed for each variable are variable name; logistic regression significance level; variable definition and units; mean, sample size, and standard error for occupied and unoccupied sites; *P*-values from Wilcoxon rank-sum test and logistic regression; determination of whether the variable is included in the multivariate model-building process and a reason why if not included; and a determination of whether the variable is included in the FRIS model-building process.

Most of the variable definitions require no additional clarification; however, it is important to note that the diameter cut-offs used are actually *diameter classes* that match the diameter-classes used to summarize data in FRIS. The 7" cut-off includes trees ≥6.5" in diameter; the 22" cut-off includes trees ≥21" in diameter; the 32" cut-off includes trees ≥31" in diameter; and the 42" cut-off includes trees ≥41" in diameter. Quadratic mean diameter is the square root of the mean squared tree diameters, $\sqrt{\sum dbh^2 / (\#\, of\ trees)}$. Shannon diversity index, $H'$, and Berger-Parker diversity index, $d$, for tree-height classes measure the heterogeneity of tree heights at a site. Higher values indicate that canopies are multi-layered. The Shannon index is the negative of the sum of the products of the proportions of trees in each height class and their natural logs, $-\sum p_i \ln p_i$ (Magurran 1988:35). The Berger-Parker index is usually expressed in its reciprocal form, which is the ratio of the total number trees to the number of trees in the most abundant height class, $N \ / \ N_{\max}$ (Magurran 1988:41).

After the research sites were divided between the occupied and unoccupied sites, only 13 of the 100 variables had normal data in both groups based on the Shapiro-Wilk test. Thus, *t*-test results are not reported at all, and results of the nonparametric 2-sample Wilcoxon rank sum test are reported for all of the variables. Univariate logistic regression was conducted for each variable against the binary variable, *status*, occupied or unoccupied. Wald $X^2$ *P*-values from these regressions are reported for all of the variables.

Average elevation, *elev*, is significantly different between occupied and unoccupied sites, with occupied sites having a mean average elevation of 558 feet versus 1147 feet for unoccupied sites (Wald $X^2$ $P = 0.0011$). However, elevation is correlated with distance to marine waters ($r = 0.657$, $P = 0.0001$). Because the mean elevation for unoccupied sites is well below the zones of mountain hemlock and silver fir, which seldom produce murrelet nesting opportunities (Hamer 1995), distance to marine waters, *distmw*, which has energetic implications, is probably more significant biologically. Occupied and unoccupied sites are an average 8.6 miles and 33.4 miles from marine waters, respectively (Wald $X^2$ $P = 0.0002$). Other studies of murrelet habitat relationships have found percent slope, *slope*, to be an important variable in describing marbled murrelet habitat. Hamer (1995) found slope to be positively correlated with murrelet occupancy for sites in western Washington. Hamer (1996) found slope to be negatively correlated with murrelet occupancy for sites in Elliot State Forest near the south coast of Oregon. However, for sites in the South Coast and Columbia planning units, average slope is not significantly different between occupied and unoccupied sites (Wald $X^2$ $P = 0.3670$). North, south, east, and west binary variables for aspect are also not significant to murrelet occupancy. The linear feet per acre of roads that are present in DNR's roads database is negatively correlated with occupancy, with 25 linear feet of roads per acre at occupied sites versus 36 feet per acre at unoccupied sites (Wald $X^2$ $P = 0.0352$). Linear feet per acre of rivers, streams, and creeks, that are present in DNR's hydrology database is positively correlated with murrelet occupancy, with 76 linear feet per acre at occupied sites versus only 60 feet per acre at unoccupied sites (Wald $X^2$ $P = 0.0270$).

Basal area per acre and trees per acre are summarized for all conifer species, western hemlock, Douglas-fir, sitka spruce, and western redcedar trees for diameter classes ≥7", ≥22", ≥32", and

≥42". Quadratic mean diameter is summarized for trees ≥7". In general, all conifer species, western hemlock, western redcedar, and sitka spruce variables are positively correlated with murrelet occupancy, while Douglas-fir variables are negatively correlated with murrelet occupancy. Western hemlock and Douglas-fir are more strongly correlated than the other species. For example, occupied sites have an average 7.5 trees per acre of western hemlock trees ≥32", versus only 1.9 trees per acre for unoccupied sites (Wald $X^2$ $P = 0.0001$). Occupied sites have an average of 23 feet$^2$ of basal area per acre of Douglas-fir trees ≥7", versus 130 feet$^2$ per acre for unoccupied sites (Wald $X^2$ $P = 0.0001$). Tree-height diversity indices and numbers of broken-top trees per acre are not significantly different between occupied and unoccupied sites.

Platform trees per acre and total platforms per acre were calculated for all species and by species. Almost all of these variables are significantly correlated with murrelet occupancy, with the western hemlock platform variables being the most strongly correlated. For example, occupied sites have an average of 3.9 western hemlock platform trees per acre, versus an average of 0.5 trees per acre at unoccupied sites (Wald $X^2$ $P = 0.0001$). Douglas-fir platform variables are negatively correlated with occupancy.

Two moss variables are significant between occupied and unoccupied sites. They are average depth of moss on platform trees (Wald $X^2$ $P = 0.0051$) and the percentage of platform trees with moss depth >4 cm (Wald $X^2$ $P = 0.0241$). All the mistletoe variables are strongly correlated with murrelet occupancy. Mistletoe is present at 24 of the 25 occupied sites, and only 34 of the 81 unoccupied sites (Wald $X^2$ $P = 0.0008$). Information about cover around platform limbs was collected only in the Columbia planning unit, not in the South Coast planning unit. Platform cover is not correlated with murrelet occupancy. Percentage of canopy cover, number of canopy layers, and openness of the canopy are also not significantly different between occupied and unoccupied sites.

Because the platform variables and diameter-class variables are positively correlated with murrelet occupancy for all species except Douglas-fir, new variables were built that summarized

these data for *non-Douglas-fir* conifer trees. In this way the positive effect of the other conifer species on murrelet occupancy is separated from the negative effect of Douglas-fir. These variables are listed at the end of Appendix A and are all more strongly correlated with murrelet occupancy than the all-conifer variables that include Douglas-fir.

*Multivariate Statistics*

One of the columns in Appendix A indicates which variables were excluded from the multivariate murrelet modeling process. Twelve of the 100 variables were not available at all of the sites; thus, they have total sample sizes that are less than the total number of sites and are excluded from the multivariate modeling process. These include most of the quadratic-mean-diameter variables because an average diameter for a species cannot be calculated at a site where that species does not occur. All of the variables that were collected only for platform trees are excluded because at some of the sites no platform trees occurred in any of the sample plots. These variables include the moss variables and the platform-cover variables. It was an oversight in the design of the data collection phase to not collect moss information for all the trees in the plot rather than just the platform trees. Of the remaining 88 variables, 15 have Wald $X^2$ *P*-values >0.25 and are excluded from the multivariate modeling process. Also excluded from the multivariate model-building process are the original all-conifer variables because the *non-Douglas-fir* conifer variables are more strongly correlated with occupancy. The Douglas-fir platform variables are excluded because they are negatively correlated with murrelet occupancy and for this reason are, as defined, not biologically important. The remaining 64 variables are included in the initial multivariate modeling process for the murrelet model.

Murrelet Model.—Examination of the first set of multivariate models generated using the "best-subsets" variable-selection procedure (based on the Score statistic) exposed average elevation, *elev*, as a problem variable. Elevation is repeatedly chosen in place of distance from marine waters, *distmw*. However, elevation is likely significant to murrelet occupancy only as a correlate of distance from marine waters ($r = 0.657$, $P = 0.0001$). The variable distance from marine waters, by itself, is more significantly correlated to occupancy than is elevation ($P =$

0.0002 versus $P = 0.0011$). Moreover, models with distance from marine waters all have smaller AIC values than identical models with average elevation. Thus, average elevation is excluded from further variable-selection procedures.

Twelve candidate murrelet models and their statistics are listed in Appendix B. Included for each model are model number; logit equation; joint significance of coefficients as expressed by -2LogL, AIC, and logistic $R^2$; predictive ability as expressed by Somer's D; and classification accuracy as expressed by specificity and false negatives (false-) at the 0.25 probability level, percent correct (%corr) at the 0.50 level, and sensitivity and false positives (false+) at the 0.75 probability level. Hosmer-Lemeshow tests for goodness-of-fit indicate that all of the 12 candidate models fit well. Moreover, logistic regression diagnostic plots indicate that none of the 106 research sites included in the analyses are overly influential to the fit of these models.

Appendix B model 1 and model 2 are the best 1-variable models. Model 1 includes the variable non-Douglas-fir platform trees per acre, *ndfptrpa*. Model 2 includes the variable *dfbpa7*[5] as a negative correlate to murrelet occupancy. Model 1 has a higher %corr (87.7) than model 2 (84.0), and, because it includes a positive correlate instead of a negative one, model 1 is more direct and intuitive than model 2. However, model 2 has a better joint significance of the coefficients (AIC = 72.9 versus 77.5) and a lower false- (5.6 versus 8.8).

Appendix B models 3 and 4 are 2-variable models. Model 3 includes *distmw* with *ndfptrpa* and has better statistics than model 4. Model 4 includes *dfbpa42* as a negative correlate, with *ndfptrpa*.

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[5]The tree variables are named according to the following convention. The first 2 or 3 letters stand for the species (cn = all conifer species, wh = western hemlock, df = Douglas-fir, rc = western redcedar, and ss = sitka spruce, ndf = non-Douglas-fir conifer species). The next 3 letters stand for basal area per acre (bpa), trees per acre (tpa), or quadratic mean diameter (qmd). The number at the end indicates the diameter class at or above which trees are included. For example, *whtpa32* = trees per acre of western hemlock trees ≥32" diameter class. Variable names which do not follow this convention are defined in the text.

Appendix B models 5 and 6 are 3-variable models. Model 5 includes the binary variable planning unit, *planunit*, with *distmw* and the variable non-Douglas-fir platforms per acre, *ndfplpa*. Model 5 has a lower AIC than model 6 (50.9 versus 52.3). However, model 6, which includes *distmw*, *ndfptrpa*, and *whtpa32*, has a lower false- (5.2 versus 6.8). The univariate statistics for the binary variable, *planunit*, describe it as positively correlated with murrelet occupancy; however, because *planunit* and *distmw* are correlated ($r$ = -0.624, $P$ = 0.0001), they have a confounding relationship. When both variables are included in a model, as in model 5, *planunit* becomes negatively correlated with occupancy. Because of this confounding, model 6 is more direct and intuitive than model 5.

Appendix B models 7-12 are 4-variable models. Models 7 and 8 include *planunit*, *distmw*, *whtpa32*, with *ndfplpa* or *ndfptrpa*, respectively. Model 7 has better joint significance of the coefficients (AIC = 47.9 versus 49.1), but it has a slightly higher false- than model 8 (4.1 versus 3.8). Model 8 is more desirable than model 7 because counts of platform trees are easier and more reproducible than counts of total platforms. Models 9 through 12 all include *distmw* and western hemlock platform trees per acre, *whpltrpa*, with a large-tree western hemlock variable and a western redcedar variable. Model 9, with *whtpa32* and *rcbpa7*, has the lowest AIC (49.9) and the highest rescaled logistic $R^2$ of the 4 models. Model 10, with *whtpa32* and *rctpa32*, has the lowest false- (5.2). Model 11, with *whtpa32* and *rctpa42*, has the lowest false+ (5.3). Model 12, with *whbpa22* and western redcedar platform trees per acre, *rcpltrpa*, has the best predictive ability (Somer's D = 0.920). Of these, model 10, with the lowest false- is the most desirable. Model 9, with the lowest AIC, is also desirable, but the inclusion of small-diameter western redcedar trees, *rcbpa7*, makes it less biologically intuitive because nesting opportunities generally do not occur on small-diameter trees.

All of the 5-variable models either had high AIC values (>50) or included variables with coefficients that were not significant at the 0.05 probability level, based on the Wald $X^2$ statistic. Appendix B model 10 is selected as the murrelet model for the South Coast and Columbia HCP planning units. It has a low false- (5.2), a fairly low AIC (50.9), and does not include the

confounding variable, *planunit*, or the small-diameter variable, *rcbpa7*. However, all of the other 3- and 4-variable Appendix B candidate models would be quite adequate.

FRIS Model.—Of the 64 variables included in the murrelet modeling process, 19 are not derivable from DNR's inventory and are thus excluded from the FRIS modeling process. These include variables that other studies have found useful to predict marbled murrelet occupancy, specifically, numbers of platforms and moss coverage of platform limbs. Average elevation, *elev*, is also excluded due to the problem of its high correlation with *distmw*, as explained above. Thus, the remaining 44 variables are included in the multivariate FRIS modeling process. The FRIS model is the primary model used to formulate the threshold habitat definitions.

Twelve candidate FRIS models and their statistics are listed in Appendix C. Again, Hosmer-Lemeshow tests for goodness-of-fit indicate that all of the models fit well, and logistic regression diagnostic plots indicate that none of the research sites are overly influential to the fit of these models.

Appendix C models 1, 2, and 3 are the best 1-variable FRIS models and include *whtpa32*, *dfbpa7*, and *distmw*, respectively. Their AIC values are all greater than 70. Model 2 has the lowest AIC (72.9) and lowest false- (5.6) of the 3 models.

Appendix C models 4-7 are the 2-variable models and all have AIC values greater than 60. Model 4 has the best joint significance of the coefficients (AIC = 61.5) and best predictive ability (Somer's D = 0.895) of the 4 models. It includes *distmw* with *ndfbpa22*. Model 5 has the lowest false+ (8.3) with *distmw* and *whbpa22*. Model 6 has the highest %corr (89.6) with *distmw* and *dfbpa7*. Model 7 has the lowest false- (4.2) with *dfbpa7* and *whtpa32*. Model 5 is the most desirable of these with the second-lowest AIC (62.8), the second-lowest false-(4.3) and the lowest false+ (8.3).

Appendix C models 8 and 9 are 3-variable FRIS models, and both have excellent statistics. Model 8 includes *distmw*, *whtpa32*, and *rctpa22*, and has the lowest AIC value (53.7) of all the FRIS candidate models. Model 9 includes *distmw*, *whtpa32*, and *rcbpa7*, and has not only a low AIC (54.7) but also a low false- (4.0) and a very low false+ (5.9). Based on statistics alone, model 8 or model 9 would be selected as the FRIS model; however, closer examination of these models reveals that, because *distmw* is the only negative correlate, the models assign sites close to marine waters relatively high predicted probabilities of occupancy, regardless of their habitat type. Because a large portion of these sites close to marine waters would be false positives, this characteristic is biologically and statistically unacceptable for the FRIS model. The candidate 4-variable models all include a Douglas-fir variable as a negative correlate and are described below.

Appendix C models 10, 11, and 12 are the 4-variable candidate FRIS models. Of the 3 models, model 10 has the best joint significance of the coefficients (AIC = 54.6, $R^2 = 0.736$). It includes *distmw*, *whtpa32*, *rctpa22*, and *dfbpa7*. Model 11 includes *distmw*, *whtpa42*, *rctpa22,* and *dftpa7*. Model 11 has the best classification accuracy of all the FRIS candidate models (specificity = 91.4, false- = 3.9, %corr = 89.6), except for the false+ (21.1). Model 12 does not include *distmw*, but instead includes the variables, *sstpa7*, *whtpa32*, *rcbpa22*, and *dftpa42*. Model 12 has a relatively high AIC value (62.1) and a high false+ (23.5).

Appendix C model 10 is selected as the FRIS model for the South Coast and Columbia HCP planning units. It has a low AIC (54.6), a high Somer's D (0.930), and an acceptable false-(6.6). Models 11 and 12 are undesirable because of their high false+ values.

## Threshold Habitat Definition

The LULC model has not yet been selected, and the threshold habitat definitions have not yet been calculated because DNR's FRIS inventory is in the process of being updated for harvest activities that have occurred since the first FRIS data were collected in the early 1990's. Once

these activity updates are complete, selection of the LULC model and calculation of the threshold definitions will occur. However, FRIS will not yet have been updated to account for tree growth that has occurred since the data were collected. This update will occur within the next 2 years.

Three FRIS minimum model criteria were selected after examination of sorts of the research sites on several FRIS variables. The FRIS model criteria are *cnbpa22* ≥74 $ft^2$, *cntpa22* ≥14, and *cntpa32* ≥2. Of these criteria, *cntpa32* ≥2, is the most restrictive. Of the 110 research sites, 105 met all 3 of these criteria. The LULC model criteria were selected in the same manner, from sorts of the research sites on several LULC variables. The LULC model criteria are *cnbpa7* ≥135 $ft^2$, *cntpa7* ≥44, and *cnqmd7* ≥15. The last criterion, *cnqmd7* ≥15, is the most restrictive. An additional LULC model criterion specifies that, among the primary, secondary, and tertiary species, at least 1 species have an origin date before 1950. Of the 110 research sites, 102 met all of these criteria. These criteria will undoubtedly miss some stands that have ≥1 platform, and they will also include some stands that do not have 1 platform. The FRIS and the LULC criteria compare to each other fairly well. In general, the FRIS criteria are more restrictive than the LULC criteria.

## DISCUSSION

### How well does the FRIS model, which excluded murrelet nesting variables, compare to the murrelet model which included them?

All of the statistics for the murrelet model are better than the statistics for the FRIS model (Appendices B, C). However, closer examination indicates that their classification accuracies are nearly equivalent. Remember, false positives are unoccupied sites that a model classifies as occupied, and false negatives are occupied sites that a model classifies as unoccupied. With respect to murrelet conservation, false negatives are more serious than are false positives. At the 0.25 probability level, the murrelet model and the FRIS model classify only 6 of the 106 research

sites differently. The murrelet model has 1 false positive that the FRIS model classifies correctly, and the FRIS model has 5 false positives that the murrelet model classifies correctly. At the 0.50 level, the FRIS model classifies 3 sites as false positives that the murrelet model classifies correctly. At the 0.75 probability level, the FRIS models classifies 3 sites as false negatives that the murrelet model classifies correctly; however, at the 0.75 level, these false negatives are not as critical as they would be at the 0.25 level. The 2 models classify all of the other sites identically.

**Is the scale of the marbled murrelet research sites and DNR's forest inventory units appropriate for identification and conservation of marbled murrelet habitat?**

The PSG protocol for conducting marbled murrelet forest surveys (Ralph et. al 1994) delineates guidelines for determining probable presence, absence, or occupancy of murrelets in a *forest stand*. The guidelines regarding number and placement of survey stations, as well as the number and timing of surveys, are directed at the scale of the forest stand. In these studies, the marbled murrelet research sites are not always entire stands of habitat, but the sites are at the scale of forest stands, ranging in size from 15 to 120 acres. Sites in the South Coast and Columbia planning units are an average 54.6 acres (SE = 2.0, $n$ = 110). The murrelet habitat models that are built from data collected at these research sites are applied to DNR's forest inventory units to formulate threshold murrelet habitat definitions. These forest inventory units are also at the scale of forest stands and are similar in size to the scale of the research sites. Forest inventory units in the South Coast and Columbia planning units that meet the FRIS and LULC model criteria are an average 64.6 acres (SE = 1.6, $n$ = 1353). It is important that the scale of the research sites and the forest inventory units are both at the same scale.

Individual pairs of marbled murrelets are likely selecting habitat on a finer scale than that of the forest stand. Several marbled murrelet nest stands in the Pacific Northwest are as small as 7 or 10 acres (Hamer and Nelson 1995). Hamer's preliminary data from tree-climbing research being conducted on the western Olympic Peninsula in Washington indicate that murrelets might be selecting habitat at as fine a scale as the individual tree (T. E. Hamer, Hamer Environmental, pers. commun.). It is likely that some small patches of murrelet habitat at this scale will not be

captured when the habitat models are applied to DNR's forest inventory units. However, because the scale of the research sites matches the scale of the inventory units, the formulation of the threshold habitat definitions should, overall, be unbiased by this disparity between the scale of murrelet ecology and the scale of forest management.

**What ecological phenomena might confound the results of these marbled murrelet forest habitat relationships studies?**

The results of these studies are appropriate to describe the general features of marbled murrelet forest habitat and estimate the probability a forest stand will be occupied by murrelets — for the particular geographic area in which and for the time period during which the data were collected. Several ecological phenomena might confound the results of these studies, perhaps biasing their applicability to other geographic areas or to subsequent years. Also note that results of these studies describe habitat relationships only. Inferences of habitat quality, suitability, or preference are not valid (Van Horne 1983). Models to estimate habitat suitability must include a component of species density, reproductive rates, genetic contribution of adults to the next generation, and/or survival rates of adults and juveniles. The following ecological phenomena might confound the results of these marbled murrelet forest habitat relationships studies.

Habitat selection might be density dependent. As the local abundance of a species becomes large or the local extent of suitable habitat becomes small, some individuals are forced to use lower-quality habitat. Conversely, when the local abundance of a species becomes small or the local extent of suitable habitat becomes large, one might observe species occupancy in only the highest-quality habitat. Consequently, if the former is true, the results of a species-habitat relationship study will be biased toward lower-quality habitat, and, if the latter are true, the results will be biased toward higher-quality habitat (Van Horne 1983). These biases could be particularly acute for a threatened species which presumably has either a very small population compared to its natural abundance and/or a small extent of habitat compared to its natural occurrence. If habitat loss is occurring faster than species loss, results will be biased toward

lower-quality habitat. If species loss is occurring faster than habitat loss, results will be biased toward higher-quality habitat. Because the marbled murrelet is being impacted by oil spills, net fisheries, and forest fragmentation, as well as the loss of old-forest habitat, it is unclear whether species loss or habitat loss is occurring faster than the other. Thus, it is also unclear whether the results of these habitat relationships studies might be biased toward lower-quality or higher-quality habitat.

The quality of marine habitat might have an influence on the selection of terrestrial habitat, affecting the distribution of murrelet occupancy both perpendicular and parallel to the marine coast (Burkett 1995). Ocean conditions affect prey density which affects foraging efficiency which affects the risk associated with nesting far from the food source or nesting at all. In times of plenty murrelets can afford to nest farther from marine waters. Ocean conditions have year-to-year variation (el Niño, la Niña) and decadal oscillations which affect prey density. Low murrelet occupancy rates farther than 15 miles from the coast in Southwest Washington could be related to this phenomenon. Ocean conditions also affect prey distribution along the coast which affects where murrelets forage which might affect the distribution of murrelet nesting along, or parallel to, the coast.

Marbled murrelets might exhibit strong breeding site fidelity and fidelity to natal sites (Divoky and Horton 1995). Thus, murrelets observed in these studies might not be exhibiting habitat selection behavior but rather homing behavior. The research sites might have been occupied through a habitat selection process that occurred many generations ago when the characteristics of the stand might have been very different (e.g. less fragmented or many decades younger).

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ACKNOWLEDGMENTS

Thanks to Lenny Young and Chuck Turley who conceived the marbled murrelet interim conservation strategy. Thanks also to the Washington Department of Fish and Wildlife who conducted the field work in the OESF and South Coast HCP planning units. Thanks to Tom Hamer, Sabra Hull, Bill Ritchie, Richard Bigley, Dave Richards, and Steve Curry for their help in designing the habitat characterization methods. Thanks to Tami Riepe (Jones), Dorene Cahill, Sam Jacobson, and Jean Williams for leading teams of field crews conducting murrelet surveys and collecting habitat data. Thanks to Paul Whitney for his help with training field crews and data management. Thanks to Meghann Hurst for her help with data entry and to Kirsten Schilt for digitizing. Thanks to Scott Sagor and Kristen Jamison for their help with GIS and to Steve Curry for his help with DNR's forest inventory system. Thanks to Scott Horton, George Wilhere, Steve Curry, Richard Bigley, and Lenny Young for their support of this analysis method and for their helpful review comments of this paper.

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined.

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| **geographic and topographic variables, computed using GIS:** | | | | | | | | | | | | | |
| planunit | | 1 if in South Coast planning unit; 0 if in Columbia | 25 | 0.56 | 0.101 | 81 | 0.37 | 0.054 | 0.0979 | 0.0962 | yes | | yes |
| elev | ** | average elevation (feet) | 25 | 557.72 | 73.270 | 81 | 1146.67 | 86.237 | 0.0002 | 0.0011 | yes | | no |
| slope | | average slope (%) | 25 | 22.24 | 2.698 | 81 | 24.86 | 1.388 | 0.1374 | 0.3670 | no | $P > 0.25$ | no |
| aspectn | | 1 if most of the grid-acres have a north-facing aspect; 0 if not | 25 | 0.24 | 0.087 | 81 | 0.23 | 0.047 | 0.9597 | 0.9554 | no | $P > 0.25$ | no |
| aspects | | 1 if most of the grid-acres have a south-facing aspect; 0 if not | 25 | 0.24 | 0.087 | 81 | 0.30 | 0.051 | 0.5911 | 0.5857 | no | $P > 0.25$ | no |
| aspecte | | 1 if most of the grid-acres have a east-facing aspect; 0 if not | 25 | 0.16 | 0.075 | 81 | 0.22 | 0.046 | 0.5093 | 0.5045 | no | $P > 0.25$ | no |
| aspectw | | 1 if most of the grid-acres have a west-facing aspect; 0 if not | 25 | 0.36 | 0.098 | 81 | 0.25 | 0.048 | 0.2744 | 0.2705 | no | $P > 0.25$ | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined.

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| distmw | *** | shortest distance (miles) to marine waters | 25 | 8.55 | 1.037 | 81 | 33.39 | 2.428 | 0.0001 | 0.0002 | yes | | yes |
| road | * | linear feet per acre of roads within the site plus 300-foot buffer around site | 25 | 25.12 | 3.976 | 81 | 35.51 | 2.359 | 0.0295 | 0.0352 | yes | | yes |
| water | * | linear feet per acre of rivers and streams within the site plus 300-foot buffer around site | 25 | 76.24 | 5.869 | 81 | 59.70 | 3.454 | 0.0131 | 0.0270 | yes | | yes |
| water1 | | linear feet per acre of Type 1 rivers within the site plus 300-foot buffer around site | 25 | 3.24 | 1.810 | 81 | 3.68 | 1.860 | 0.5144 | 0.8995 | no | $P > 0.25$ | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| water1-2 | | linear feet per acre of Type 1 & 2 rivers and streams within the site plus 300-foot buffer around site | 25 | 3.48 | 1.808 | 81 | 5.00 | 2.233 | 0.4585 | 0.7147 | no | *P* > 0.25 | no |
| water1-3 | | linear feet per acre of Type 1 - 3 rivers and streams within the site plus 300-foot buffer around site | 25 | 10.12 | 3.298 | 81 | 9.73 | 2.506 | 0.6430 | 0.9354 | no | *P* > 0.25 | no |
| **diameter-class tree variables:** | | | | | | | | | | | | | |
| cnbpa7 | | basal area ($ft^2$) per acre of conifer trees ∃ 7" diameter class | 25 | 269.94 | 16.993 | 81 | 236.22 | 7.625 | 0.0722 | 0.0540 | no | ndfbpa7 used instead | no |
| cntpa7 | | trees per acre of conifer trees ∃ 7" diameter class | 25 | 94.68 | 6.678 | 81 | 100.00 | 5.640 | 0.9526 | 0.6212 | no | *P* > 0.25 ndftpa7 used instead | no |
| cnqmd7 | | quadratic mean diameter (in) of conifer trees ∃ 7" diameter class | 25 | 23.36 | 0.765 | 81 | 21.84 | 0.472 | 0.0865 | 0.1154 | yes | | yes |
| whbpa7 | **** | basal area ($ft^2$) per acre of western hemlock trees ∃ 7" diameter class | 25 | 168.01 | 11.091 | 81 | 77.44 | 8.316 | 0.0001 | 0.0001 | yes | | yes |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| whtpa7 | * | trees per acre of western hemlock trees ∃ 7" diameter class | 25 | 76.31 | 6.097 | 81 | 48.78 | 6.090 | 0.0003 | 0.0326 | yes | | yes |
| whqmd7 | *** | quadratic mean diameter (in) of western hemlock trees ∃ 7" diameter class | 25 | 20.71 | 0.722 | 74 | 16.55 | 0.518 | 0.0002 | 0.0003 | no | total sample size < 106 | no |
| dfbpa7 | **** | basal area ($ft^2$) per acre of Douglas-fir trees ∃ 7" diameter class | 25 | 22.71 | 6.383 | 81 | 130.28 | 8.869 | 0.0001 | 0.0001 | yes | | yes |
| dftpa7 | **** | trees per acre of Douglas-fir trees ∃ 7" diameter class | 25 | 6.32 | 2.025 | 81 | 40.74 | 3.331 | 0.0001 | 0.0001 | yes | | yes |
| dfqmd7 | | quadratic mean diameter (in) of Douglas-fir trees ∃ 7" diameter class | 14 | 28.54 | 2.122 | 76 | 27.63 | 1.276 | 0.2568 | 0.7677 | no | *P* > 0.25; total sample size < 106 | no |
| ssbpa7 | * | basal area ($ft^2$) per acre of sitka | 25 | 22.95 | 6.644 | 81 | 5.51 | 2.775 | 0.0001 | 0.0224 | yes | | yes |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| | | spruce trees ∃ 7" diameter class | | | | | | | | | | | |
| sstpa7 | * | trees per acre of sitka spruce trees ∃ 7" diameter class | 25 | 5.12 | 1.648 | 81 | 1.15 | 0.455 | 0.0001 | 0.0112 | yes | | yes |
| ssqmd7 | | quadratic mean diameter (in) of sitka spruce trees ∃ 7" diameter class | 20 | 30.51 | 2.639 | 12 | 22.44 | 3.329 | 0.1440 | 0.0848 | no | total sample size < 106 | no |
| rcbpa7 | * | basal area ($ft^2$) per acre of western redcedar trees ∃ 7" diameter class | 25 | 53.56 | 19.319 | 81 | 15.27 | 3.428 | 0.0226 | 0.0148 | yes | | yes |
| rctpa7 | | trees per acre of western redcedar trees ∃ 7" diameter class | 25 | 5.73 | 1.136 | 81 | 5.63 | 1.237 | 0.0701 | 0.9662 | no | *P* > 0.25 | no |
| rcqmd7 | | quadratic mean diameter (in) of western redcedar trees ∃ 7" diameter class | 19 | 32.00 | 4.943 | 44 | 23.83 | 1.670 | 0.3268 | 0.0656 | no | total sample size < 106 | no |
| cnbpa22 | * | basal area ($ft^2$) per acre of conifer trees ∃ 22" diameter class | 25 | 202.93 | 16.611 | 81 | 164.84 | 8.549 | 0.0363 | 0.0429 | no | ndfbpa22 used instead | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| cntpa22 | | trees per acre of conifer trees ∃ 22" diameter class | 25 | 30.44 | 1.892 | 81 | 31.13 | 1.209 | 0.6777 | 0.7761 | no | *P* > 0.25 ndftpa22 used instead | no |
| whbpa22 | **** | basal area ($ft^2$) per acre of western hemlock trees ∃ 22" diameter class | 25 | 111.46 | 9.509 | 81 | 38.23 | 4.903 | 0.0001 | 0.0001 | yes | | yes |
| whtpa22 | **** | trees per acre of western hemlock trees ∃ 22" diameter class | 25 | 21.32 | 1.757 | 81 | 8.33 | 0.998 | 0.0001 | 0.0001 | yes | | yes |
| dfbpa22 | **** | basal area ($ft^2$) per acre of Douglas-fir trees ∃ 22" diameter class | 25 | 19.20 | 5.473 | 81 | 104.30 | 8.270 | 0.0001 | 0.0001 | yes | | yes |
| dftpa22 | **** | trees per acre of Douglas-fir trees | 25 | 4.02 | 1.206 | 81 | 19.62 | 1.504 | 0.0001 | 0.0001 | yes | | yes |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| | | ∃ 22" diameter class | | | | | | | | | | | |
| ssbpa22 | * | basal area ($ft^2$) per acre of sitka spruce trees ∃ 22" diameter class | 25 | 19.78 | 6.148 | 81 | 5.02 | 2.633 | 0.0001 | 0.0362 | yes | | yes |
| sstpa22 | * | trees per acre of sitka spruce trees ∃ 22" diameter class | 25 | 2.13 | 0.532 | 81 | 0.64 | 0.304 | 0.0001 | 0.0367 | yes | | yes |
| rcbpa22 | * | basal area ($ft^2$) per acre of western redcedar trees ∃22" diameter class | 25 | 51.02 | 19.271 | 81 | 12.14 | 3.004 | 0.0924 | 0.0133 | yes | | yes |
| rctpa22 | | trees per acre of western redcedar trees ∃ 22" diameter class | 25 | 2.74 | 0.759 | 81 | 1.69 | 0.431 | 0.1217 | 0.2496 | yes | | yes |
| cnbpa32 | * | basal area ($ft^2$) per acre of conifer trees ∃ 32" diameter class | 25 | 136.62 | 17.998 | 81 | 90.61 | 8.692 | 0.0071 | 0.0217 | no | ndfbpa32 used instead | no |
| cntpa32 | | trees per acre of conifer trees ∃ 32" diameter class | 25 | 11.66 | 0.918 | 81 | 10.12 | 0.778 | 0.1318 | 0.3070 | no | $P > 0.25$ ndftpa32 used instead | no |
| whbpa32 | **** | basal area ($ft^2$) per acre of western hemlock trees ∃ 32" diameter | 25 | 62.72 | 7.547 | 81 | 16.01 | 2.970 | 0.0001 | 0.0001 | yes | | yes |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| | | class | | | | | | | | | | | |
| whtpa32 | **** | trees per acre of western hemlock trees ∃ 32" diameter class | 25 | 7.48 | 0.884 | 81 | 1.94 | 0.322 | 0.0001 | 0.0001 | yes | | yes |
| dfbpa32 | *** | basal area ($ft^2$) per acre of Douglas-fir trees ∃ 32" diameter class | 25 | 8.79 | 3.079 | 81 | 58.03 | 6.847 | 0.0001 | 0.0003 | yes | | yes |
| dftpa32 | *** | trees per acre of Douglas-fir trees ∃ 32" diameter class | 25 | 1.18 | 0.432 | 81 | 6.63 | 0.723 | 0.0001 | 0.0002 | yes | | yes |
| ssbpa32 | | basal area ($ft^2$) per acre of sitka spruce trees ∃ 32" diameter class | 25 | 15.38 | 5.736 | 81 | 4.02 | 2.351 | 0.0001 | 0.0690 | yes | | yes |
| sstpa32 | | trees per acre of sitka spruce trees | 25 | 0.80 | 0.242 | 81 | 0.38 | 0.199 | 0.0001 | 0.2911 | no | $P > 0.25$ | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| | | ∃ 32" diameter class | | | | | | | | | | | |
| rcbpa32 | * | basal area ($ft^2$) per acre of western redcedar trees ∃32" diameter class | 25 | 48.50 | 19.234 | 81 | 9.14 | 2.447 | 0.0754 | 0.0133 | yes | | yes |
| rctpa32 | * | trees per acre of western redcedar trees ∃ 32" diameter class | 25 | 2.02 | 0.703 | 81 | 0.85 | 0.205 | 0.0934 | 0.0449 | yes | | yes |
| cnbpa42 | * | basal area ($ft^2$) per acre of conifer trees ∃ 42" diameter class | 25 | 87.40 | 18.788 | 81 | 42.27 | 7.091 | 0.0007 | 0.0135 | no | ndfbpa42 used instead | no |
| cntpa42 | | trees per acre of conifer trees ∃ 42" diameter class | 25 | 4.40 | 0.599 | 81 | 2.91 | 0.451 | 0.0030 | 0.1012 | no | ndftpa42 used instead | no |
| whbpa42 | *** | basal area ($ft^2$) per acre of western hemlock trees ∃ 42" diameter class | 25 | 25.56 | 4.411 | 81 | 6.47 | 1.920 | 0.0001 | 0.0004 | yes | | yes |
| whtpa42 | *** | trees per acre of western hemlock trees ∃ 42" diameter class | 25 | 2.02 | 0.352 | 81 | 0.49 | 0.140 | 0.0001 | 0.0002 | yes | | yes |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| dfbpa42 | * | basal area ($ft^2$) per acre of Douglas-fir trees ∃ 42" diameter class | 25 | 1.78 | 0.858 | 81 | 24.72 | 4.743 | 0.0006 | 0.0354 | yes | | yes |
| dftpa42 | * | trees per acre of Douglas-fir trees ∃ 42" diameter class | 25 | 0.12 | 0.065 | 81 | 1.69 | 0.330 | 0.0002 | 0.0148 | yes | | yes |
| ssbpa42 | | basal area ($ft^2$) per acre of sitka spruce trees ∃ 42" diameter class | 25 | 14.10 | 5.656 | 81 | 2.92 | 1.929 | 0.0002 | 0.0546 | yes | | yes |
| sstpa42 | | trees per acre of sitka spruce trees ∃ 42" diameter class | 25 | 0.60 | 0.215 | 81 | 0.21 | 0.130 | 0.0003 | 0.1894 | yes | | yes |
| rcbpa42 | * | basal area ($ft^2$) per acre of western redcedar trees ∃42" diameter class | 25 | 45.39 | 18.784 | 81 | 6.10 | 1.969 | 0.0634 | 0.0128 | yes | | yes |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| rctpa42 | * | trees per acre of western redcedar trees ∃ 32" diameter class | 25 | 1.58 | 0.595 | 81 | 0.41 | 0.121 | 0.0789 | 0.0143 | yes | | yes |
| **tree-height and broken-top variables:** | | | | | | | | | | | | | |
| swthdi | | average Shannon diversity index, HN, for tree-height classes | 25 | 1.28 | 0.045 | 81 | 1.26 | 0.029 | 0.7979 | 0.7496 | no | *P* > 0.25 | no |
| bpthdi | | average Berger-Parker index, d, for tree-height classes | 25 | 2.56 | 0.142 | 81 | 2.38 | 0.074 | 0.2998 | 0.2354 | yes | | no |
| bttrpa | | broken-top trees per acre | 25 | 3.48 | 0.501 | 81 | 2.60 | 0.338 | 0.0457 | 0.1969 | yes | | no |
| bttr% | | percentage of trees with broken tops | 25 | 10.44 | 1.554 | 81 | 7.43 | 0.956 | 0.0345 | 0.1273 | yes | | no |
| **platform variables:** | | | | | | | | | | | | | |
| bpapltr | *** | basal area ($ft^2$) per acre of platform trees | 25 | 74.08 | 16.514 | 81 | 18.52 | 4.501 | 0.0001 | 0.0009 | yes | | no |
| pltrpa | **** | platform trees per acre | 25 | 5.56 | 0.810 | 81 | 1.47 | 0.286 | 0.0001 | 0.0001 | no | ndfptrpa used instead | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| plpa | ** | platforms per acre | 25 | 16.42 | 3.010 | 81 | 4.82 | 1.405 | 0.0001 | 0.0035 | no | ndfplpa used instead | no |
| qmdpltr | | quadratic mean diameter (in) of platform trees | 23 | 47.28 | 3.039 | 46 | 41.37 | 2.032 | 0.1281 | 0.1073 | no | total sample size < 106 | no |
| whpltrpa | **** | western hemlock platform trees per acre | 25 | 3.94 | 0.706 | 81 | 0.50 | 0.128 | 0.0001 | 0.0001 | yes | | no |
| whplpa | **** | western hemlock platforms per acre | 25 | 9.82 | 1.527 | 81 | 1.61 | 0.587 | 0.0001 | 0.0001 | yes | | no |
| dfpltrpa | | Douglas-fir platform trees per acre | 25 | 0.04 | 0.028 | 81 | 0.64 | 0.140 | 0.0074 | 0.0649 | no | negative correlation not biologically important | no |
| dfplpa | | Douglas-fir platforms per acre | 25 | 0.08 | 0.062 | 81 | 2.51 | 0.829 | 0.0093 | 0.1030 | no | negative correlation not biologically important | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| sspltrpa | * | sitka spruce platform trees per acre | 25 | 0.55 | 0.201 | 81 | 0.06 | 0.039 | 0.0001 | 0.0137 | yes | | no |
| ssplpa | * | sitka spruce platforms per acre | 25 | 3.05 | 1.668 | 81 | 0.08 | 0.055 | 0.0001 | 0.0415 | yes | | no |
| rcpltrpa | ** | western redcedar platform trees per acre | 25 | 1.01 | 0.366 | 81 | 0.16 | 0.049 | 0.0170 | 0.0071 | yes | | no |
| rcplpa | * | western redcedar platforms per acre | 25 | 3.45 | 1.754 | 81 | 0.30 | 0.107 | 0.0146 | 0.0150 | yes | | no |
| **moss, lichen, mistletoe, platform-cover, and limb-size variables:** | | | | | | | | | | | | | |
| moss%p | | average moss coverage (%) on limbs of platform trees | 23 | 58.13 | 5.224 | 46 | 52.76 | 4.581 | 0.6572 | 0.4685 | no | *P* > 0.25; total sample size < 106 | no |
| mossdpp | ** | average depth (cm) of moss on platform trees | 23 | 2.02 | 0.239 | 46 | 1.18 | 0.142 | 0.0076 | 0.0051 | no | total sample size < 106 | no |
| moss%1p | | percentage of platform trees with moss depth ∃ 1 cm | 23 | 51.65 | 7.576 | 46 | 34.89 | 6.011 | 0.0535 | 0.1016 | no | total sample size < 106 | no |
| moss%4p | * | percentage of platform trees with | 23 | 14.26 | 5.271 | 46 | 0.67 | 0.439 | 0.0001 | 0.0241 | no | total sample size < 106 | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| | | moss depth > 4 cm | | | | | | | | | | | |
| lich% | | average lichen coverage (%) on tree limbs | 25 | 19.60 | 4.157 | 81 | 26.17 | 2.476 | 0.1548 | 0.1957 | yes | | no |
| lich%p | | average lichen coverage (%) on limbs of platform trees | 23 | 23.00 | 4.971 | 46 | 27.59 | 4.295 | 0.9746 | 0.5104 | no | *P* > 0.25; total sample size < 106 | no |
| mist | **** | average mistletoe index; rated 0-6 | 25 | 1.24 | 0.216 | 81 | 0.36 | 0.066 | 0.0001 | 0.0001 | yes | | no |
| mistpres | *** | 0 if mist = 0; 1 if mist > 0 | 25 | 0.96 | 0.040 | 81 | 0.42 | 0.055 | 0.0001 | 0.0008 | yes | | yes |
| ms%tr1 | **** | percentage of trees with mistletoe index ∃ 1 | 25 | 37.76 | 5.695 | 81 | 8.28 | 1.596 | 0.0001 | 0.0001 | yes | | no |
| ms%tr4 | **** | percentage of trees with mistletoe | 25 | 14.20 | 3.329 | 81 | 2.52 | 0.664 | 0.0001 | 0.0002 | yes | | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites $n$ | occupied sites $\bar{x}$ | occupied sites SE | unoccupied sites $n$ | unoccupied sites $\bar{x}$ | unoccupied sites SE | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | index ∃ 4 | | | | | | | | | | | |
| plcovpl | | average platform-cover code on platform trees; rated 1-4 | 4 | 2.11 | 0.111 | 23 | 2.27 | 0.121 | 0.5794 | 0.5860 | no | *P* > 0.25; total sample size < 106 | no |
| plcv%tr3 | | percentage of platform trees with platform-cover code ∃ 3 | 4 | 22.25 | 13.677 | 23 | 41.43 | 7.923 | 0.4326 | 0.3466 | no | *P* > 0.25; total sample size < 106 | no |
| llsize | ** | average size (cm) of largest limb on trees | 25 | 9.20 | 0.583 | 81 | 7.32 | 0.266 | 0.0039 | 0.0040 | yes | | no |
| **canopy variables:** | | | | | | | | | | | | | |
| cancov | | average percent canopy cover | 25 | 94.04 | 0.780 | 81 | 94.60 | 0.424 | 0.4073 | 0.5190 | no | *P* > 0.25 | no |
| canlay | | average number of canopy layers | 25 | 2.77 | 0.087 | 81 | 2.52 | 0.091 | 0.0397 | 0.1515 | yes | | no |
| openness | | average accessibility of site to murrelets, rated as 1, 2, or 3 | 25 | 2.32 | 0.092 | 81 | 2.16 | 0.066 | 0.3102 | 0.2372 | yes | | no |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| **platform and diameter-class variables for non-Douglas-fir conifer trees:** | | | | | | | | | | | | | |
| ndfptrpa | **** | non-Douglas-fir platform trees per acre | 25 | 5.52 | 0.806 | 81 | 0.83 | 0.175 | 0.0001 | 0.0001 | yes | | no |
| ndfplpa | **** | non-Douglas-fir platforms per acre | 25 | 16.37 | 2.994 | 81 | 2.31 | 0.686 | 0.0001 | 0.0001 | yes | | no |
| ndfbpa7 | **** | basal area ($ft^2$) per acre of non-Douglas-fir conifer trees ∃ 7" diameter class | 25 | 247.23 | 19.212 | 81 | 105.94 | 10.444 | 0.0001 | 0.0001 | yes | | yes |
| ndftpa7 | * | trees per acre of non-Douglas-fir conifer trees ∃ 7" diameter class | 25 | 88.36 | 6.692 | 81 | 59.26 | 6.204 | 0.0005 | 0.0275 | yes | | yes |
| ndfbpa22 | **** | basal area ($ft^2$) per acre of non- | 25 | 183.73 | 18.486 | 81 | 60.54 | 7.605 | 0.0001 | 0.0001 | yes | | yes |

Appendix A. Univariate statistics for the variables examined for the research sites of the South Coast and Columbia HCP planning units combined (continued).

| variable name | logistic regression significance * #0.05 ** #0.01 *** #0.001 **** #0.0001 | variable definition and units | occupied sites | | | unoccupied sites | | | non-parametric 2-sample Wilcoxon rank-sum test: *P*-value | univariate logistic regression: Wald $X^2$ *P*-value | variable included in multivariate murrelet modeling? | if no, why not? | variable included in FRIS modeling? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *n* | $\bar{x}$ | SE | *n* | $\bar{x}$ | SE | | | | | |
| | | Douglas-fir conifer trees ∃ 22" diameter class | | | | | | | | | | | |
| ndftpa22 | **** | trees per acre of non-Douglas-fir conifer trees ∃ 22" diameter class | 25 | 26.42 | 1.717 | 81 | 11.50 | 1.243 | 0.0001 | 0.0001 | yes | | yes |
| ndfbpa32 | **** | basal area ($ft^2$) per acre of non-Douglas-fir conifer trees ∃ 32" diameter class | 25 | 127.83 | 18.856 | 81 | 32.58 | 5.687 | 0.0001 | 0.0001 | yes | | yes |
| ndftpa32 | **** | trees per acre of non-Douglas-fir conifer trees ∃ 32" diameter class | 25 | 10.48 | 0.937 | 81 | 3.49 | 0.512 | 0.0001 | 0.0001 | yes | | yes |
| ndfbpa42 | *** | basal area ($ft^2$) per acre of non-Douglas-fir conifer trees ∃ 42" diameter class | 25 | 85.63 | 18.876 | 81 | 17.55 | 4.346 | 0.0001 | 0.0002 | yes | | yes |
| ndftpa42 | **** | trees per acre of non-Douglas-fir conifer trees ∃ 42" diameter class | 25 | 4.28 | 0.613 | 81 | 1.22 | 0.279 | 0.0001 | 0.0001 | yes | | yes |

Appendix B. Candidate multivariate models and statistics for selection of the Murrelet Model for the South Coast and Columbia HCP planning units combined.

| model | logit | joint significance of coefficients | | | predictive ability | classification accuracy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0.25 prob. level | | 0.50 prob. level | 0.75 prob. level | |
| | | !2LogL [a] | AIC | $R^2$ [b] | Somer's D | spec. [c] | false! [d] | % correct [e] | sens. [f] | false+ [g] |
| 1 | g($x$) = ! 2.570 + 0.578 ndfptrpa | 73.5 | 77.5 | 0.495 | 0.754 | 90.1 | 8.8 | 87.7 | 44.0 | 21.4 |
| 2 | g($x$) = + 0.919 ! 0.033 dfbpa7 | 68.9 | 72.9 | 0.538 | 0.796 | 82.7 | 5.6 | 84.0 | 0.0 | -- |
| 3 | g($x$) = ! 0.863 ! 0.112 distmw + 0.745 ndfptrpa | 49.7 | 55.7 | 0.699 | 0.883 | 90.1 | 6.4 | 90.6 | 60.0 | 6.3 |
| 4 | g($x$) = ! 2.485 + 0.927 ndfptrpa ! 0.080 dfbpa42 | 52.6 | 58.6 | 0.676 | 0.825 | 87.7 | 7.8 | 89.6 | 64.0 | 0.0 |
| 5 | g($x$) = + 2.172 ! 2.608 planunit ! 0.228 distmw + 0.258 ndfplpa | 42.9 | 50.9 | 0.748 | 0.923 | 85.2 | 6.8 | 89.6 | 60.0 | 6.3 |
| 6 | g($x$) = ! 1.654 ! 0.111 distmw + 0.598 ndfptrpa + 0.234 whtpa32 | 44.3 | 52.3 | 0.738 | 0.906 | 90.1 | 5.2 | 90.6 | 64.0 | 5.9 |
| 7 | g($x$) = + 1.266 ! 2.662 planunit ! 0.226 distmw + 0.233 whtpa32 + 0.227 ndfplpa | 37.9 | 47.9 | 0.783 | 0.939 | 87.7 | 4.1 | 91.5 | 64.0 | 11.1 |
| 8 | g($x$) = + 0.103 ! 2.146 planunit ! 0.159 distmw + 0.231 whtpa32 + 0.616 ndfptrpa | 39.1 | 49.1 | 0.775 | 0.935 | 92.6 | 3.8 | 92.5 | 64.0 | 11.1 |
| 10 | g($x$) = ! 1.604 ! 0.139 distmw + 0.615 whpltrpa + 0.277 whtpa32 + 0.443 rctpa32 | 40.9 | 50.9 | 0.763 | 0.914 | 90.1 | 5.2 | 91.5 | 68.0 | 5.6 |
| 11 | g($x$) = ! 1.524 ! 0.133 distmw + 0.602 whpltrpa + 0.269 whtpa32 + 0.560 rctpa42 | 40.6 | 50.6 | 0.764 | 0.910 | 88.9 | 6.5 | 92.5 | 72.0 | 5.3 |
| 12 | g($x$) = ! 2.423 ! 0.127 distmw + 0.604 whpltrpa + 0.025 whbpa22 + 1.046 rcpltrpa | 40.8 | 50.8 | 0.763 | 0.920 | 87.7 | 6.6 | 92.5 | 64.0 | 5.9 |

[a] !2LogL = !2 log likelihood = likelihood ratio test statistic

[b] $R^2$ = rescaled, or adjusted, logistic $R^2$ (Nagelkerke 1991)

[c] spec. at the 0.25 prob. level = specificity, or the percentage of unoccupied sites correctly classified, assessed at the 0.25 probability cutpoint

[d] false! at the 0.25 prob. level = false negatives, or the percentage of sites classified as unoccupied that are actually occupied, assessed at the 0.25 probability cutpoint

[e] % correct at the 0.50 prob. level = percentage of sites correctly classified at the 0.50 probability cutpoint

[f] sens. at the 0.75 prob. level = sensitivity, or the percentage of occupied sites correctly classified, assessed at the 0.75 probability cutpoint

[g] false+ at the 0.75 prob. level = false positives, or the percentage of sites classified as occupied that are actually unoccupied, assessed at the 0.75 probability cutpoint

Appendix C. Candidate multivariate models and statistics for selection of the FRIS Model for the South Coast and Columbia HCP planning units combined.

| model | logit | joint significance of coefficients | | | predictive ability | classification accuracy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0.25 prob. level | | 0.50 prob. level | 0.75 prob. level | |
| | | !2LogL [a] | AIC | $R^2$ [b] | Somer's D | spec. [c] | false! [d] | % correct [e] | sens. [f] | false+ [g] |
| 1 | g($x$) = ! 2.719 + 0.363 whtpa32 | 81.2 | 85.2 | 0.419 | 0.756 | 85.2 | 9.2 | 81.1 | 24.0 | 25.0 |
| 2 | g($x$) = + 0.919 ! 0.033 dfbpa7 | 68.9 | 72.9 | 0.538 | 0.796 | 82.7 | 5.6 | 84.0 | 0.0 | -- |
| 3 | g($x$) = + 1.304 ! 0.161 distmw | 75.7 | 79.7 | 0.474 | 0.739 | 70.4 | 8.1 | 81.1 | 0.0 | 100.0 |
| 4 | g($x$) = ! 1.246 ! 0.125 distmw + 0.019 ndfbpa22 | 55.5 | 61.5 | 0.653 | 0.895 | 90.1 | 6.4 | 86.8 | 44.0 | 15.4 |
| 5 | g($x$) = ! 0.991 ! 0.159 distmw + 0.029 whbpa22 | 56.8 | 62.8 | 0.643 | 0.874 | 82.7 | 4.3 | 85.8 | 44.0 | 8.3 |
| 6 | g($x$) = + 2.158 ! 0.115 distmw ! 0.025 dfbpa7 | 57.7 | 63.7 | 0.635 | 0.864 | 84.0 | 5.6 | 89.6 | 36.0 | 25.0 |
| 7 | g($x$) = ! 0.513 ! 0.029 dfbpa7 + 0.252 whtpa32 | 58.7 | 64.7 | 0.627 | 0.859 | 85.2 | 4.2 | 84.0 | 44.0 | 21.4 |
| 8 | g($x$) = ! 2.134 ! 0.192 distmw + 0.038 whbpa22 + 0.384 rctpa22 | 45.7 | 53.7 | 0.728 | 0.926 | 88.9 | 6.5 | 85.8 | 60.0 | 11.8 |
| 9 | g($x$) = ! 1.297 ! 0.139 distmw + 0.388 whtpa32 + 0.028 rcbpa7 | 46.7 | 54.7 | 0.721 | 0.913 | 88.9 | 4.0 | 88.7 | 64.0 | 5.9 |
| 10 | g($x$) = ! 0.091 ! 0.123 distmw + 0.306 whtpa32 + 0.269 rctpa22 ! 0.017 dfbpa7 | 44.6 | 54.6 | 0.736 | 0.930 | 87.7 | 6.6 | 86.8 | 60.0 | 16.7 |
| 11 | g($x$) = + 0.889 ! 0.144 distmw + 0.553 whtpa42 + 0.290 rctpa22 ! 0.052 dftpa7 | 47.7 | 57.7 | 0.714 | 0.916 | 91.4 | 3.9 | 89.6 | 60.0 | 21.1 |

Appendix C. Candidate multivariate models and statistics for selection of the FRIS Model for the South Coast and Columbia HCP planning units combined.

| | | joint significance of coefficients | | | predictive ability | classification accuracy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0.25 prob. level | | 0.50 prob. level | 0.75 prob. level | |
| model | logit | !2LogL [a] | AIC | $R^2$ [b] | Somer's D | spec. [c] | false! [d] | % correct [e] | sens. [f] | false+ [g] |
| 12 | g($x$) = ! 3.158 + 0.090 sstpa7 + 0.425 whtpa32 + 0.021 rcbpa22 ! 1.206 dftpa42 | 52.1 | 62.1 | 0.680 | 0.889 | 88.9 | 5.3 | 87.7 | 52.0 | 23.5 |

[a] !2LogL = !2 log likelihood = likelihood ratio test statistic

[b] $R^2$ = rescaled, or adjusted, logistic $R^2$ (Nagelkerke 1991)

[c] spec. at the 0.25 prob. level = specificity, or the percentage of un-occupied sites correctly classified, assessed at the 0.25 probability cutpoint

[d] false! at the 0.25 prob. level = false negatives, or the percentage of sites classified as un-occupied that are actually occupied, assessed at the 0.25 probability cutpoint

[e] % correct at the 0.50 prob. level = percentage of sites correctly classified at the 0.50 probability cutpoint

[f] sens. at the 0.75 prob. level = sensitivity, or the percentage of occupied sites correctly classified, assessed at the 0.75 probability cutpoint

[g] false+ at the 0.75 prob. level = false positives, or the percentage of sites classified as occupied that are actually un-occupied, assessed at the 0.75 probability cutpoint

# Marbled Murrelet
# Forest Habitat Relationships Studies

Results for South Coast, Columbia, OESF, Straits

by Danielle Prenzlow Escene

December 12, 2001

Washington Department of
Natural Resources

# Results for South Coast and Columbia

- For model building, data from the 2 planning units were combined
- 110 sites -- 25 occupied
  - 27 sites high-quality habitat -- 13 occupied
  - 29 sites medium-quality habitat -- 9 occupied
  - 54 sites low-quality habitat -- 3 occupied

# Results for South Coast and Columbia

| data | correlation | variable | occupied | unoccupied | logistic regression P-value |
|---|---|---|---|---|---|
| distance to marine waters | negative | distmw | 8.6 miles | 33.4 miles | 0.0002 |
| western hemlock | positive | whtpa32 | 7.5 trees / acre | 1.9 trees / acre | 0.0001 |
| douglas-fir | negative | dfbpa7 | 23 $ft^2$ / acre | 130 $ft^2$ / acre | 0.0001 |
| platforms | positive | whpltrpa | 3.9 trees / acre | 0.5 trees / acre | 0.0001 |
| mistletoe | positive | mistpres | 96% | 42% | 0.0008 |

# Results for South Coast and Columbia

Murrelet Model

$g(x) = - 1.604 - 0.139\ \text{distmw} + 0.615\ \text{whpltrpa} + 0.277\ \text{whtpa32} + 0.443\ \text{rctpa32}$

- AIC 50.9
- $R^2$ 0.763
- Somer's D 0.914
- False- (0.25) 5.2
- False+ (0.75) 5.6

# Results for South Coast and Columbia

FRIS Model

$$g(x) = -0.0914 - 0.1234\ \text{distmw} + 0.3062\ \text{whtpa32} + 0.2685\ \text{rctpa22} - 0.0166\ \text{dfbpa7}$$

- AIC 54.6
- $R^2$ 0.736
- Somer's D 0.930
- False- (0.25) 6.6
- False+ (0.75) 16.7

# Results for South Coast and Columbia

## LULC Model

$$g(x) = 0.1078 - 0.1235\ \text{distmw} + 0.0029\ \text{whbpa7} + 0.0294\ \text{rcbpa7} - 0.0178\ \text{dfbpa7}$$

## LULC Old Growth Model

$$g(x) = -\ 1.6626 - 0.1449\ \text{elev} + 4.1253\ \text{othog} - 1.1306\ \text{dfog}$$

# Results for South Coast and Columbia

Minimum Model Criteria

- FRIS
  - cnbpa22 $\geq$ 74 $ft^2$
  - AND cntpa22 $\geq$ 14
  - AND cntpa32 $\geq$ 2
- LULC
  - cnbpa7 $\geq$ 135 $ft^2$
  - AND cntpa7 $\geq$ 44 (if allcnbpa7 = pstcnbpa7)
  - AND cnqmd7 $\geq$ 15.5
  - AND origin date < 1950 for $\geq$ 1 species

# Results for South Coast and Columbia

## Threshold Habitat Definition

| | South Coast | Columbia |
|---|---|---|
| Total DNR-managed acres within 66 miles of marine waters | 256,400 | 166,800 |
| no data or not forested | 14,800 | 10,800 |
| has been recently harvested | 26,700 | 24,600 |
| remaining acres | 214,900 | 131,400 |
| not modeled --- did not meet minimum model criteria | 161,900 | 108,100 |
| remaining acres --- modeled --- did meet minimum model criteria | 53,000 | 23,300 |
| marginal habitat --- contains 5% of sites expected to be occupied | 32,500 | 16,700 |
| **reclassified habitat** --- contains 95% of the sites expected to be occupied | 20,500 | 6,600 |
| threshold probability | 0.0205 | 0.0274 |

# Results for OESF and Straits

- For model building, data from the 2 planning units were combined
- 107 sites -- 41 occupied
  - 33 sites high-quality habitat -- 21 occupied
  - 42 sites medium-quality habitat -- 19 occupied
  - 32 sites low-quality habitat -- 1 occupied

# Results for OESF and Straits

| data | correlation | variable | occupied | unoccupied | logistic regression P-value |
|---|---|---|---|---|---|
| within original North Coast planning unit? | positive | nccoast | 73% | 28% | 0.0001 |
| linear feet per acre of water | positive | water | 49 feet/acre | 33 feet/acre | 0.0073 |
| large conifer | positive | cntpa32 | 10.7 trees/acre | 6.2 trees/acre | 0.0001 |
| platforms | positive | ptrpa18 | 10.0 trees/acre | 4.5 trees/acre | 0.0001 |
| mistletoe | positive | mstr1% | 43% | 29% | 0.0082 |

# Results for OESF and Straits

FRIS Model

$g(x) = -4.3940 + 1.4138\ ncoast + 0.00103\ elev + 0.0471\ water1_3 + 0.2249\ cntpa32$

- AIC 104.6
- $R^2$ 0.458
- Somer's D 0.716
- False- (0.25) 7.5
- False+ (0.75) 21.1

# Results for OESF and Straits

LULC Model for Straits

$$g(x) = -7.1477 + 0.00102\ elev + 0.0496\ water1_3 + 0.2169\ cnqmd7$$

LULC Model for OESF

$$g(x) = -8.8550 + 1.7201\ ncoast + 0.00172\ elev + 0.04772\ water1_3 + 0.2897\ cnqmd7$$

# Results for OESF and Straits

Minimum Model Criteria

- FRIS
  - cnbpa22 $\geq$ 50 $ft^2$
  - AND cntpa22 $\geq$ 13
  - AND cntpa32 $\geq$ 1
- LULC
  - cnbpa7 $\geq$ 157 $ft^2$
  - AND cntpa7 $\geq$ 62 for Straits, cntpa7 $\geq$ 43 for OESF
    (if allcnbpa7 = pstcnbpa7)
  - AND cnqmd7 $\geq$ 13.5
  - AND origin date < 1950 for $\geq$ 1 species

# Results for OESF and Straits

## Threshold Habitat Definition for Straits

| | Straits |
|---|---|
| Total DNR-managed acres within 66 miles of marine waters | 116,800 |
| no data or not forested | 5,400 |
| has been recently harvested | 13,700 |
| remaining acres | 97,700 |
| not modeled --- did not meet minimum model criteria | 78,900 |
| remaining acres --- modeled --- did meet minimum model criteria | 18,800 |
| marginal habitat --- contains 5% of sites expected to be occupied | 3,200 |
| **reclassfied habitat** --- contains 95% of the sites expected to be occupied | 15,600 |
| threshold probability | 0.0512 |

# Results for OESF and Straits

## Threshold Habitat Definition for OESF

| | OESF |
|---|---|
| Total DNR-managed acres within 66 miles of marine waters | 271,100 |
| no data or not forested | 4,000 |
| has been recently harvested | 33,400 |
| remaining acres | 233,700 |
| not modeled --- did not meet minimum model criteria | 167,800 |
| remaining acres --- modeled --- did meet minimum model criteria | 65,900 |
| marginal habitat --- contains 5% of sites expected to be occupied | 11,400 |
| **reclassfied habitat** --- contains 95% of the sites expected to be occupied | 54,500 |
| threshold probability | 0.3805 |