Chapter 18

A Landscape-Level Analysis of Marbled Murrelet Habitat in Western Washington

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Abstract: Relationships between landscape-level patterns of forest cover and occupancy by Marbled Murrelets in the state of Washington where state-wide forest-cover information was available were investigated. Using a geographic information system, a 203-hectare circular area surrounding each of 261 previously surveyed locations was delineated. Within each area, we calculated the amount, distribution, and pattern of various classes of late-seral forest. Proportions of old-growth forest and large sawtimber were greater at sites that were occupied by murrelets than at sites where they were not detected. Mean size of patches (contiguous cover) of old growth and large sawtimber were also greater among occupied sites than among detected and undetected sites. On average, old growth and large sawtimber combined comprised about 36 percent of occupied sites (203-ha areas) vs. 30 percent and 18 percent on detected and undetected sites, respectively. Various indices of landscape pattern were less useful in distinguishing these sites, but in general, occupied sites had more complex patterns with more edge, a greater variety of cover types, and more complex shapes (greater lengths of edge relative to area of patches). Broader patterns, evaluated within large river basins, are also described, but lack of consistent survey effort among these basins precluded analyzing rates of occupancy in relation to forest cover at that scale.

Studies of murrelet nesting behavior in the Pacific Northwest have shown that breeding birds select stands of old-growth forest or stands that provide platforms for nests and suitable protection from predators in California (Paton and Ralph 1988), Oregon (Grenier and Nelson, this volume), and Washington (Hamer and Cummins 1990, 1991). All murrelet nests found in these states have been located in old-growth conifer forests (Hamer and Nelson, this volume b). Whereas nesting habitat requirements of murrelets at the individual tree or nest platform and the stand level have been examined in some detail, characteristics of murrelet nesting habitat at the landscape level are less understood (Hamer and Cummins 1990).

Recently-completed studies by Hamer and others (1993) have provided much needed information on suitable nesting habitat characteristics *within* forest stands in Washington that can be used as predictors of murrelet occupancy from ground-based surveys or forest inventories. No studies have as yet considered whether landscape-level characteristics of nesting habitat such as shape, size, or configuration *among* forest stands have predictive capabilities for occupancy by murrelets. To determine if broad-scale patterns of habitat distribution influence murrelet occupancy, we initiated a study of relationships between amount and configuration of habitat and occupancy of murrelets at previously surveyed locations. Information on relationships between habitat characteristics and occupancy by murrelets at broader scales could be of value in planning conservation strategies and guidelines for management at the regional level. Assessments of habitat requirements across all scales — nest, stand, site, and landscape — are necessary to determine the proper mix of management guidelines to assure adequate amounts and configuration of nesting habitat for the murrelet in the Pacific Northwest.

Methods

Analysis of landscape attributes of Marbled Murrelet habitat selection proceeded at two scales. A broad scale analysis within major river basins considered the distribution of potential habitat among land owners (Federal and non-Federal) over the species' range in Washington. A more site-specific analysis considered the influence of landscape characteristics immediately adjacent to survey sites on occupancy status of murrelets. We generated statistical measures for both scales of analysis using Geographic Information Systems (GIS) and landscape pattern programs.

Data Sources

We obtained a database of all murrelet survey locations (through 1992) from the Washington Department of Fish and Wildlife (WDFW). This database was used previously in regional conservation planning efforts for the Northern Spotted Owl, Marbled Murrelet, and other species associated with late-successional forests (Thomas and Raphael 1993). Murrelet survey locations (n = 708) are represented by x,y coordinate locations and associated attributes mapped in GIS form (*fig. 1*). Survey points were coded by the WDFW into five levels of murrelet detection (*table 1*) following protocols and definitions of the Pacific Seabird Group (Ralph and others 1993). Many of the locations were collected before the currently accepted survey protocol was developed. In addition, some of the database records represent multiple sites clustered around a single survey station. For purposes of this analysis, we analyzed only those surveys conducted following protocol standards, and we eliminated any additional multiple sites around a single station. The number of resulting sites were n = 261.

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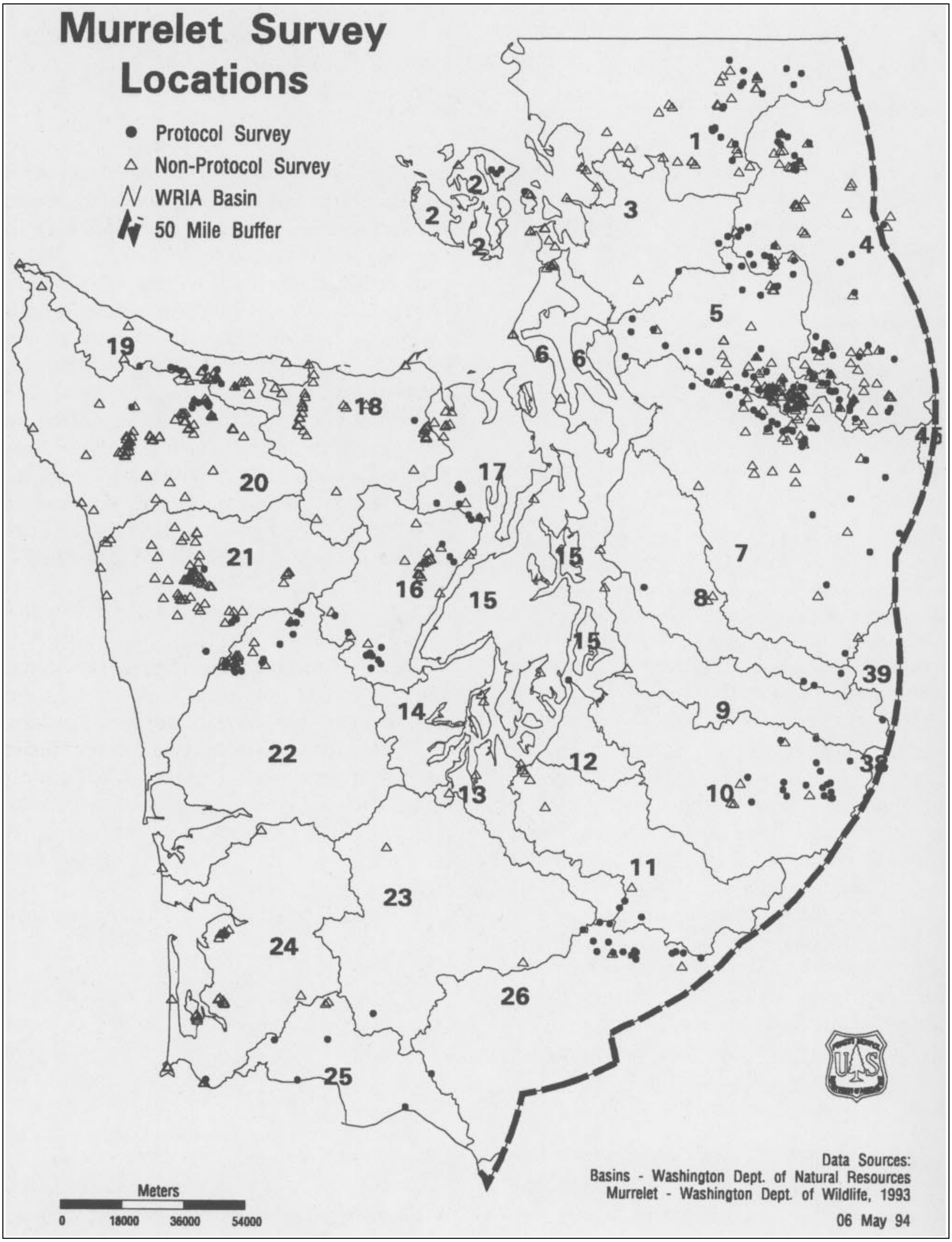

Figure 1—Marbled Murrelet survey locations in western Washington. Murrelet surveys are identified as those conducted following accepted protocols (Ralph and others 1993) or otherwise. The heavy dashed line indicates a 50-mile zone from marine water, an area considered by Washington Department of Fish and Wildlife as the range of the Marbled Murrelet for management purposes. Map is divided into Washington Department of Natural Resources' designated Water Resource Inventory Areas (WRIA) identifying corresponding river basins. Numbers within WRIAs indicate identifications assigned to each WRIA by the Washington Department of Natural Resources.

Table 1—Status of inland sites where Marbled Murrelets have been surveyed in Washington[1], through 1992

Survey code	Status[2]	Number of surveys	
		All surveys	Surveys following protocol standards[2]
1	Active nest	5	0
2	Nest site	19	3
3	Occupied site	141	66
4	Presence	308	108
5	No detection	235	84
Total		708	261

[1]Source: Washington Department of Fish and Wildlife.
[2]Protocol developed by Pacific Seabird Group (Ralph and others 1993). Multiple records from the same station are also excluded. See this document for definition of status categories.

We obtained two maps of forest vegetation from Washington State natural resource databases for this analysis. These maps represent the only sources of forest cover classified across both Federal and non-Federal lands in Washington. A digital map of old-growth and other cover classes was obtained from the WDFW (Eby and Snyder 1990, Collins 1993). This map was updated by Washington Department of Natural Resources (WDNR), Forest Practices Division, using 1991 Landsat Thematic Mapper (TM) imagery to account for timber cutting since 1988 (Collins 1993). The map displays old-growth and other forest conditions in western Washington from the Pacific coast to 50 miles inland on lands below 3200' elevation (*table 2*). The 50-mile limit was defined by WDFW as the inland extent of murrelet activity, even though their database contains three records at greater distances (to 53 miles).

The WDFW forest-cover map was used for both a basin-level analysis and a site-level analysis. We received the data as 1:100,000 vector (polygon) maps. We converted the vector maps into a raster (grid) format using the ARC/INFO GRID software (Environmental Systems Research Institute, Inc., Redlands, CA) at a cell resolution of 50 by 50 meters. We projected the maps from a State Plane coordinate system into a Universal Transverse Mercator (UTM) map projection and joined the individual 1:100,000 scale maps together to form one seamless map that we could use with our existing GIS databases.

We used a second source of vegetation data for basin-level analysis to compare against the WDFW data. The WDNR, Forest Practices Division provided a map of forest seral stages that was developed for the state from 1988 Landsat TM imagery (Green and others 1993). This map is in a raster (grid) format with a cell resolution of 147 by 147 meters and was classified into six classes (*table 3*). To match the WDFW map, we created a murrelet zone map by drawing a boundary 50 miles inland from the Washington Pacific and Puget Sound coasts. This map was used as the geographic extent for all subsequent analyses; maps of vegetation, river basins, and elevation were subset to coincide with this zone map.

We used other GIS data sources in conjunction with the above sources of forest vegetation data to analyze murrelet

Table 2—Washington Department of Fish and Wildlife old-growth classification[1]

Class name	Description
Old growth	Coniferous forest stands, dominant trees > 30" d.b.h.[2], co-dominant trees > 16" d.b.h., 8 or more dominant trees per acre, multi-layered canopy, several snags per acre > 20" d.b.h., many down logs > 24" diameter
Large sawtimber	Coniferous forest stands, dominant trees 20-30" d.b.h., co-dominant trees > 14" d.b.h., 10 or more dominant trees per acre, 2-3 layer canopy, few snags or downed logs
Small sawtimber	Coniferous forest from sapling/pole stands to large sawtimber, < 20" d.b.h., closed single layer canopy, very little dead wood
Other	Non-forested, or non-vegetated. Also includes closed mature deciduous stands
Above 3,200 feet	All areas above 3200 feet were masked out of the updated version of Eby and Snyder's (1990) map
Cleared	Clear-cut since 1988
Partial harvest	Partial harvest since 1988
Salt water	Ocean, Puget Sound, other marine waters
Freshwater	Inland lakes, rivers

[1] Source: Washington Department of Fish and Wildlife, Eby and Snyder (1990), Collins (1993).
[2] D.b.h. = diameter at breast height

Table 3—Washington Department of Natural Resources seral stage classification (Green and others 1993)

Class	Description
Late seral	Coniferous forest stands, > 10 pct tree crown closure in trees > 21" d.b.h., with > 70 pct total crown closure, and < 75 percent of the crown in hardwoods or shrubs
Mid-seral	Coniferous forest stands, < 10 pct tree crown closure in trees > 21" d.b.h., with > 70 pct total crown closure and < 75 percent of the crown in hardwoods or shrubs
Early seral	Coniferous forest stands, 10-70 pct total crown closure and < 75 pct of the crown in hardwoods or shrubs
Cleared/Other	< 10 pct crown closure conifers and/or > 75 pct of the crown in hardwoods or shrubs
Water	Open water bodies
Non-forested	Non-forest land (agriculture, urban, rock, etc.)

occurrence against measures of landscape pattern and composition. A map of major river basins depicting WDNR's Water Resource Inventory Areas (WRIA's) was obtained from WDNR and used to subdivide the vegetation maps into analysis units based on river drainages (*fig. 1*) for the basin-level analysis (Green and others 1993).

Accuracy of Forest-Cover Maps

Forest-cover maps used for the Marbled Murrelet landscape analysis were developed by WDFW and WDNR. The WDFW data set was developed from 1984 and 1986 Landsat Multi-Spectral Scanner (MSS) imagery. This imagery has a minimum spatial resolution of approximately 80 m^2 and collects information in four spectral bands. Digital elevation models were used by WDFW to compensate for shadowing on north-facing slopes (Eby and Snyder 1990). The stated accuracy of this data source for mapping old-growth cover is 80 percent for the Cascades (20 percent error of commission and 7 percent error of omission) and 85 percent for the Olympic Peninsula (15 percent error of commission and 7 percent error of omission) (Eby and Snyder 1990). Errors of commission are areas that are mapped as old-growth forest, for example, but are found to be some other type upon field inspection. Errors of omission are areas of old-growth forest that are missed in the mapping but are found to exist on the ground. Accuracy was assessed by WDFW by checking mapped interpretations against field observations (Eby and Snyder 1990). Other potential errors in this data set are large sawtimber stands mapped as old-growth forest, wind-throw or fire regenerated stands mapped as old growth, and the omission of small, narrow features and stand edges (Eby and Snyder 1990). In addition, areas of mature deciduous forest and sapling conifer are lumped into the "other forest" class, which causes difficultly in determining actual stand boundaries in areas with little older forest, such as in southwest Washington (Snyder, pers. comm.). In addition, because the focus of the mapping effort was to determine areas of old-growth forest, errors associated with other types of land cover were not distinguished.

The WDNR data set was developed from 1991 TM imagery. This imagery has a minimum spatial resolution of 30 m^2 and collects information in seven spectral bands. High altitude aerial photography, field reconnaissance, and WDNR maps were used to guide the classification (Green and others 1993). The stated overall accuracy of this data set within the range of the Marbled Murrelet is 92 percent, with the lowest accuracy in the Puget lowland (87 percent) and the highest in the North Cascades (97 percent) (Green and others 1993). No information is given on errors of commission or omission. Potential confusion in this dataset may be caused by the grouping of stands with >75 percent crown closure in hardwoods and young conifer in the "other forest" category.

GIS Processing

We subdivided both habitat maps (WDFW and WDNR) into WRIA river basins by using ARC/INFO GRID commands for the basin level analysis. Attributes from each basin were then input to the DISPLAY landscape pattern program. DISPLAY is a package of statistical routines that calculates indices of landscape pattern from GIS maps (Flather and MacNeal 1993). Landscape pattern indices calculated by DISPLAY (*table 4*) are based on pattern indices discussed in O'Neill and others (1988), Milne (1991, 1992), and Krummel and others (1987).

For the site-level analysis, we subsetted the WDFW forest condition map into 0.5-mile radius circles around survey locations (*fig. 2*). We calculated indices of pattern on each resulting circular landscape using the FRAGSTATS program (Marks and McGarigal 1993). FRAGSTATS is a set of routines that calculates indices of pattern on landscapes. FRAGSTATS calculates many of the same indices as

Table 4—***Landscape pattern indices output by DISPLAY and used in the basin level analysis***

Pattern index	Possible values[1]	Description
Landscape diversity	0 - ∞	Measures proportion of landscape in different types; 0 = lowest diversity (only 1 type); larger value indicates more diverse landscape
Landscape dominance	0 - ∞	Extent to which 1 or few types dominate the landscape; as value approaches 0, all types are present in equal proportions; max. value depends on number of types in landscape
Landscape contagion	0 - ∞	Extent to which landscape is aggregated or clumped; as value approaches 0, many small patches exist; max. value depends on number of types in landscape
Number of different types	WDFW[2] = 9 WDNR[3] = 6	Number of types possible in landscape, also termed "patch richness"
Proportion of each type in landscape	0 - 1	Percent of total area
Number of patches of each type in landscape	0 - ∞	Count of patches by type
Mean patch size by type	0 - total landscape area	Sum of patch area by type divided by total area
Perimeter/area fractal dimension	1.0 - 2.0	Index of patch edge complexity, contrasts log (patch perim.) with log (patch area)
Grid based fractal dimension	1.0 - 2.0	Index of patch edge complexity, calculated using a grid-cell counting method

[1] Values reported are theoretical limits, not actual ranges.
[2] WDFW = Washington Department of Fish and Wildlife
[3] WDNR = Washington Department of Natural Resources

DISPLAY and also calculates additional landscape-level and patch-level indices (*table 5*). We attempted to use FRAGSTATS for the basin level analysis, but these landscapes were too large to process using this program. We tabulated indices of pattern for each of the 261 circular areas and compared site-level attributes among survey-status attributes (those sites where murrelets were not detected, were detected, or classified as occupied).

We computed additional site-level variables using the GIS to add other environmentally related measures to the multivariate comparison of site-level pattern and occupancy status. Distance to closest coastline (meters) was calculated for each murrelet survey location using the NEAR function in ARC/INFO. This represents a straight-line distance between a survey location and the closest body of salt water.

We identified patch size and type for each survey location by recording the contiguous patch on the overall landscape (whether or not that patch was outside of the 0.5-mi radius circle) directly underneath each survey point. The definition of patch used here differs significantly from the concept of a stand typically used by foresters. In this case, a patch is defined in terms of the GIS map as each unique set of contiguous cells of the same cover class type. Some of these patches can be quite large (up to 25,000 hectares) and should not be considered equivalent to typically defined stands in forest management. Rather, these are areas defined by pixels sharing the same class value.

We determined survey-site elevations by overlaying the map of survey locations on a digital elevation model and interpolating the elevation at each point using GIS operations. United States Geological Survey 1:250,000 scale digital elevation models were used to derive an elevation surface for the state of Washington. These elevation models are a regular (grid) sample of elevations and have a vertical accuracy

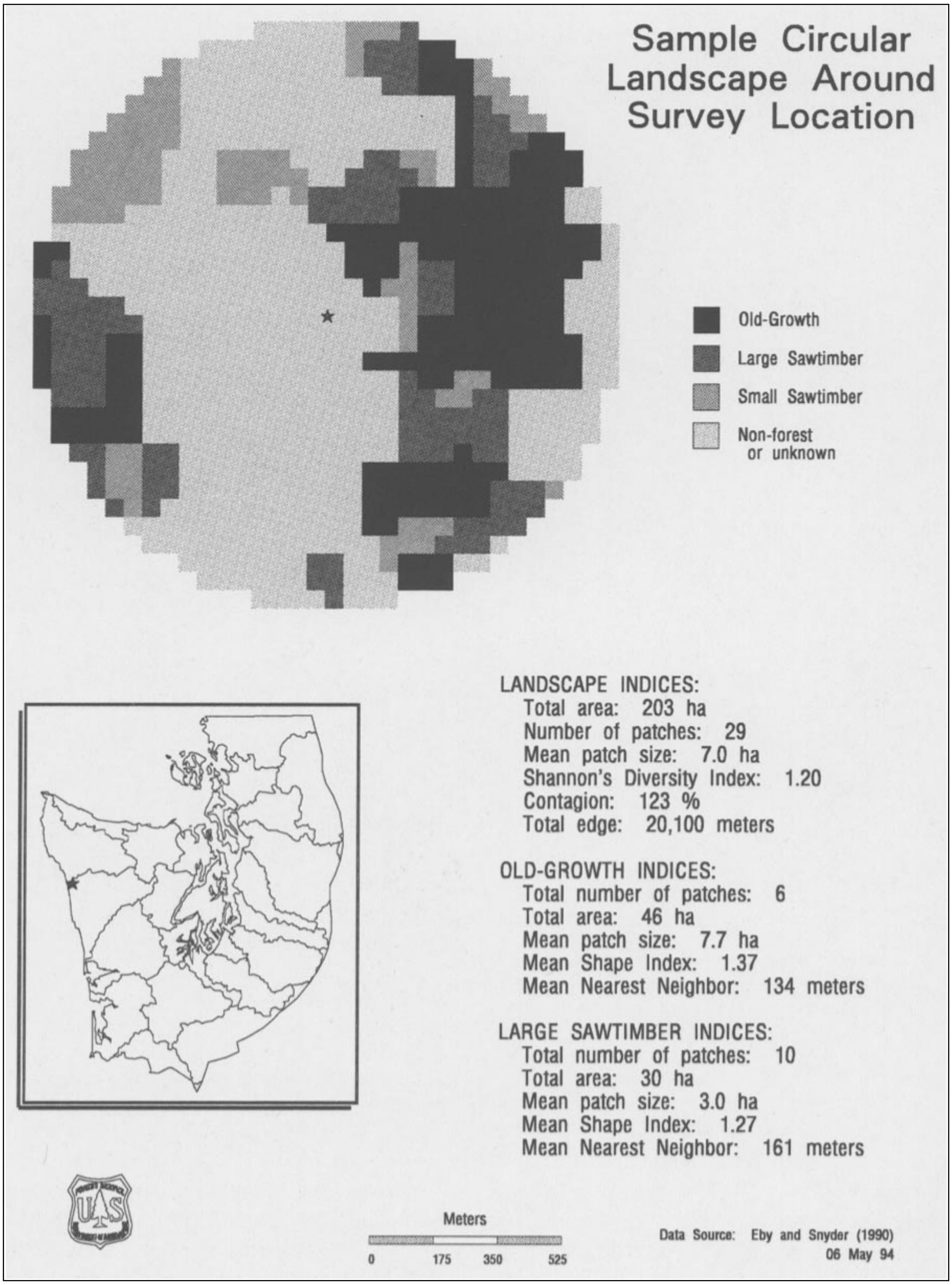

Figure 2—Example of forest cover classification within a 203-ha circular area surrounding a Marbled Murrelet survey location. Forest cover from classification by Washington Department of Fish and Wildlife (Eby and Snyder 1990). See *table 5* for explanation of landscape indices.

Table 5—Landscape pattern statistics output by the FRAGSTATS program and used in the site-level analysis, Washington Department of Fish and Wildlife old-growth data set

Pattern index	Range of values for 203-ha circles (n = 261)	Description
Number of patches	1 - 46	Count of number of patches
Mean patch size	44.1 - 203	Average size (ha) of all patches in landscape
Patch size std dev	0 - 143	Standard deviation of patch sizes in landscape (ha)
Patch size coeff var	0 - 321.81	Coefficient of variation of patch sizes in landscape
Mean shape index	1.06 - 1.98	Average shape index (complexity) of all patches in landscape
Area weighted mean shape index	1.12 - 3.36	Average shape of patches standardized by patch area
Landscape shape index	0.98 - 4.85	Overall complexity of landscape
Mean patch fractal dimension	1.0 - 1.1	Fractal edge complexity for all patches in landscape
Patch richness	1 - 9	Maximum number of different types in landscape
Shannon's diversity index	0 - 1.77	An index of patchiness, dependent on proportion of landscapes of different types
Simpson's diversity index	0 - 0.83	Another index of patchiness, 1 minus the squared sum of the proportion of the landscape in different types
Modified Simpson's diversity index	0 - 1.75	The Simpson index modified by taking the negative log of the sum of landscape proportion of patch types
Shannon's evenness index	0 - 1	Index relating the proportion of landscape in each type to the number of different types
Simpson's evenness index	0 - 1	Index relating 1 minus the proportion of landscape in each type to 1 minus the inverse of the number of different types
Modified Simpson's evenness index	0 -1	Modified evenness index , relates the negative log of squared proportion of landscape in different types to log of the number of types
Mean nearest neighbor	0 - 1304	Average distance (m) to closest patch of similar type
Nearest neighbor std dev	0 - 721	Std. deviation of nearest neighbor distance by type
Nearest neighbor coeff var	0 - 124	Coefficient of variation (m) for nearest neighbor distances
Contagion	0 - 154	Extent to which landscape is aggregated or clumped; as value approaches 0, many small patches exist; maximum value depends on number of types in landscape
Contagion(2)[1]	0 - 80	Extent to which landscape is aggregated or clumped; as value approaches 0, many small patches exist; maximum value depends on number of types in landscape (excludes landscape border)
Total edge	5600 - 27650	Total length of edge (m) between patches of different types

[1] Varies from contagion in that landscape border is excluded.

of (+/-) 30 m (U.S. Geological Survey 1990). The original cell resolution of 90 m was resampled to 200 m to create a statewide elevation grid. Elevations were recorded as height above sea level in meters.

Results

Basin-Level Analysis

Landscape characteristics for the WDFW data by major river basin (*table 6*) show the majority of the basins' area is in the "other forest/unknown" category ($\bar{x}$ = 84 percent). Two basins have 100 percent of their area in this class. Mean proportion of old growth was only 5 percent over all 25 basins, although one basin (number 21) had 21 percent of its area in old growth (*table 6*). Pattern statistics calculated on these basins show a low diversity of types ($\bar{x}$ = 0.57), a high dominance ($\bar{x}$ = 0.94) or influence of one or a few types, and a high contagion ($\bar{x}$ = 4.55) or "clumpiness" in the data (*table 6*).

In contrast, the WDNR seral-stage data (*table 7*) show a more even distribution of classes. Late-seral classes averaged 15 percent of the basin's area, and had higher mean patch sizes ($\bar{x}$ = 69 ha) than the mean patch sizes of old growth from the WDFW data set (10 ha) (*table 6*). Pattern indices show the WDNR seral stage data by basin as relatively less "clumpy" ($\bar{x}$ contagion = 5.58), and with a greater diversity ($\bar{x}$ = 1.40) than the WDFW classification. Basins classified using the WDNR seral stages also have a greater proportion of area in mid-seral ($\bar{x}$ = 27 percent) and cleared ($\bar{x}$ = 32 percent) classes.

The range outlined in *figure 1* encompasses about 5.2 million ha, over half of which is privately managed (2.9 million ha, 56 percent). Another 0.6 million ha (12 percent) are managed by the Washington Department of Natural

Table 6—Water Resource Inventory Area (WRIA) basin characteristics: Landscape pattern indices and proportion of basin area in cover classes, Washington Department of Fish and Wildlife cover classification (Eby and Snyder 1990, Collins 1993)[1]

WRIA Basin	Diversity	Dominance	Contagion	Old growth	Mean patch size (ha) old growth	Large sawtimber	Small sawtimber	Cleared/ thinned	Other forest/ unknown
1	0.31	1.30	4.61	0.01	6.5	0.01	0.03	0.01	0.94
2	0	0	0.01	0	0	0	0	0	1.00
3	0.27	1.34	4.63	0.01	4.2	0.01	0.03	0.01	0.95
4	0.74	0.86	4.62	0.08	12.7	0.04	0.06	0.01	0.80
5	0.85	0.76	4.59	0.08	10.9	0.05	0.09	0.03	0.76
6	0	0	0.01	0	0	0	0	0	1.00
7	0.84	0.77	4.98	0.05	7.9	0.09	0.07	0.02	0.77
8	0.36	1.25	4.70	0.02	6.4	0.02	0.03	0.01	0.92
9	0.56	1.05	4.65	0.03	6.0	0.03	0.05	0.02	0.87
10	0.43	1.18	4.74	0.02	8.6	0.01	0.03	0.02	0.91
11	0.61	1.18	6.65	0.04	9.9	0.03	0.06	0.02	0.85
12	0.56	1.05	4.19	0.05	7.3	0.02	0.03	0.02	0.87
13	0.40	1.39	5.96	0.01	2.8	0.01	0.04	0.03	0.91
14	0.46	1.15	4.58	0	1.8	0.02	0.07	0.02	0.89
15	0.66	0.95	4.46	0.03	5.5	0.05	0.08	0.01	0.83
16	1.13	0.48	4.95	0.17	22.8	0.12	0.11	0.01	0.60
17	1.02	0.77	6.33	0.09	10.8	0.07	0.13	0.02	0.69
18	1.00	0.79	6.65	0.16	29.0	0.07	0.09	0.01	0.68
19	0.90	0.71	4.61	0.06	9.8	0.04	0.14	0.03	0.73
20	1.02	0.59	4.80	0.16	28.6	0.05	0.11	0.02	0.67
21	0.96	0.65	4.92	0.21	50.9	0.04	0.06	0.02	0.68
22	0.60	1.01	4.77	0.04	15.3	0.02	0.07	0.02	0.85
23	0.29	1.32	4.39	0	2.5	0.01	0.04	0.01	0.94
24	0.16	1.45	4.22	0	1.7	0	0.02	0	0.97
25	0.42	1.19	4.45	0	2.2	0.02	0.06	0.02	0.90
26	0.31	1.30	4.46	0.01	4.5	0.01	0.02	0.02	0.94
Mean	0.57	0.94	4.55	0.05	10.4	0.03	0.06	0.02	0.84
Std. dev.	0.33	0.39	1.53	0.06	11.6	0.03	0.04	0.01	0.12

[1] See *figure 1* for location of each basin; table excludes fragments of WRIA basins 38, 39, and 45 along western boundary of range.

Table 7—Water Resource Inventory Area (WRIA) basin characteristics: landscape pattern indices and proportion of basin area in cover classes, Washington Department of Natural Resources seral stage data (Green and others 1993)[1]

WRIA Basin	Diversity	Dominance	Contagion	Late seral	Mean patch size (ha) LS[2]	Mid-seral	Early seral	Cleared	Water	Other/non-forest
1	1.55	0.24	6.06	0.16	88.6	0.13	0.09	0.31	0.01	0.30
2	1.44	0.35	4.67	0.02	10.2	0.37	0.06	0.27	0.04	0.23
3	1.44	0.35	6.20	0.03	41.8	0.15	0.10	0.36	0.03	0.34
4	1.38	0.41	6.00	0.43	149.0	0.15	0.01	0.26	0.02	0.13
5	1.48	0.31	5.81	0.26	117.7	0.23	0.05	0.33	0	0.11
6	1.29	0.50	5.27	0	4.6	0.15	0.07	0.43	0.02	0.33
7	1.54	0.26	5.53	0.24	70.5	0.25	0.05	0.31	0.01	0.14
8	1.46	0.33	6.26	0.05	43.4	0.19	0.03	0.21	0.08	0.44
9	1.44	0.35	5.73	0.11	34.4	0.24	0.03	0.28	0.01	0.34
10	1.48	0.31	6.04	0.20	97.1	0.27	0.02	0.29	0.01	0.20
11	1.43	0.36	6.07	0.07	162.6	0.36	0.06	0.35	0.01	0.15
12	1.05	0.56	4.17	0	0.0	0.14	0.01	0.23	0.02	0.60
13	1.33	0.28	3.77	0	0.0	0.29	0.08	0.36	0.01	0.26
14	1.41	0.38	5.36	0.05	108.5	0.40	0.09	0.35	0.03	0.09
15	1.33	0.28	3.35	0	0.0	0.43	0.09	0.26	0.02	0.19
16	1.42	0.37	5.57	0.47	126.4	0.15	0.04	0.21	0.01	0.12
17	1.50	0.29	5.20	0.20	72.5	0.27	0.06	0.36	0.01	0.10
18	1.38	0.41	5.49	0.46	202.0	0.10	0.04	0.17	0	0.23
19	1.22	0.57	5.91	0.14	38.5	0.46	0.01	0.35	0.02	0.02
20	1.49	0.30	5.99	0.29	84.9	0.28	0.08	0.28	0.02	0.06
21	1.48	0.31	5.70	0.38	150.8	0.22	0.23	0.12	0.01	0.05
22	1.32	0.47	5.71	0.17	34.4	0.33	0.02	0.40	0.01	0.07
23	1.28	0.51	5.92	0	12.8	0.34	0.09	0.39	0	0.17
24	1.25	0.54	5.52	0.03	10.7	0.44	0.05	0.37	0.01	0.10
25	1.34	0.45	6.07	0	11.4	0.34	0.12	0.41	0.03	0.10
26	1.38	0.41	6.33	0.02	51.0	0.27	0.10	0.45	0.02	0.13
Mean	1.40	0.37	5.58	0.15	69.0	0.27	0.0	0.32	0.02	0.18
Std. dev.	0.09	0.09	0.72	0.16	57.8	0.10	0.05	0.08	0.02	0.11

[1] See *figure 1* for locations of each basin; table excludes fragments of WRIA basins 38, 39, and 45 along western boundary of range.
[2] LS = late seral

Resources and 0.9 million ha (18 percent) by the National Park Service. Based on the WDNR classification, private and state lands are predominantly mid-seral and other forest, whereas National Forest and Park Service lands are predominantly late-seral (*fig. 3*). An analysis based on the WDFW classification (*fig. 4*) shows a similar distribution of forest age classes among land managers. However, the amount of late-seral forest (old growth and large sawtimber) is much lower than that estimated from the WDNR classification. This difference reflects the elevation cutoff (3200 feet) used by the WDFW (*table 2*).

The WRIA basin is too large an area relative to the number of surveys conducted within each basin (*fig. 1*) to detect relationships among landscape pattern variables and detection rate. Analysis of smaller basins with greater sampling intensities may help to clarify what, if any relationship exists between broad landscape pattern and likelihood of murrelet detection. However, the description of amount and configuration of forest vegetation within river basins given here may help to determine those areas in Washington that are in need of closer examination at finer scales of analysis and with greater surveying effort.

Site-Level Analysis

Stand Characteristics

Most (59 percent) of the Marbled Murrelet survey sites were centered within the various other forest categories (WDFW forest-cover map). Most of the remaining sites were located within old-growth stands (*table 8*). The proportion of sites within the various forest-cover classes differed significantly among detection classes (chi-square = 40.2, P = 0.000). Patch area did not differ significantly among occupied, detected or undetected sites, nor did it differ among forest-cover classes (*table 9*). Survey sites averaged 30.6 km from nearest saltwater; mean distance did not significantly vary among occupied, detected, and un-

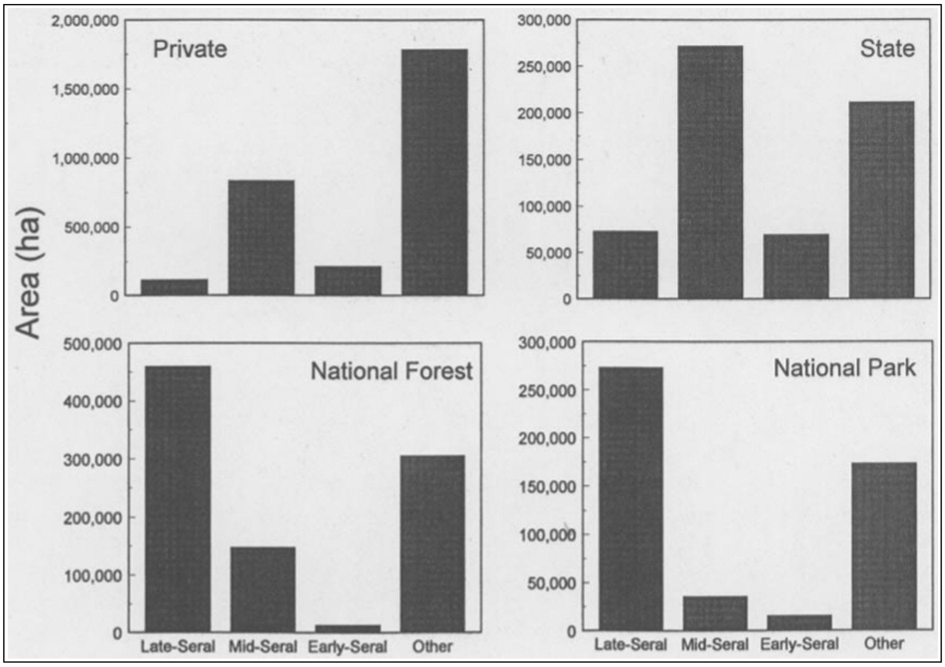

Figure 3—Classification by Washington Department of Natural Resources of the distribution of forest-cover classes among Federal, state, and private lands within the range of the Marbled Murrelet in Washington (Green and others 1993). “Other” includes all remaining cover classes from *table 3*. See *figure 1* for map.

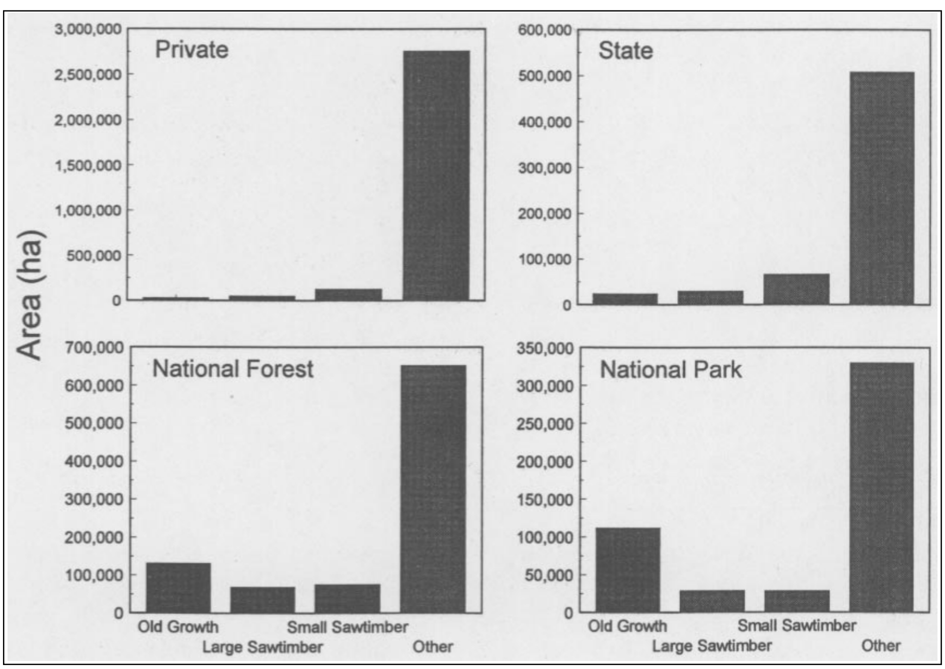

Figure 4—Classification by Washington Department of Fish and Wildlife of the distribution of forest-cover classes among Federal, state, and private lands within the range of the Marbled Murrelet in Washington (Eby and Snyder 1990, Collins 1993). “Other” includes all remaining cover classes from *table 2*. See *figure 1* for map.

Table 8—Frequency of Marbled Murrelet survey sites among forest-cover classes by detection class, western Washington

	Detection class			
Forest-cover class[1]	Occupied	Detected	Undetected	Total
Old growth	27	17	8	52
Large sawtimber	9	17	4	30
Small sawtimber	10	10	5	25
All other classes	23	64	67	154
Total	69	108	84	261

[1]Cover classes from Washington Department of Fish and Wildlife (Eby and Snyder 1990, Collins 1993), updated by Washington Department of Natural Resources (Collins, pers. comm.). See *table 2* for cover class descriptions.

Table 9—Analysis of variance of patch size in relation to survey status (occupied, detected, unoccupied) and cover class (old-growth, large sawtimber, small sawtimber) of Marbled Murrelet survey sites, western Washington[1]

Source of variation	*df*	*F*	Significance
Status	2	0.40	0.671
Cover class	2	2.35	0.100
Interaction	4	0.69	0.603

[1]Patch area was estimated for contiguous cover surrounding each survey site as classified from cover maps of Eby and Snyder (1990), Collins (1993).

detected sites (31.2, 30.3, 30.6 km, respectively). Elevation of survey sites averaged 482 meters and mean elevation did not significantly differ among occupied, detected, and undetected sites (520, 467, and 473 meters, respectively). Maximum elevation for all surveys was 1,455 meters, minimum elevation was sea-level (0 meters).

Site Characteristics

We investigated two general characteristics in describing the 203-ha area surrounding each site—amount and pattern of forest-cover classes (WDFW forest-cover map). The relative amounts of each of four general forest cover classes varied significantly among each of the detection classes (*table 10*). Over the entire sample of 261 survey sites, old-growth forest averaged 18 percent of the 203-ha landscape surrounding each site. Percentages of large sawtimber, small sawtimber and other averaged 9 percent, 11 percent, and 61 percent, respectively. Percentage of old-growth forest was significantly greater on occupied sites compared to undetected sites (*table 10*). Similarly, the proportion of large sawtimber was greater on occupied sites than on undetected sites. Proportion of other forest land was greater on undetected sites than occupied sites.

Many of the landscape pattern indices are correlated. Rather than report estimates for each of the 21 different indices we computed, we used principal components analysis to produce composite landscape shape index variables. This analysis resulted in four factors that contained about 88 percent of the variation inherent in the original set of variables. The first factor contained about 61 percent of the variation in the original variables and was used in subsequent analyses. This composite factor was highly correlated ($r > 0.80$) with 10 of the original variables. Values of this composite index increased with increasing number of patches, landscape shape index, Shannon's diversity index, Simpson's diversity index, modified Simpson's density index, Shannon's and Simpson's evenness indices, modified Simpson's evenness index, contagion index, and total edge. Mean values of this composite landscape pattern index (*table 11*) varied significantly among detection classes ($F = 14.88$, $P = 0.000$), and was significantly greater among occupied sites than in either of the other detection classes (planned contrast, $t = 5.17$, $P = 0.000$).

We also investigated the influence of shape and size of old-growth and large sawtimber patches (*table 11*). These attributes are correlated with the amount of each cover

Table 10—Forest cover (mean percentage) within 203-ha circles centered on Marbled Murrelet survey sites, western Washington[1]

	Forest-cover class[2]											
	Other forest			Small sawtimber			Large sawtimber			Old growth		
Status	$\bar{x}$	min	max	$\bar{x}$	min	max	$\bar{x}$	min	max	$\bar{x}$	min	max
Occupied[3]	51.7A	2.5	100	12.1A	0	46.7	11.4A	0	55.4	24.7A	0	76.3
Detected	57.8AB	4.4	100	12.1A	0	51.5	10.3AB	0	70.3	19.8AB	0	73.9
Undetected	72.4B	0	100	9.6A	0	61.7	6.4B	0	91.8	11.6B	0	54.2

[1] Letters indicate results of pairwise comparisons among means; experiment-wise $P \leq 0.05$, using Tukey's test. Means with same letter (within columns) did not differ significantly.

[2] Forest cover map from Washington Department of Fish and Wildlife (Eby and Snyder 1990, Collins 1993).

[3] Includes status codes 1, 2, and 3 from *table 1*.

Table 11—Attributes of forest cover within 203-ha circles centered on Marbled Murrelet survey sites, western Washington

Site attribute	Detection class: Occupied	Detection class: Detected	Detection class: Undetected	Univariate significance[1]	Correlation with discriminant function
Old growth:					
Proportion	0.247	0.198	0.116	0	0.90
Mean patch size	18.600	13.900	8.500	0	0.96
Mean shape index	1.500	1.400	1.100	0	0.65
Large sawtimber:					
Proportion	0.115	0.103	0.064	0	0.73
Mean patch size (ha)	4.100	3.800	4.100	0	0.58
Mean shape index	1.300	1.200	1.000	0	0.69
Small sawtimber:					
Proportion	0.121	0.121	0.096	0	0.49
Other forest proportion[2]	0.517	0.578	0.723	0	---[2]
Landscape pattern index	0.413	0.062	-0.419	0	0.76
Sample size	69	108	84		

[1]Significance of univariate analysis of variance, based on transformed variables where appropriate.
[2]Variable was not included in the discriminant analysis.

type; as the amount increases, the values of the pattern indices increase. Therefore, using planned contrasts we found that mean patch size of old-growth (t = 4.67, P = 0.000) and large sawtimber (t = 3.03, P = 0.003) was greater among occupied sites than among detected and undetected sites and that mean shape index was greater as well (t = 3.64, P = 0.000 for old growth; t = 4.24, P = 0.000 for large sawtimber).

To evaluate the relative contributions of the amounts of various forest cover classes and the pattern of those classes over the 203-ha landscapes, we used discriminant analysis to compare attributes among the three detection classes. For this analysis, we used all of the attributes listed in *table 11* with the exception of proportion other forest (because all of the proportions sum to 1.00 within any 203-ha area, the proportion of other forest is directly implied by the sum of the remaining proportions). This analysis resulted in a single significant discriminant function (chi-square = 48.8, df = 16, P = 0.000); each detection class differed significantly from each of the other classes. The variables that best discriminated among the classes were old-growth proportion, landscape pattern index, old-growth patch size, large sawtimber proportion, and large sawtimber shape index (*table 11*). Although the average differences among the detection classes were significant, there was considerable overlap among the sites; R^2 was only 17.5 percent and only about 44 percent of the sites could be correctly classified based on the discriminant function (*table 12*).

Discussion

Landscape-level analysis of amount and configuration of forest vegetation can be a valuable tool for assessing the nesting habitat requirements of murrelets. However, the scale of analysis influenced our ability to predict occupancy in a given landscape. We found the forest-cover attributes within a 203-ha circular area surrounding each survey location were useful predictors of occupancy by the Marbled Murrelet. Both the amount and the pattern of various forest-cover classes differ among occupied, detected, and undetected 203-ha sites. Given the strong correlations among the forest pattern and amount attributes, the variables describing the amounts of the various cover classes are probably most useful in describing Marbled Murrelet habitat as it occurs in this sample from western Washington. Among the forest-cover classes, old-growth cover, and to a lesser extent, large sawtimber, seem best to predict murrelet occupancy. Sites occupied by murrelets, as evidenced by nests or circling behavior, have a higher proportion of these mature forest classes than do non-occupied sites.

More definitive analyses must await completion of additional surveys. The present database is not the result of a survey designed to understand the statewide distribution of the species. Instead, it is heavily influenced by one intensive study (Hamer and Cummins 1990, 1991) and by sites selected at the location of proposed timber sales. Therefore, the set of survey sites we analyzed may be biased. Until more systematic

Table 12—Predicted and observed classification of detection-status of Marbled Murrelet survey locations based on discriminant analysis using forest-cover attributes within 203-ha acres surrounding each site, western Washington

	Predicted status (pct)[1]			
Actual status	Occupied[2]	Detected	Undetected	Locations
Occupied[2]	71	16	13	69
Detected	49	21	30	108
Undetected	29	19	52	44

[1] Predicted from discriminant function (see *table 11*).
[2] Includes status codes 1, 2, and 3 from *table 1*.

surveys are completed, it will be difficult to judge the reliability of estimates of habitat selectivity.

Until such surveys are completed, we offer the following tentative guidelines. For purposes of identifying potential habitat, areas composed of at least 35 percent large sawtimber and old-growth forest (as classified by WDFW) are most likely to be occupied. Landscapes on the order of 200-300 ha should be examined to determine proportion of potential habitat.

In evaluating areas of about 200 ha, we conclude that the amount and configuration of old-growth or large sawtimber forest (Eby and Snyder 1990) are important components of murrelet nesting requirements, as has been previously demonstrated in analyses at the stand (Hamer 1993) and the nest level (Hamer and Cummins 1991) in Washington. Quantifying the amount and pattern of late-seral forests in larger landscapes can help to determine areas that may be at risk to loss of suitable nesting habitat for murrelets. Further landscape analysis at a basin level between the small landscapes and broad river basins we used here may help to determine the appropriate configurations and amounts of nesting habitat necessary to support murrelets, assuming adequate surveying has been conducted. This information would be a useful component of local or regional conservation planning for the murrelet and other old-growth associated species.

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