B. Marbled Murrelet

Species Ecology/Literature Review

INTRODUCTION

In October 1992, the U.S. Fish and Wildlife Service listed the marbled murrelet, a Pacific seabird, as threatened, due primarily to loss of nesting habitat and secondarily to loss of the bird in gill nets. The state of Washington has also listed the marbled murrelet as threatened.

TAXONOMY

The marbled murrelet belongs to the family Alcidae, which consists of 22 species divided into 12 genera worldwide (DeSanto and Nelson 1995). Other familiar members of this marine family of diving birds include murres, puffins, guillemots, auks, and auklets. There are two subspecies of marbled murrelet, the North American race, *Brachyramphus marmoratus marmoratus,* and the Asian race, *Brachyramphus marmoratus perdix*, commonly known as the long-billed murrelet. Recent evidence indicates that the long-billed murrelet may be a distinct species (Friesen et al. 1994). A related North American murrelet is the Kittlitz's murrelet (*Brachyramphus brevirostris),* whose habitat is strongly associated with glacial ice (Ralph et al. 1995a).

PHYSICAL CHARACTERISTICS

The marbled murrelet is a medium-size seabird (approximately 9.5 inches in length) with a heavy compact body, short tail and neck, and short stubby wings. Males and females have identical plumage, though their plumages vary seasonally (Marshal 1989). Adult marbled murrelets have an alternate plumage in summer and a basic plumage in winter (Carter and Stein 1995). The alternate plumage coincides with the breeding season when the birds are blackish-brown on the upper part of their body with rust coloring at the tips of the back feathers. The sides of their heads, the sides and front of their necks, and their underparts have white feathers with broad dark-brown margins (Kozlova 1957). This pattern gives the murrelet its "marbled" look, which most likely protects breeding birds from detection by predators in forested environments (Binford et al. 1975; Nelson and Hamer 1995a). Adults in the winter have a brownish-gray upper body, a white lower body, and a white band below the neck. Fall juveniles have a brownish mottling on their chest, breast, and sides and are otherwise similar to winter adults. By winter, juveniles are indistinguishable from adults (Marshal 1989; Carter and Stein 1995).

Distinguishing characteristics of murrelets on the water include an upward pointing tail and bill (Marshal 1989; Nelson 1992). The murrelet's body shape facilitates underwater swimming, but its short wings require that it fly faster than 50 miles per hour to avoid stalling.

GEOGRAPHIC DISTRIBUTION

Marbled murrelets occur in North America along 6,500 miles of coastline between the Bering Sea, Alaska, and central California. The geographic center of their distribution is in the northern portion of southeast Alaska, near the Alexander Archipelago (Ralph et al. 1995a; see Map III.2). Populations are fairly large and continuous between the coastline just west of Kodiak Island and the southern edge of British Columbia, with the largest concentrations occurring between the southern part of southeast

Alaska and Prince William Sound (Ralph et al. 1995a). Distribution becomes more disjunct at the southern end of the marbled murrelet's range. In Washington, Oregon, and California, there are distinct gaps between breeding populations. These gaps are thought to be a result of logging activity that has removed nesting habitat, i.e., old-growth and late successional forest (Carter and Erickson 1992; Leschner and Cummins 1992; Nelson et al. 1992; Ralph et al. 1995a). See section below on population status and demography for numbers of murrelets in each portion of their range.

Distribution of the murrelet population at sea during breeding seasons appears to be determined by the distribution and accessibility of adjacent old-growth and late successional forest (Ralph et al. 1995a). The correlation between old-growth and offshore murrelet populations has been circumstantially established between California and southwest Washington. During the breeding season, the largest concentrations of marbled murrelets have been observed at sea adjacent to areas where nesting habitat was available (Sowls et al. 1980; Nelson et al. 1992). The fact that marine productivity is high along this entire coast during the breeding season suggests that foraging habitat is not a limiting factor (Ralph et al. 1995a). The relation between occurrence of murrelets at sea and onshore late successional and old-growth habitat has been more difficult to observe in northern Washington, British Columbia, and Alaska because the coastline is more complex, more old growth remains, and extensive survey efforts have not been made (Ralph et al. 1995a).

Marbled murrelets nest along the coast and in late successional and old-growth forests. The maximum distance inland murrelets have been found is approximately 66 miles in Oregon. In Washington, the detection farthest inland has been at 52.25 miles (Hamer 1995). Most detections of murrelets have been within 40 miles of marine waters (Hamer 1995; Miller and Ralph 1995). However, their inland nesting distribution is not fully known because survey effort is inconsistent in areas greater than 40 miles from saltwater (Hamer 1995; Miller and Ralph 1995; Ralph et al. 1995a).

BEHAVIOR

The following section briefly reviews recently published literature on marbled murrelet behavior and nesting ecology. For a more detailed treatment of foraging behavior and food habits, see Strachen et al. (1995), Burkett (1995), and Hunt (1995). For a more detailed treatment of nesting ecology and behavior, see Nelson and Hamer (1995a).

Foraging

The marbled murrelet feeds in near-shore ocean waters and in inland saltwater bays, sounds, and inland passageways. It also occurs occasionally on large freshwater lakes, though its foraging habits there have not been documented (Marshal 1989). Murrelets feed on marine invertebrates and small fish traveling in schools. Euphasids and mysids (invertebrates) are dominant prey items in the winter and spring, and small fish such as sand lance, herring, anchovy, and sea perch are more important during the breeding season (Burkett 1995). Interannual changes in the marine environment can result in major changes in prey consumption (Burkett 1995).

Marbled murrelets dive to catch prey (Ashmole 1971). They are most often observed to forage singly or in pairs in a band between approximately 328 and 2,200 yards offshore (Strachen et al. 1995). Murrelets have been observed farther than 2,200 yards offshore, but in much lower numbers (Sealy 1975; Ainely et al. 1995; Piatt and Naslund 1995; Ralph and Miller

1995). Strachen et al. (1995) suggest that murrelets dive simultaneously when foraging in pairs for efficiency. Larger foraging flocks occur in the northern part of the murrelet's range than in the southern portion (Carter 1984; Carter and Sealy 1990). Murrelets forage at all times of day but most actively during the morning and late afternoon. They forage at night as well, possibly when there is enough ambient light to allow them to locate prey (Strachen et al. 1995) and to take advantage of fish that feed near the surface at night (Carter and Sealy 1987, 1990). Nelson and Hamer (1995a) hypothesize that adults may forage at night in order to make dawn feeding flights to nestlings.

Marbled murrelets forage in pairs or small single-species flocks in exposed ocean waters but in mixed-species flocks in protected waters. Glaucous-winged gulls *(Larus glaucescens)*, Bonaparte's gulls *(Larus philadelphia)*, pigeon guillemots (*Cepus columba)*, common mergansers *(Mergus merganser)*, and pelagic cormorants *(Phalacrocorax pelagicus)* join foraging murrelets after murrelets drive jumping schools of sand lance and herring to the surface (Mahon 1992; Hunt 1995). Mixed-species foraging generally occurs in the northern part of the murrelet's range (Stachen et al. 1995). The reason for mixed-species versus monospecific foraging is unknown (Hunt 1995).

Nesting

Murrelets are the only member of the Alcidae family that nests in trees (Nelson 1992; Nelson and Hamer 1995a). Murrelets do not build nests but use large limbs covered with a thick layer of moss or duff, or use mistletoe brooms or other deformities that create a sufficiently wide and flat space. They nest almost exclusively in inland mature and old-growth coniferous forests. In Alaska, beyond the extent of coastal coniferous forests, they nest on the ground where trees are absent. There is also some ground nesting at or near the tree line (Piatt and Ford 1993).

Courtship occurs at sea. It is believed that pairs visit the nest stand to copulate, form and maintain pair bonds, and select nest sites before laying an egg (Nelson and Hamer 1995a).

The marbled murrelet nesting season varies in length and by starting and ending dates in different parts of its range. Hamer and Nelson (1995a) constructed nesting chronologies based on 86 breeding records from California (n = 25), Oregon (n =1 3), Washington (n = 13), British Columbia (n = 23), and Alaska (n = 12). In Washington, the breeding period is estimated to be 124 days long, with incubation occurring between April 26 and July 30 and nestling (the period after the chick has hatched and before it leaves the nest) occurring between May 26 and August 27. They estimated a 118-day breeding period in British Columbia in which incubation started on May 2 and ended July 4. The nestling period began June 1 and ended by August 30. The breeding season in Alaska was estimated to be only 106 days long. Incubation occurred between May 14 and July 30 and nestling occurred between June 13 and August 27. Hamer and Nelson found the nesting season decreased as they went north in the murrelet's range.

Murrelets have been observed to lay one egg per nesting attempt. Incubation lasts 27-28 days (Sealy 1974, 1975; Simons 1980; Hirsch et al. 1981; Carter 1984). Both the female and the male share incubation responsibilities, with one brooding the egg while the other forages. Incubation shifts can last up to 24 hours. Murrelets will leave the egg unattended for three to four hours (Nelson and Hamer 1995a p. 59). This may be a strategy to maximize forage time and accumulate energy reserves, as similar behavior for these purposes has been observed in other seabirds (Nelson and Hamer 1995a).

Murrelet pairs exchange incubation shifts from 82 minutes before to one minute after dawn in Alaska, Oregon, and California (n = 12 nests), but later on rainy or overcast days (Nelson and Hamer 1995a). No incubation exchanges have been observed in Washington or British Columbia.

Murrelet chicks are born with downy feathers. Juvenile plumage begins to develop under the down before they are 26 days old. The chick removes any remaining down 12-48 hours prior to leaving the nest. Chicks fledge at 30-40 days. Their first flight is believed to be directly to the ocean (Sealy 1975; Quinlan and Hughes 1990; Hamer and Cummins 1991).

Murrelet chicks appear to be inactive for most of the time they are on the nest until two days prior to fledging. Researchers have observed chicks (n = 8 nests) sleeping or remaining motionless 80-94 percent of the time while on the nest (Hamer and Cummins 1991; Naslund 1993; Nelson and Hamer 1995a). Chick activity increases markedly on the two evenings prior to fledging (Hamer and Cummins 1991; Singer et al. in press), when they pace continually and rapidly on the nest platform, flap their wings frequently and vigorously, peer over the edge of the nest platform, move their heads rapidly, and preen constantly (Nelson and Hamer 1995a).

Flight Behavior

Murrelets have distinctive flight behaviors near nest trees and in nest stands. These subcanopy behaviors are associated with nesting and include single or paired birds flying into, through, and out of the canopy and landing in trees (Nelson and Hamer 1995a). Nelson and Hamer (1995a p. 64) report that "landings and departures from trees have been observed at nests, on other branches in nest trees, in trees adjacent to nest trees, and other trees in the nest stand throughout breeding season." Observation of murrelets landing in trees where a nest has not yet been located is a good indication that nesting activity is occurring somewhere in the stand (Ralph et al. 1994). Murrelet researchers have also seen single birds or flocks of murrelets circling above the forest canopy of nesting stands (Gaston 1992; Nelson and Hamer 1995a) and consider this behavior to indicate that the stand is occupied by murrelets (Ralph et al. 1993, 1994). Occupied behaviors suggest, but do not definitively confirm breeding (Paton 1995).

Murrelets follow linear openings such as creeks, roads, or other natural or human-made corridors to directly approach and depart from nest stands (Eisenhawer and Reimchen 1990; Singer et al. 1991, in press; Nelson and Peck in press). Murrelets use similar flight paths to approach and depart from nest trees (Nelson and Hamer 1995a). There appears to be a positive correlation between the direction of approach and departure from nest trees and openings in the canopy around the nest tree, as well as in gaps in horizontal cover around the nest limb (Nelson and Hamer 1995a p. 64).

NESTING SUCCESS AND PREDATION

Seabird nesting success is influenced by a variety of factors such as food availability, habitat quality, physiological condition of breeding females, predation, and climatic conditions (Nettleship and Birkhead 1985; Croxall 1987; Vermeer et al. 1993). However, the relatively low number of known marbled murrelet nests limits current knowledge of the manner in which different factors influence nesting success, and thorough studies have not been conducted (Nelson and Hamer 1995b). Nelson and Hamer (1995b) compiled and analyzed existing information on nest success from records of 65 marbled murrelet nest trees found in North America between 1974 and 1993. Adequate information to determine nest success was available for 32 of the 65 nest tree sites. Of these 32 sites, 72 percent failed (23 of 32). Predation was the cause of egg or chick mortality at 43 percent of the 23 nesting attempts that failed. Predation was the cause of failure for 57 percent, or eight of 14 nests, that failed in Washington, Oregon, and California. These rates of predation are higher than those observed for other alcid species, with the possible exception of those in areas with high numbers of predators or introduced predators (Nelson and Hamer 1995b p. 93). Nelson and Hamer (1995b) also reported that the source of mortality was unknown for 22 percent of the 23 nest sites that failed. Abandonment, the chick falling out of the nest, and the chick dying from other than predation accounted collectively for 34 percent of the 23 nests that failed (Nelson and Hamer 1995b p. 92).

The authors recognized that the high rates of predation reported in their study may have resulted from a biased sample because most of the records came from nests that were in fragmented areas and near forest edges (Nelson and Hamer 1995b p. 94). Nests that were successful were located significantly farther from forest edges than those that failed (Nelson and Hamer 1995b, p. 96). Nests located by researchers may also be more easily located by predators, although information is insufficient to evaluate that source of bias (Nelson and Hamer 1995b p. 94). Other factors believed to affect predation rates are stand size, canopy closure, percent cover over the nest cup, and distance of the nest from the tree trunk (Nelson and Hamer 1995b).

Observed predators of marbled murrelet chicks and eggs are common ravens (*Corvus corax)* and Stellar's jays (*Cyanocitta stelleri)* (Singer et al. 1991; Naslund et al. in press). Other suspected or potential predators are great horned owls (*Bubo virginianus*), other species of forest owls, accipiters such as the northern goshawk, American crows (*Corvus brachyrynchos),* raccoons (*Procyon lotor),* martens (*Martes americana)*, fishers (*Martes pennati)*, and several species of rodents (Nelson and Hamer 1995b p. 93).

Both the relation between nest predation and distance to an edge and the high rate of nest failure due to predation raise concern for the effects of forest fragmentation on increased predator access to murrelet nest trees and consequently, concern for the effects of forest practices on increased predation of murrelets. Because marbled murrelets produce only one egg per clutch, high rates of nest predation can have a significant negative effect on the murrelet population. This concern is discussed more thoroughly in the section on status and threats.

NESTING HABITAT

Several detailed studies of marbled murrelet nesting habitat have been conducted since 1990. These studies have examined nest stand characteristics (Nelson and Hamer 1992; Hamer and Nelson 1995b), nest tree characteristics (Hamer and Nelson 1995b), inland habitat associations, i.e., landscape, stand, and tree characteristics statistically associated with marbled murrelet occupancy and documented nesting (Hamer and Cummins 1990; Hamer et al. 1994b; Burger 1995a; Grenier and Nelson 1995; Hamer 1995; Kuletz et al. 1995; Miller and Ralph 1995), and larger scale forest landscape patterns associated with murrelet occupancy (Raphael et al. 1995). The results of these studies establish a strong association of marbled murrelet occupancy and known nest sites with old-growth forests or uneven-aged forests with old-growth characteristics. This section summarizes the results of these studies with a focus on data from Washington. Studies are under way to establish habitat associations in younger forest stands. (See the later section in this chapter on DNR's Survey Studies for more discussion of these studies.)

Nest Stand Characteristics

Hamer and Nelson (1995b) compiled published and unpublished information from 61 nest stands and nest trees in North America exclusive of ground nests in Alaska. They defined a nest stand as a contiguous group of trees (including the nest tree) with gaps no larger than 330 feet. They calculated mean, range, and standard deviation for each nest stand characteristic by state or province and also pooled sample statistics for California, Oregon, Washington, and British Columbia. They treated Alaska separately because stand and tree conditions there are different from those further south in the murrelet's range. Results are shown in Table III.3.

Table III.3: Characteristics of nest stands used by the marbled murrelet

The mean, standard deviation, and range, for characteristics of forest stands in North America containing marbled murrelet nest trees (n = 61). Sample sizes for each variable are shown in parentheses. The Pacific Northwest data include nests located in California, Oregon, Washington, and British Columbia. For some characteristics, either no data were available for that state or province, or the sample size was too small to calculate the mean and range.

(Source: Hamer and Nelson 1995b)

Characteristics	California n = 10	Oregon n = 20	Washington n = 6	British Columbia n = 9	Pacific Northwest n = 45	Alaska n = 14
Aspect (degrees)	210±122	147±63	180±121	——	166±92	267±66
	45-352	48-253	39-331	——	35-39	270-360
	(7)	(19)	(5)		(33)	(14)
Elevation (feet)	938±410	1243±499	1142±577	1053±1017	1089±676	315±164
	148-151	200-2119	49-2001	46-3599	46-3599	98-853
	(10)	(10)	(6)	(9)	(35)	(14)
Slope (percent)	18±14	41±27	21±13	3±4	23±23	69±16
	0-41	10-87	0-39	0-11	0-87	47-100
	(7)	(10)	(6)	(7)	(30)	(10)
Slope position[1]	1±0	2.1±0.9	1.3±0.5	1.3±0.7	1.5±0.8	——
	1-1	1-3	1-2	1-3	1-3	——
	(7)	(10)	(6)	(7)	(30)	
Stand size (acres)	871±1070	198±121	877±993	——	510±869	77±64
	248-2725	7-369	12-2452	——	7-2724	10-156
	(4)	(9)	(5)		(16)	(10)

[1] Slope position codes: 1 = lower 1/3, 2 = middle 1/3, and 3 = upper 1/3.

Table III.3: Characteristics of nest stands used by the marbled murrelet *(continued)*

Characteristics	**California n = 10**	**Oregon n = 20**	**Washington n = 6**	**British Columbia n = 9**	**Pacific Northwest n = 45**	**Alaska n = 14**
Stand composition[2]	100±0	100±0	90±9	64±29	91±19	64±14
(percent in low-	100-100	100-100	78-100	20-100	20-100	39-91
elevation trees)	(10)	(10)	(5)	(6)	(31)	(8)
Total tree density	95±72	48±29	55±30	120±55	73±53	232±92
(number/acre)	37-203	19-114	34-65	60-214	19-214	119-395
	(5)	(10)	(5)	(5)	(25)	(8)
Canopy height	289±0	194±26	177±16	——	210±53	75±13
(feet)	289-2899	157-246	144-194	——	125-289	52-98
	(5)	(9)	(5)		(20)	(14)
Canopy layers	——	2.2±0.4	3.4±0.5	——	2.5±0.7	——
(number)	——	2-3	3-4	——	2-4	——
		(10)	(4)		(20)	
Canopy closure	39±6	43±27	69±18	——	49±23	62±15
(percent)	25-48	12-99	36-88	——	12-99	40-85
	(7)	(8)	(5)		(21)	(12)
Distance to coast	8±5	16±6	10±18	7±2	10±7	0.3±0.2
(miles)	3-17	1-25	3-21	2-11	1-5	0.06-0.7
	(10)	(10)	(6)	(9)	(35)	(14)
Distance to stream	354±220	919±1024	230±226	328±541	522±735	358±354
(feet)	998-705	26-328	46-656	16-1640	16-3281	7-1066
	(7)	(10)	(5)	(7)	(29)	(9)
Distance to	——	219±230	213±108	——	302±430	——
nearest opening	——	49-984	59-394	——	49-2298	——
(feet)		(20)	(5)		(30)	
Stand age (years)	——	209±48	879±606	——	522±570	——
	——	180-350	450-1736	——	180-1824	——
		(10)	(3)		(16)	

[2] Measure of the percent of western hemlock, Douglas fir, western redcedar, Sitka spruce, and coast redwood in a stand.

Hamer and Nelson (1995b) described both landscape and forest stand characteristics associated with nest trees and stands. Landscape variables included distance to marine waters, elevation, slope, and aspect. The 45 nest stands in the Pacific Northwest were located a mean distance of 10.4 miles from marine waters. The maximum distance was 24.8 miles on the south fork of the Coos River in Oregon (Nelson et al. 1992). In Washington, the mean distance from marine water for six nests was 9.9 miles, and the nest stand farthest inland was 21.2 miles.

The mean elevation of the 35 nest stands (measured from nest tree) in the Pacific Northwest was 1,089 feet. The highest elevation was 3,599 feet in British Columbia. In Washington, the mean nest tree elevation was 1,142 feet and the highest was 2,001 feet. Nests in the Pacific Northwest occurred on slopes averaging 23 percent grade. In Washington, the mean slope was 21 percent, with a range from 0 percent to 39 percent. Eighty percent of nests in the Pacific Northwest were located on the lower two-thirds of slopes. Aspects of the nest varied. (See Table III.3.)

Forest stand characteristics described by Hamer and Nelson (1995b) included age, tree and snag size in stand, tree species composition, canopy height, number of canopy layers and percent canopy cover, stand size, and distance to openings. Ages of stands were determined by using either an increment borer, or stand information data bases from landowners, or by counting rings on nearby stumps. For the Pacific Northwest, mean age of 16 nest stands was 522 years, ranging from 180 years (Oregon) to 1,824 years (mainland coast of British Columbia). In Washington, the mean nest stand age for six nests was 879 years, and the range was 450 years to 1,736 years old. All 61 nest sites reported to date have been in mature or old-growth forests (Hamer and Nelson 1995b p. 72).

Data for tree size (diameter at breast height) in nest stands were available only for Washington and Oregon (Hamer and Nelson 1995b p. 72), where mean tree size was 19 inches dbh (Nelson and Hamer 1992). Tree density in nest stands in the Pacific Northwest was 73 per acre. For five nests in Washington, tree density in nest stands averaged 55 per acre and ranged from 34 to 65 trees per acre.

Nest stands in the Pacific Northwest were largely composed of tree species that occur at low elevations, including Douglas fir, western redcedar, Sitka spruce, western hemlock, and coast redwood (California). Nest stands in Washington had a mean composition of 90 percent low-elevation species.

Forest canopies in nest stands in the Pacific Northwest (no data reported for British Columbia) were characterized by multiple layers — between two and four (n = 20), heights averaging 210 feet (n = 20), and an average canopy closure (n = 21) of 49 percent. In Washington nest stands, there were three to four canopy layers, a mean canopy height of 177 feet, and a mean canopy closure of 69 percent.

Nest stands in the Pacific Northwest (n = 16) averaged 510 acres. The smallest nest stand was 7 acres (Oregon) and the largest was 2,725 acres (California). In Washington, mean nest stand size was 877 acres. The smallest nest stand size was 12 acres and the largest was 2,452 acres.

Nest Tree Attributes

Hamer and Nelson (1995b) described several attributes of nest trees. (See Table III.4.) Nest tree species in the Pacific Northwest (n = 47) were Douglas fir (57 percent), Sitka spruce (15 percent), western hemlock (13 percent), coast redwood (11 percent) and western redcedar (2 percent). One nest was located in an Alaska yellow cedar tree in British Columbia (2 percent). Of six Washington nests, three nests (50 percent) were located in Douglas fir trees, two (33 percent) in western hemlocks, and one nest (17 percent) was located in a western redcedar. Nest trees in the Pacific Northwest had a mean diameter of 83 inches dbh. The smallest nest tree was 34.7 inches dbh, and the largest (in California) was 210 inches dbh (17.5 feet). In Washington, the mean diameter for nest trees was 59.9 inches dbh, with the smallest nest tree measuring 34.7 inches dbh and the largest measuring 86.7 inches dbh.

Data on branch width indicate that murrelets prefer large platforms for nesting. In the Pacific Northwest, mean tree branch diameter measured at the nest was 12.6 inches. The largest branch diameter at the nest was 31.9 inches and the smallest was 3.9 inches. In Washington (n = 4), mean branch diameter was 11.4 inches. The range was 4.3 to 18 inches.

Nest branch height in the Pacific Northwest averaged 147.6 feet above the ground, with a range of 59 feet to 239.5 feet above the ground. The mean nest branch height in Washington was 121.4 feet and the range was 75.4 feet to 173.9 feet.

Murrelets used moss and litter (small twigs, conifer needles, bark pieces) as substrate in their nest platforms. Moss comprised the majority of substrate in 67 percent of nests and litter formed the substrate in 33 percent of nests in the Pacific Northwest. When moss was the substrate, mean depth of moss in or directly adjacent to the nest cup was 1.8 inches. For litter substrate, mean depth was 2 inches.

Nest platforms were formed by large primary branches (32 percent), the fork of two primary branches (23 percent), the juncture between a branch and the bole of the tree (18 percent), dwarf mistletoe brooms (9 percent), large secondary limbs (7 percent), limb damage (2 percent), and an old stick nest (2 percent). Many of the limb nests had natural depressions in which murrelets created a nest cup (Nelson and Hamer 1995b p. 79).

Nests tended to have high canopy closure over them. Mean percent cover over nests in the Pacific Northwest was 85 percent. In Washington, the mean was 90 percent. Most nest trees were within 300 feet of a stream. Many nests were also within 300 feet of clear cuts or roads, but there may be bias in this observation due to ease of access to nest trees by observers (Hamer and Nelson 1995b p. 80).

From the data on 47 marbled murrelet nests and nest stands described to date outside of Alaska, some generalizations can be made about murrelet nesting habitat. Marbled murrelets nest in mature and old-growth trees and stands. No nests have been reported in stands younger than 180 years old, with most nest stands being significantly older. All 61 nest trees located to date have been in mature or old-growth stands. All murrelet nests have been found in low-elevation stands. Nelson and Hamer (1995b p. 80) speculate that low-elevation conifers — Douglas fir, western hemlock, western redcedar, Sitka spruce, and coast redwood — probably have a higher abundance of potential nest platforms than higher elevation stands that are dominated by Pacific silver fir and mountain hemlock.

Table III.4: Characteristics of nest trees used by the marbled murrelet

The mean, standard deviation, and range for platform and tree characteristics of marbled murrelet nest trees (n = 61) located in North America. Sample sizes for each variable are shown in parentheses. The Pacific Northwest data include nests located in California, Oregon, Washington, and British Columbia. For some characteristics, either no data were available for that state or province or the sample size was too small to calculate the mean and range. Calculations were rounded to the nearest inch for measurements except nest substrate depth.

(Source: Hamer and Nelson 1995b)

Characteristics	California n = 10	Oregon n = 22	Washington n = 6	British Columbia n = 9	Pacific Northwest n = 47	Alaska n = 14[1]
Tree species:						
Sitka spruce		1		6	7	5[1]
Douglas fir	4	20	3		27	
western hemlock	1	1	2	2	6	
western redcedar			1		1	
Alaska yellow cedar				1	1	
coast redwood	5				5	
mountain hemlock						7[1]
Tree diameter (inches)	110±54 55-210 (10)	76±19 50-109 (22)	60±18 35-87 (5)	84±30 35-146 (9)	83±36 35-210 (46)	25±7 12-41 (14)
Tree height (feet)	240±26 200-282 (10)	220±36 118-282 (22)	187±23 148-213 (5)	190±49 98-262 (9)	217±43 98-282 (46)	75±13 52-98 (14)
Tree diameter at nest height (inches)	42±19 28-78 (5)	32±9 14-48 (15)	28±8 16-38 (5)	43±24 20-82 (5)	35±15 14-82 (30)	—— ——

[1]This is the data from Hamer and Nelson (1995b). The discrepancy between the 12 trees listed and total of 14 was not explained.

Table III.4: Characteristics of nest trees used by the marbled murrelet *(continued)*

Characteristics	California n = 10	Oregon n = 22	Washington n = 6	British Columbia n = 9	Pacific Northwest n = 47	Alaska n = 14
Branch height (feet)	154±36 108-223 (10)	167±39 59-240 (21)	121±36 75-174 (5)	108±26 59-144 (9)	148±43 59-240 (45)	43±7 33-56 (14)
Branch diameter at trunk (inches)	14±5 8-24 (8)	12±4 6-22 (19)	14±5 6-19 (5)	13±4 7-17 (9)	13±4 4-24 (41)	6±2 4-11 (12)
Branch diameter at nest (inches)	13±5 6-24 (10)	13±7 4-32 (20)	11±5 4-18 (4)	11±4 6-15 (7)	13±6 4-32 (41)	7±2 5-11 (11)
Branch crown position (percent)	64±13 50-91 (10)	74±12 50-92 (21)	63±15 41-81 (5)	58±11 40-74 (9)	68±14 40-92 (45)	59±12 44-79 (14)
Branch orientation (degrees)	203±103 45-360 (10)	173±87 20-360 (20)	233±109 110-342 (4)	187±90 18-341 (9)	189±96 18-360 (43)	—— ——
Distance trunk to nest (inches)	19±24 0-72 (10)	48±63 0.4-300 (21)	10±10 0-22 (4)	53±48 0-134 (9)	35±52 0-300 (44)	24±26 0-88 (13)
Nest platform length (inches)	9±4 3-16 (10)	16±7 5-28 (21)	11±6 4-22 (5)	8±5 5-20 (6)	13±7 3-28 (42)	—— ——
Nest platform width (inches)	6±3 2-9 (10)	11±5 3-20 (21)	9±4 4-15 (5)	5±1 4-7 (6)	9±5 3-20 (42)	—— ——
Nest platform moss depth (inches)	1±1 0.3-3 (5)	2±1 0.2-5 (17)	1±0.3 0.8-1.3 (2)	2±0.5 1-3 (9)	2±1 0.2-5 (33)	2±5 0.8-2 (12)
Nest platform duff and litter depth (inches)	3±3 1-8 (4)	1±0.2 1-1 (2)	1±.3 0.8-1 (3)	—— ——	2±2 0.8-8 (9)	—— ——
Cover above nest (percent)	90±28 5-100 (10)	79±14 40-100 (18)	90±10 70-100 (5)	100±0 100-100 (2)	85±20 5-100 (35)	89±0.5 81-95 (8)

Most nest stands were within 19 miles of marine waters and all of them were within 25 miles. These near distances most likely do not represent the inland distribution of nesting activity for two reasons. First, occupied behavior, which is indicative of nesting, has been observed in many stands located farther than 25 miles from the coast. In Washington, 36 percent of occupied stands are more than 29 miles from marine water, with the farthest occupied stand located 52.2 miles inland. In Oregon, one instance of occupied behavior was observed more than 66 miles inland, though most detections of murrelets have been within 25 miles of the coast (Hamer and Nelson 1995b). Second, survey effort has not been high in areas further than 40 miles from marine waters (Hamer 1995). There are no data on which to assess how much of the population nests farther from, as opposed to closer to, marine waters (Hamer and Nelson 1995b p. 80).

Murrelets appear to nest in stands that have somewhat open canopies. This probably is related to ease of access to the nest tree, which would be important for a bird that approaches the nest at high speeds. The nest itself is well covered, which is probably a predator-avoidance strategy, given the murrelet's apparently high rates of predation (see previous text and Hamer and Nelson 1995b; Nelson and Hamer 1995b). Nests also tended to be close to streams or other openings that facilitate access to the nest tree. Murrelets have been observed using stream and road corridors to travel through forest stands (Nelson and Hamer 1995b).

Nests themselves were located on large branches, in deformities in branch structure or in mistletoe brooms. This suggests that the presence of structure in the stand and the processes that create those structures are important features of murrelet nest habitat (Hamer and Nelson 1995b; Grenier and Nelson 1995). Large, old trees without the structural attributes of nest platforms would probably not constitute nesting habitat. A study by Nelson et al. (in press) in which 15 nest trees were compared to randomly located trees within the same nest stand showed that nest trees had significantly more platforms than the other trees. In addition, murrelets selected trees that had four or more platforms and avoided trees that had three or fewer platforms. Naslund et al. (in press) also showed that nest trees in Alaska had more platforms than random trees surrounding the nest trees. Nest trees also had higher percentages of epiphyte cover, which likely contributes hiding cover for nests.

The data suggest strong associations between murrelet nesting habitat and old, structurally complex, low-elevation forests. Further evidence in Burger (1995a), Grenier and Nelson (1995), and Miller and Ralph (1995) corroborate these observations. In addition, occupancy of stands and abundance of murrelets appear to be correlated with the amount of old-growth habitat available (Hamer and Cummins 1990; Hamer 1995; Miller and Ralph 1995; Raphael et al. 1995; Kuletz et al. in press). Generalizations of nest stand, nest tree, and nest attributes should be viewed cautiously in light of the small sample size from which they were drawn. Furthermore, nest tree and nest stand characteristics describe what birds are using, but do not indicate habitat quality. Habitat quality will need to be assessed by correlating habitat attributes with reproductive success (Hamer 1995; Nelson and Hamer 1995b; Ralph et al. 1995a). In addition, more extensive surveys of non-old-growth habitat will help determine if, and the extent to which, murrelets use younger and smaller trees.

Inland Habitat Associations in Washington

As of 1993, murrelet occupancy had been verified in 1,107 stands in California, Oregon, and Washington (Washington Forest Practices Board 1995). In Washington, occupied behavior has been verified in 229 stands (WFPB 1995). Occupied behavior is indicative of nesting activity in a stand (Ralph et al. 1994; Paton 1995). Thus, the number of documented occupied stands provides a larger sample from which to draw conclusions about murrelet nesting habitat than is available from the six known nest tree stands in Washington. Hamer (1995) used logistic regression analysis to compare characteristics of 62 occupied stands with characteristics of 87 unoccupied stands. Starting with 38 forest stand variables, he found that the probability of occupancy of an old-growth stand increased with an increase in the total number of potential nest platforms, percent moss coverage on limbs of trees greater than 32 inches diameter at breast height, percent slope, stem density of dominant trees (dominant trees are greater than or equal to 32 inches dbh), and the mean dbh of western hemlock. At the same time, he found that the probability of occupancy of a stand decreased with an increase in the percent coverage of lichens on the branches of dominant trees, stand elevation, and canopy closure. (See WFPB 1995 and Hamer 1995 for a complete description of the model and variables used.)

Hamer (1995) also analyzed detection rates and number of surveyed stands that were verified as occupied against elevation and distance inland. He found that mean detection rate and number of stands verified as occupied declined sharply above 3,500 feet and at distances greater than 39 miles from marine waters. More than 98 percent of all murrelet detections were from forest stands below 3,500 feet, and 98.5 percent of all detections were from areas less than 40 miles inland.

Statistical models such as described by Hamer (1995) can be useful for predicting what forest types are potentially occupied murrelet nesting habitat, for determining what forest management activities would degrade potentially occupied or suitable habitat, and for designing silvicultural prescriptions that could accelerate the development of habitat from currently unsuitable stands. As discussed above, descriptions of nesting habitat associations need to be augmented by a more thorough understanding of how these associations relate to reproductive success of murrelets. Statistical models based on occupancy versus non-occupancy are only an interim step until habitat quality can be defined in terms of reproductive success.

ESTIMATES OF MURRELET ABUNDANCE, POPULATION DEMOGRAPHY, AND TRENDS

Population Estimates

Marbled murrelet population is currently estimated by surveys done at sea, from both planes and boats. Total population based on the most current information is 300,000 individuals. Approximately 85 percent of this estimated population is concentrated along the Gulf of Alaska and Prince William Sound. The total Alaska population is estimated to be 220,900 birds (Piatt and Naslund 1995: Klosiewski and Laing 1994). At the edge of the murrelet's range, in the Aleutian Islands, the population is less than 5,000 (Piatt and Naslund 1995). The British Columbia population is estimated to be between 45,000 and 50,000 birds (Rodway et al. 1992). The Washington population is estimated at approximately 5,500 birds (Speich and Wahl 1995; Varoujean and Williams 1995). Two estimates have been derived for Oregon: Varoujean and Williams (1995) used aerial surveys to derive an estimate of 6,600 individuals, and Strong et al. (1995) arrived at an estimate of between 15,000 and 20,000 using boat surveys. For California, Ralph and Miller (1995) estimated 6,450 individuals.

The use of at-sea surveys for murrelets is a recent technique whose accuracy is currently being assessed (Ralph et al. 1995a). Well-established methods for determining population sizes of other alcid species are ineffectual for marbled murrelets because they have secretive nesting habits and consequently are virtually inaccessible for banding. Census survey results have varied between years, locations, and methods. Ralph et al. (1995a) identified aspects of surveys that can affect accuracy and suggested ways to reduce sources of error.

Population Trends

Keeping in mind these limitations for population estimates, researchers still think there is enough evidence to suggest that the murrelet population is declining. Circumstantial evidence of population decline includes observations that murrelets are abundant offshore of areas where extensive old-growth stands still exist (the Gulf of Alaska), while distribution is disjunct in areas where most of the old growth has been harvested (Washington, Oregon, and California), with murrelets found offshore along remaining stands of older forest (Ralph et al. 1995a). More quantitative assessments are available from Alaska and British Columbia for trends over the past 20 years. In Alaska, Piatt and Naslund (1995) concluded from comparing small-boat survey counts from 1972-1973 and 1989-1991 and Christmas bird counts that populations have decreased on the order of 50 percent in the past 20 years. In British Columbia, Burger (1995b) also concluded that populations have decreased by 50 percent in Clayquot Sound, based on density estimates made from surveys between 1979 and 1993. However, Burger (1995b) found that survey results in Barclay Sound indicated populations there decreased in 1992 and 1993, but doubled or tripled the following year, in 1994. He speculates that the low numbers in 1992 and 1993 may have been due to El Niño factors.

Data for quantitative assessment of long-term population trends is lacking in many parts of Washington, Oregon, and California. Speich et al. (1992) and Speich and Wahl (1995) report that qualitative accounts of murrelet abundance in the Puget Sound from early this century suggest that numbers are lower now than they were then. These authors indicate that further analysis of recent census data is needed to assess the role that spatial and temporal variation in census results plays in the low numbers that have been observed in recent years. Speich and Wahl (1995) also report that no early qualitative assessments of murrelet populations on the outer Pacific coast of Washington are available, but census data collected over the last 23 years from nearshore waters off Grays Harbor, Washington, indicate that murrelet abundance has decreased there since 1989, with especially low numbers observed in 1993. Their 1993 observations were confirmed by aerial surveys done along the Washington outer coast by Varoujean and Williams (1995). Speich and Wahl (1995 p. 323) suggest that overall changes in marine carrying capacity may be contributing to observed population declines in the past two years because other oceanic bird species with various foraging strategies have been observed the past two years to have the lowest recorded abundances since 1971.

Historic anecdotal accounts of murrelet occurrence in Oregon reported that murrelets were "common" or "abundant" near the Columbia River and offshore of Tillamook County in the northern half of the state and near the mouth of the Yaquina River in central Oregon (Taylor 1921; Strong et al. 1995). Onshore sightings of murrelets in these areas have been infrequent in recent years, suggesting a population decline in the northern half of Oregon (Nelson et al. 1992; Strong et al. 1993; Strong et al. 1995). Historical accounts of murrelet abundance in California also suggest that the population has declined (Carter and Morrison 1992). The presence of two small disjunct populations in California, one off the coast of central California and the other off the coast of northern California, coincides with the existence of remnant old-growth stands onshore and suggests that populations may be declining as the availability of nesting habitat is declining (Ralph et al. 1995a p. 12). Incidental killing in gill nets and by oil spills and other marine pollution is also thought to reduce murrelet populations (see below).

Demography

Long-term data on the vital rates of marbled murrelet sub-populations are unavailable. This information is crucial for determining rates of population change and what segments of the population (i.e., juveniles or adults) contribute most to population stability and for predicting what rates of decline the population can sustain and for how long before extinction thresholds are crossed. (See discussion of population viability analysis in the spotted owl ecology literature review in the preceding section of this chapter.) Understanding these aspects of murrelet population ecology is necessary to design adequate long-term conservation plans. Preliminary research on nesting success (Nelson and Hamer 1995b) indicates that marbled murrelets may have one of the lowest juvenile survival rates of alcid species (DeSanto and Nelson 1995). Observations of ratios of juveniles to adults at sea indicate that the adult reproductive rate is low (Ralph and Long 1995; Varoujean and Williams 1995; but see below). Low rates of juvenile survival and annual reproduction in any species mean that high rates of adult survival are necessary for a stable population. If high rates of juvenile mortality are the result of human management activity and not a part of natural demographic processes in the population (see above and Hamer and Nelson 1995a), a change in management practices that reduce juvenile mortality rates could significantly improve long-term prospects for the species.

Preliminary demographic modeling indicates that the marbled murrelet population is declining at between 4 and 6 percent per year (Beissinger 1995). This assessment is based on juvenile to adult ratios observed at sea and from inferences of possible adult survival rates made from other alcid species. Ralph et al. (1995a) caution that there are several potential sources of error in counting juveniles at sea and that the years in which these data were taken were characterized by unusually warm sea temperatures. Counts of juveniles at sea assume that observers can accurately distinguish adults from juveniles. In addition, nesting chronology data (Hamer and Nelson 1995a) indicate that in some areas, murrelet chicks may not fledge until September. By this point in the season, adults have molted and are not distinguishable from juveniles; the result is a potential low estimate of the number of juveniles. Warm ocean conditions can reduce prey availability and result in adults forgoing breeding or in chicks starving (Ainley and Boekelheide 1990), which may have adversely affected reproductive rates and thus given a non-representative picture of long-term demographic trends.

Knowledge of population dynamics in general and of demographic data from other alcid species allows for identification of some factors that affect demography of marbled murrelets. These factors include age at first breeding, the proportion of the adult population that breeds, the number of young that survive to breeding age, adult mortality rates, and subadult mortality rates (Ralph et al. 1995a p. 13). Conditions that affect the proportion of the adult population that breeds include limitations of the amount of suitable nesting habitat that is not already occupied by other murrelets and prey availability offshore of suitable nesting habitat (Ralph et al. 1995a). Loss of nesting habitat is occurring and is very likely limiting the proportion of adults that can breed. Evidence (discussed earlier) of large local concentrations of murrelet populations offshore of extensive old-growth forest, smaller populations where old growth is limited, and no murrelet activity at sea where old growth is absent supports this hypothesis.

Food availability will be affected by oceanic conditions and the degree to which prey species of murrelets are over-fished by humans. El Niño events have decreased the availability of food for seabirds (Ainley and Boekleheide 1990). Long-term changes in marine productivity have had major effects on seabirds in the Bering Sea (Ralph et al. 1995a). Fisheries exist for some prey species of the murrelet — primarily Pacific herring, rockfish, and northern anchovy. These fish populations are currently depressed due to overfishing (Ainley et al. 1994). However, Ralph et al. (1995a) do not think that food availability is currently a limiting factor affecting murrelet populations, though El Niño events could have short-term effects on the number of adults breeding.

Predation appears to have a large influence on reproductive success. Thirty-one percent of all nests discovered thus far have failed due to predation, and 43 percent of all nests that have failed for any reason have failed due to documented predation (Nelson and Hamer 1995b). Nelson and Hamer (1995b) also found that successful nests were located significantly further from stand edge than those that failed. (See earlier discussion on predation.) This suggests that forest fragmentation could have an adverse effect on reproductive success of marbled murrelets.

Adult mortality is affected by predation in transit between foraging areas and nests. It may also be affected by predation at sea, but no predator takings of murrelets at sea have been recorded (Ralph et al. 1995a p. 16). Adult and subadult mortality rates are increased by deaths due to human activities such as gill-netting (Carter et al. 1995; Fry 1995), pollution, and oil spills (Carter and Kuletz 1995).

Currently, demographic analyses cannot distinguish the relative effects of habitat loss from other factors affecting population trends (Ralph et al. 1995a). It is generally known, however, that populations that do not produce enough young to replace adults eventually become extinct. Thus, the extent to which murrelet nesting habitat has been lost will certainly have a negative effect on the size of the murrelet population. In addition, because murrelets only produce one egg per clutch, they will not recover quickly from higher adult mortality. Increased adult mortality at sea from human activities will also have a large negative effect on the overall population.

Collecting demographic data for murrelets is difficult because of their inaccessibility. Traditional banding and re-observation techniques of both adults and juveniles are not practical, given the difficulties in locating murrelet nests. Alternative methodologies such as refinement of at-sea observation techniques and completely new techniques suitable to murrelet biology will need to be developed to assess accurately demographic trends and determine the relative contribution of different influences on population viability (Ralph et al. 1995a).

HABITAT STATUS IN WASHINGTON

Estimates of the amount of potential marbled murrelet nesting habitat in Washington have been made using satellite data developed by the Washington Department of Fish and Wildlife and modified by DNR (see Raphael et al. 1995; WFPB 1995 based on data developed by Eby and Snyder 1990 and updated by Collins 1993). These estimates were based on broad definitions of old-growth and large-saw forests. The amount of potential nesting habitat by ownership based on these estimates is shown in Table III.5.

Table III.5: Old-growth, large-saw, and small-saw forests below 3,500 feet and less than 66 miles from marine waters, by ownership

(Source: DNR GIS, November 1994)

Ownership	Old growth (acres)	Large saw (acres)	Small saw (acres)
Federal	798,231	710,347	352,853
State	62,950	64,656	173,131
Local	1,162	3,227	2,659
Tribal	3,607	1,302	5,614
Private	67,154	100,656	335,232
Total	**933,104**	**880,188**	**869,489**

Status of Habitat on DNR-managed Lands

From data in Hamer et al. (1994b), DNR derived another estimate of potentially suitable nesting habitat for the lands it manages, assuming that (1) marbled murrelets would use a stand that contains at least eight trees per acre that are equal to or greater than 32 inches dbh; (2) at least 40 percent of such trees are Douglas fir, western hemlock, western redcedar, or Sitka spruce; and (3) the stand contains at least two nesting platforms per acre. This definition was derived from minimum conditions of occupied murrelet stands in Washington. Using forest growth models incorporating site index and assumptions of how managed stands versus unmanaged stands grow, DNR estimated the age at which a stand would develop eight trees greater than or equal to 32 inches dbh. Data from Hamer et al. (1994b) indicate that in unmanaged low-elevation stands, three trees per acre that are greater than or equal to 30 inches dbh would produce at least two platforms per acre. The platform per acre criterion is thus captured by the tree size and density criteria.

DNR's computerized geographic information system data base was queried to assess how many acres of DNR-managed land met this minimum definition of murrelet habitat within 66 miles of marine waters. The estimate was between 55,773 and 63,614 acres, depending on whether growth was assumed to be for a managed stand or a natural stand. This represents 3.4 percent to 3.8 percent of all DNR-managed forest lands in the area covered by the HCP. However, combining old-growth and large-saw estimates from the Washington Department of Fish and Wildlife results in an estimate of 126,606 acres of potential murrelet habitat on DNR-managed land.

The two-year murrelet habitat relationship study currently under way on DNR-managed lands will result in the most accurate picture yet of how much actual potential nesting habitat exists. This study is explained in more detail later in this chapter.

Habitat trends

The amount of available murrelet nesting habitat has been decreasing. Murrelets have been found thus far to nest almost exclusively in low-elevation old-growth and mature forests within 40 miles of marine waters, although they have been observed as far as 66 miles inland. About 10 percent of pre-settlement old growth remains in western Washington (Norse 1990; Booth 1991). Logging, urbanization, and agricultural development have all contributed to the loss of this habitat.

Management under the President's Forest Plan is expected to result in retention of 97 percent of the remaining 980,000 acres of potential murrelet habitat on federal lands in Washington (USDA and USDI 1994a; Perry 1995). Although there are currently no federal restrictions on logging of murrelet nesting habitat on nonfederal lands, landowners are still liable for take of murrelets under the Endangered Species Act. To avoid risk of taking, DNR began a voluntary deferral of timber harvesting in potential murrelet habitat in 1992. The Forest Practices Board is developing a rule for murrelet habitat on state and private lands under the State Forest Practices Act.

THREATS

Habitat Loss and Fragmentation

In its listing decision, the U.S. Fish and Wildlife Service identified habitat loss as the major factor causing the decline of marbled murrelet populations (Federal Register v. 57, p. 45328-37). Threats associated with loss of nesting habitat are (1) a decrease in the proportion of the population that is able to reproduce through reduced availability of nest sites; (2) decrease in reproductive rate of population due to inability of displaced adult breeders to locate new nest sites after their previous sites have been destroyed; (3) packing, i.e., an increased density of birds nesting in the habitat that is available; and (4) fragmentation of existing habitat, which increases the accessibility of nest sites to predators and isolates portions of the population, leading to increased vulnerability to genetic and environmental changes (Divoky and Horton 1995; Ralph et al. 1995a; WFPB 1995).

A decrease in the proportion of the population breeding threatens the species because it could lead to rates of population decline from which the species could not recover. In other words, an extinction threshold could be reached. Current knowledge of murrelet demography is not sufficient to determine where this threshold lies (Beissinger 1995; Ralph et al. 1995a).

The ability of adult breeders to disperse to new nesting stands is not well understood. Drawing from a comparative study of other alcids and knowledge of murrelet nesting habits, Divoky and Horton (1995) suggest that murrelet adults may not be well adapted to disperse to new nest stands once their natal stand has been destroyed. If this is true, it may be difficult for displaced adults to be able to breed, thus reducing the reproductive output of local populations.

Packing is problematic for at least two reasons. First, when all high-quality nest sites are occupied, murrelets may be forced to nest in lower quality habitat or at the edge of suitable stands. Either of these cases could result in a lower likelihood of nesting success. For instance, if a nest is established on a smaller limb or platform than would otherwise be chosen, there could be a higher risk of a chick falling out of the nest. Dead chicks that have fallen out of nests have been documented (Nelson and Hamer 1995b). Nesting on the edge of a stand increases likelihood of nest failure due to predation (Nelson and Hamer 1995b). Second, a high density of nest sites in a stand provide more opportunities for predators to form search images of murrelets as they approach or depart from the nest stand (Ralph et al. 1995).

Forest fragmentation in general increases the number of smaller forest patches (Harris 1984; Forman and Godron 1986). Forests in the Pacific Northwest have experienced a high degree of fragmentation due to clearcut harvest practices in this century (Harris 1984; FEMAT 1993; Thomas et al. 1993). The relation between increased bird nest predation and forest fragmentation has been established in several studies. Bryant (1994) demonstrated that artificial ground and shrub nests located within 328 feet of a forest clearcut edge suffered higher rates of predation than did nests located between 328 feet and 1,804 feet from an edge. Paton (1994) summarized data that demonstrated that songbirds had reduced nesting success when their nests were located near a forest edge. Populations of corvids (jays, ravens, and crows) have been observed to increase in forest edges in British Columbia (Bryant, personal communication, cited in Burger 1995a p. 158) and in the west in general (Marzluff 1994). Densities of great horned owls are also higher in fragmented forests as compared to areas with more contiguous stands (Johnson 1993). Corvids are known predators of marbled murrelets, and great horned owls are suspected predators of murrelets (Nelson and Hamer 1995b).

In addition to the above evidence, Nelson and Hamer (1995b) found that successful murrelet nests were farther from an edge than nests that failed due to predation. Stand size was greater and amount of canopy closure near the nest was higher for successful than for unsuccessful nests; however, the difference was not significant between nests that failed due to predation and nests that failed due to other reasons. Finding these characteristics of successful nests led Nelson and Hamer (1995b) to conclude that changes in configuration of habitat, such as amount of edge, may significantly affect nesting success.

Forest fragmentation also poses the risk of isolation of small sub-populations of murrelets. Small sub-populations that do not interact to a high degree with other sub-populations are susceptible to extirpation through a variety of mechanisms: inbreeding depression, which reduces the fitness of the population (Frankle and Soule 1981; Saunders et al. 1991); random demographic fluctuations, i.e., an unfavorable ratio of males to females or breeding adults to non-breeding adults or subadults; and random environmental catastrophes. (See discussion of spotted owl demography in Section A of this chapter.)

Evidence discussed in this review suggests that the amount of nesting habitat is a limiting factor for murrelet populations at this time (See also Ralph et al. 1995a.). In addition, marbled murrelet nests are extremely vulnerable to loss through predation (Nelson and Hamer 1995a, b). Loss of a chick through predation in turn appears to be influenced by the distance of the nest from forest edge (Nelson and Hamer 1995b). Thus, the overall amount, size, and contiguity of suitable nesting stands are important factors in murrelet conservation.

The U.S. Fish and Wildlife Service has designated critical habitat for the marbled murrelet (Federal Register v. 61, no. 102, p. 26255-26320). Most of this habitat designation includes lands that are to be managed as Late successional Reserves under the President's Northwest Forest Plan (USDA and USDI 1994 a and b). Some nonfederal land has been included, the vast majority of which is DNR-managed land. Most of this land occurs in southwest Washington and on the Olympic Peninsula. The U.S. Fish and Wildlife Service conducted an assessment of the effects of the HCP strategies on designated critical habitat on DNR-managed lands, the results can be found in the Biological Opinion.

Mortality at Sea

High rates of adult survivorship are necessary to maintain population stability in species with low reproductive output. Marbled murrelets are particularly sensitive to adult mortality because they only produce one egg per nesting attempt (Beissinger 1995; Ralph et al. 1995a). Thus, human-caused mortality of adult murrelets above natural levels can have significant negative impacts to the murrelet population. Large oil spills, chronic oil pollution, organochlorine pollution, and entanglement in gill nets are significant sources of mortality for marbled murrelets at sea.

Oil spills destroy the ability of feathers to regulate a bird's body temperature; oil also affects most of a bird's physiological systems (Burger and Fry 1993). The 1989 *Exxon Valdez* oil spill directly killed approximately 5,000 marbled murrelets and 3,000 unidentified murrelets, which included marbled murrelets, Kittlitz's murrelets, and ancient murrelets in Prince William Sound, Alaska (Carter and Kuletz 1995); this was the largest recorded single mortality event for marbled murrelets in North America (Carter and Kuletz 1995). Indirect effects on murrelets from the spill included sub-lethal levels of oil that reduced prey populations, disturbance from increased human activity in Prince William Sound during clean-up and monitoring after the spill, and reduced reproductive output of the local population in the vicinity of the spill (Irons 1992; Oakley and Kuletz 1994; Oakley et al. 1994; Kuletz in press; Piatt and Anderson in press; Carter and Kuletz 1995).

Oil spills also pose a significant threat to murrelets in Washington, Oregon, and California, where there is a high volume of commercial shipping, and barge and oil tanker traffic along the Pacific coast (Fry 1995). Several medium to large oil spills have occurred along the Pacific coast within the range of the murrelet since the late 1800s. Collection of systematic records of seabird carcass recovery did not begin until recently. Seven major spills have occurred in Washington since 1971. Oiled murrelet carcasses were recovered at the 1985 *Arco Anchorage* spill near Port Angeles and the 1988 *Nestucca* spill off Grays Harbor. Approximately 45 murrelet carcasses were recovered at the site of the 1991 *Tenyo Maru* spill off Willapa Bay, and estimates suggested that a total of 200-400 murrelets actually died. This represents a large portion of the local breeding population (Carter and Kuletz 1995) and is the largest recorded loss of murrelets to an oil spill on the U.S. Pacific coast south of Alaska (WFPB 1995). Thus, small murrelet populations could potentially be eliminated in a single oil spill event.

Chronic oil pollution, including small spills, bilge seeps, dumping, and undetected slow leaks from coastal tanks, pumps, and pipelines, can also pose a threat to the murrelet population. This type of oil pollution is poorly documented, making an assessment of the level of threat difficult. However, retrieval of dead oiled murrelets on beaches in times that did not coincide with medium to large oil spills indicates that chronic oil pollution does kill (Carter and Kuletz 1995). Murrelet populations in the Puget Sound and the Columbia River/Grays Harbor areas of Washington are highly susceptible to oil pollution from tanker traffic. Because the Puget Sound area is highly industrialized, the likelihood of murrelet exposure to chronic oil pollution from small spills is also increased.

Fry (1995) identified organochlorine compounds as a prevalent non-oil pollution threat within the range of the murrelet. Specifically, polychlorinated dibenzo-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF), which are contained in pulp-mill discharges, cause significant injury to fish, birds, and estuarine environments (Elliot et al. 1989; Whitehead 1989; Colodey and Wells 1992; Fry 1995). PCDDs and PCDFs bioaccumulate in marine sediments, fish, and fish-eating birds and impair bird production (Elliot et al. 1989; Bellward et al. 1990). There has been no record of bioaccumulated residues or breeding impairment in marbled murrelets to date, although murrelets that feed in areas of historic or current discharge from bleached paper mills could be at risk from eating fish with bioaccumulated organochlorine compounds (Fry 1995). Active chlorine bleach mills in Washington are located in Port Angeles, Bellingham, Everett, and Grays Harbor.

Mortality to murrelets from gill net fisheries is well documented in Alaska and British Columbia, but not in Washington (Carter et al. 1995). Results of several seabird observer programs initiated in 1993 are still preliminary. The U.S. Fish and Wildlife Service estimated a total take of 10 murrelets from all-citizen fisheries programs and tribal fisheries for 1993, which they did not judge to put the species in jeopardy (Carter et al. 1995 p. 281). However, Carter et al. (1995) estimate that there is significant mortality from gill and purse seine nets in the northern Puget Sound and San Juan Islands because of the high concentration of fishing activities and coincidence of a large portion of the murrelet breeding population there. They estimate that take is on the order of tens to hundreds of birds and recommend continuation and augmentation of observer programs in order to assess more accurately the impact of gill nets to murrelets in Washington.

DNR's Forest Habitat Relationship Studies

DNR is conducting a marbled murrelet forest habitat relationships study in each of the HCP planning units within the murrelet's Washington range. The objective of the habitat relationships studies is to determine the influences of distance from marine waters and habitat type on murrelet occupancy of DNR-managed forest lands. Results will be used to formulate a threshold definition of murrelet habitat for DNR-managed forest lands and to develop a long-term murrelet conservation strategy.

DESIGN

Two years of murrelet surveys will be conducted in each of the five westside HCP planning units and the Olympic Experimental State forest. Each planning unit will contain 54 survey areas on DNR-managed lands. These survey areas will be stratified by two factors: (1) distance from marine waters and (2) habitat type (Table III.6). Habitat descriptions of the survey areas will characterize forest conditions, nesting opportunities, and topography.

In each planning unit, 18 survey areas will be selected in each of three distance bands (near, mid, and far). Band width will be based on the distribution of DNR-managed lands from marine waters, each band containing a third of the DNR-managed lands within the planning unit. Thus, actual band width will differ within and among planning units.

Within each distance band, six survey areas will be located in each of three habitat classes: old-forest habitat with an average density of at least two suitable nesting platforms per acre, young-forest habitat with an average density of at least two suitable nesting platforms per acre and young-forest habitat with at least one suitable nesting platform. For the purposes of these studies, old forest will be defined as old-growth forests or mature forests where most of the co-dominant trees are more than 120 years old. Young forest will be defined as sub-mature forests where most of the co-dominant trees are less than 120 years old. A suitable nesting platform is a horizontal limb, tree structure, or deformity at least 7 inches in diameter and a minimum of 50 feet above the ground.

Table III.6: Allocation of survey areas in each planning unit, by habitat type and distance from marine waters

Habitat type	Distance of area from marine waters: Near band	Mid band	Far band
Old forest, ≥2 platforms/acre	6	6	6
Young forest, ≥2 platforms/acre	6	6	6
Young forest, at least 1 platform	6	6	6

In each planning unit, survey areas will be selected to ensure consistency within each habitat class. Consistency will be sought in terms of landscape context, forest type, elevation, stand origin, stand size, and distribution of platforms in the survey area. To ensure that each survey area represents an independent sampling unit, survey areas will be at least one-half mile apart.

Each survey area will be surveyed from two, three, or four stationary survey stations. Theoretically, one survey station can cover up to 30 acres of habitat, allowing for a maximum survey area size of 120 acres. However, because in many places actual station coverage will be less than 30 acres, we will select survey areas between 40 and 80 acres in size will be selected. This assumes an actual station coverage of about 15 acres per station, half the theoretical maximum. Stands less than 20 acres will not be considered as survey areas.

Each planning unit will be surveyed for two consecutive years. In year 1, each survey area will be visited on at least four mornings. Survey areas where murrelet presence is detected will receive two additional survey visits, for a total of six visits. In year 2, each survey area will again be

Table III.7: Prescribed number of visits for each survey area for both years of the DNR marbled murrelet forest habitat relationships studies

Year-1 status	Year-2 status	Number of year-1 visits	Number of year-2 visits	Number of total visits
No detections	No detections	4	4	8
	Presence	4	10	14
	Occupancy	4	6-10*	10-14*
Presence	No detections	6	10	16
	Presence	6	10	16
	Occupancy	6	6-10*	12-16*
Occupancy	No detections	6	6	12
	Presence	6	6	12
	Occupancy	6	6	12

*The number of year-2 survey visits and total visits depends on when occupancy is determined in year 2.

Definitions

detection: The sighting or hearing of one or more murrelets acting in a similar manner.

presence: A stand of potential habitat where one or more murrelets have been seen or heard.

occupancy: A stand of potential habitat where (1) an active nest or recent nest site 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. See discussion titled Flight Behavior earlier in this section for examples of subcanopy behaviors.

visited on at least four mornings. Survey areas where murrelet presence was detected in year 1 or is detected in year 2 but occupancy has not been confirmed will be surveyed until (a) occupancy is confirmed and six year-2 survey visits have been completed or (b) ten year-2 survey visits have been completed, whichever comes first. Survey areas where murrelet occupancy was determined in year 1 will receive six year-2 survey visits (Table III.7).

Observations will be made and data recorded according to procedures described in Methods for Surveying Marbled Murrelets in Forests: A Protocol for Land Management and Research (Ralph et al. 1994) and its 1995 supplement (Ralph et al. 1995b) and any subsequent updates or modifications as required by the U.S. Fish and Wildlife Service. Data will also be mapped for input into an ARC/INFO coverage on DNR's geographic information system.

The habitat of each survey area will be accurately described with respect to forest conditions, nesting opportunities, and topography. This information will be used to determine the influences of these factors on murrelet occupancy of DNR-managed forest lands. Habitat descriptions will:

(1) be made using objective, scientifically accepted methods that can be repeated with the same results,

(2) be made in a manner that allows comparison with results of other studies of murrelet habitat relationships,

(3) describe forest conditions within the entire survey area, and

(4) be limited to those variables that might reasonably influence murrelet occupancy of DNR-managed forest lands.

STUDIES IN PROGRESS

In 1994, marbled murrelet forest habitat relationships studies were initiated in the South Coast and most of the Olympic Experimental State Forest HCP planning units. This work was carried out by the Washington Department of Fish and Wildlife through an interagency agreement with DNR.

In 1995, year 2 of murrelet surveys in the South Coast and most of the Olympic Experimental State Forest planning units were again conducted by the Washington Department of Fish and Wildlife, which completed the habitat relationships studies for these planning units. Also in 1995, habitat relationships studies were initiated in the Columbia and Straits (including the rest of the Olympic Experimental State Forest) planning units; this work is being carried out by DNR. Year 1 of marbled murrelet surveys and habitat descriptions of survey areas will be completed in the Straits and Columbia Planning Units.