Exxon Valdez Oil Spill
Restoration Project Final Report

Information Needs For Habitat Protection: *Marbled Murrelet Habitat Identification*

Restoration Project 93051B
Final Report

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Study History: This study follows restoration project R15 (Identification of Marbled Murrelet Nesting Habitat in the *Exxon Valdez* Oil Spill Zone) and R4 (Feasibility Study On Identification Of Upland Habitats Used By Wildlife Affected By EVOS: Marbled Murrelets). An article regarding the findings of project 93051B was published in 1995 (Kuletz et al. 1995. Inland habitat suitability for the marbled murrelet in southcentral Alaska. *In*: C.J. Ralph, G.L. Hunt, Jr., M.G. Raphael, and J.F. Piatt [eds]. Ecology and Conservation of the Marbled Murrelet: An Interagency Scientific Evaluation. USDA For. Serv. Gen. Tech. Rep. PSW-GTR.).

Abstract: Marbled murrelets (*Brachyramphus marmoratus*) typically nest in trees, but in Alaska they sometimes nest on the ground. To define murrelet nesting habitat in southcentral Alaska, we surveyed inland activity of murrelets and measured habitat features between 1991 and 1993, in Prince William Sound, Kenai Fjords National Park and Afognak Island, Alaska (N=262 sites). In the Kenai Fjords, forested areas had higher murrelet activity levels than non-forested areas. Using all study areas, we developed statistical models that explain variation in murrelet activity levels and predict the occurrence of behaviors indicative of nesting, based on temporal, geographic, topographic, weather and habitat variables. The multiple regression analyses explained 52 percent of the variation in murrelet activity level. The highest activity levels were associated with late July surveys at the heads of bays where there was high epiphyte cover on large trees. Stepwise logistic regression was used to identify variables that could predict the occurrence of nesting behaviors. The best model included survey method (from a boat, shore or inland), location relative to the head of a bay, tree diameter and number of potential nesting platforms on trees. The best predictors were tree diameter and number of platforms. Overall, the features indicative of murrelet nesting habitat included low elevation locations near the heads of bays, with extensive forest cover of large old-growth trees.

Key Words: *Brachyramphus marmoratus*, nesting habitat, marbled murrelet, Prince William Sound, Kenai Fjords, Afognak Island, Southcentral Alaska.

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EXECUTIVE SUMMARY

The marbled murrelet (*Brachyramphus marmoratus*), a small diving seabird, was directly impacted by the *Exxon Valdez* oil spill. Murrelet restoration could benefit from protection of old-growth coniferous forests, its primary nesting habitat. The goal of this study was to develop a means of assessing the potential value of lands as murrelet nesting habitat. We developed models of murrelet habitat use based on data from murrelet surveys in Prince William Sound, Kenai Fjords National Park, and Afognak Island and examined the use of forested and non-forested habitat in the Kenai Fjords National Park.

Using data from Prince William Sound, Kenai Fjords National Park and Afognak Island, multiple regression and discriminant analyses identified topographic and vegetation variables that were consistent predictors of high murrelet activity throughout the spill zone. Murrelet activity was highest at the heads of bays and in areas with high average DBH (tree diameter at breast height). Activity was also greater at lower elevations, and in areas with more forest cover. The mean number of suitable nest platforms and percent epiphyte cover per tree were the best predictors of murrelet activity.

Forest cover, canopy cover, canopy height, tree diameter, epiphyte cover and number of platforms per tree were greater at sites where occupied behaviors (indicative of nesting) were observed than at sites where no occupied behaviors were observed (unknown status). Our models, based on murrelet activity levels, are consistent with known attributes of marbled murrelet nests and explained >50% of the observed variation in activity. The best model correctly classified 85% of the occupied sites in a jackknife procedure. Some unexplained variability was likely due to surveying sites once and not accounting for day to day changes in activity. Unmeasured sources of error included observer variability and large-scale topographic and vegetation factors, including the potential importance of local marine habitat.

In Kenai Fjords National Park, higher levels of marbled murrelet activity and more observations of occupied behaviors were observed in forested than in non-forested areas. In contrast to pooled data from throughout the spill zone, murrelet activity was not significantly higher at bay heads in Kenai Fjords National Park compared to more exposed sites. Recent deglaciation at bay heads may have been a factor.

We describe a marbled murrelet ground nest found in Kenai Fjords National Park and present results of a pilot study examining the use of radar for surveying inland activity of murrelets in a fjord environment. We also provide a summary of epiphytes found in nests and in nest stands.

PREFACE

The protection of habitat has been identified as a viable means of restoring resources injured by the *Exxon Valdez* oil spill. The marbled murrelet (*Brachyramphus marmoratus*), a small diving seabird, was one such injured species (Piatt et al. 1990a; Kuletz 1995). The murrelet could benefit from habitat protection because it nests primarily in old-growth coniferous forests (Binford et al. 1975; Quinlan and Hughes 1990; Singer et al. 1991; Hamer and Nelson 1995; Naslund et al. 1994; Piatt and Ford 1993), which are threatened by logging in the spill zone. Loss of this nesting habitat to logging could impede the natural recovery of murrelets following the oil spill.

Southcentral Alaska is an important population center of marbled murrelets (Mendenhall 1992; Piatt and Naslund 1995). Following the spill, the majority of murrelet carcasses were retrieved in Prince William Sound and along the south Kenai Peninsula (Ecological Consulting, Inc. 1991). Murrelets also showed effects of human disturbance at Naked Island, Prince William Sound, in 1989 and possible disruption of breeding (Kuletz 1995). The murrelet population in Prince William Sound has declined significantly, from approximately 300,000 in 1972 to 100,000 in 1989 (Klosiewski and Laing 1994). Though it is unlikely that all of the decline was due to the spill (Klosiewski and Laing 1994), the oil spill undoubtedly hindered recovery to historic levels.

The marbled murrelet is listed as threatened under the Endangered Species Act in California, Oregon and Washington, due in large part to loss of its forest nesting habitat (Stein and Miller 1992), and forested areas in the spill zone are under increasing pressure to be logged. In addition, tree- and ground-nesting murrelets in the spill zone are vulnerable to human disturbance. This study, in cooperation with the U.S. Forest Service, was a continuation of efforts to identify habitat features associated with nesting murrelets. These results can be used to identify areas that are most likely to be nesting habitat and, if these lands are given protective status, have the best potential for enhancing natural recovery of marbled murrelet populations in the spill area.

The spill zone covers a large area and diverse habitats. Marbled murrelets are dispersed throughout the spill zone and may exhibit different habitat choices in different regions. The difficulty and expense of finding murrelet nests, or of conducting upland surveys for murrelets, has hampered implementation of a comprehensive study throughout the spill zone. However, since 1990, studies of murrelet activity in relation to potential nesting habitat have been conducted for oil spill restoration projects by Migratory Bird Management (MBM) at Naked Island in Prince William Sound (1991), in western Prince William Sound (1992), and on the southern Kenai Peninsula, in Kenai Fjords National Park in 1993; and by the Division of Realty (DOR) on Afognak Island in 1992.

In study 93051B, we used data from these previous studies to develop a general model relating habitat attributes to murrelet activity. Additionally, we investigated the relationships between murrelet activity and specific habitat features in the Kenai Fjords, and tested new techniques to estimate total murrelet activity and to identify nesting habitat. Our objectives were to:

1. Determine habitat features that are reliable indicators of high density murrelet nesting areas in the spill-affected area.

2. Determine the feasibility of using radio telemetry to determine nesting habitat of murrelets in the spill-affected area.

Results relating to Objective 2 are presented in a separate report (Burns et al. 1994). Here we present results relating to Objective 1. In Chapter 1 we report on marbled murrelet activity relative to forested vs. non-forested habitat and location relative to bays on the Kenai Peninsula. In Chapter 2 we pool data from four study areas within the spill zone and develop regression models relating murrelet activity to weather, survey period, topographic, and vegetation variables. Chapter 2 also presents results from discriminant analyses which define characteristics of occupied sites (where behaviors indicating nesting were observed) and high activity sites.

Appendix A reports on the pilot effort to monitor dawn murrelet activity using marine radar. Appendix B describes a marbled murrelet ground nest found on the Kenai Peninsula during our 1993 surveys. Appendix C presents identifications of moss and lichen samples taken from marbled murrelet tree nests and landing trees in Alaska during 1991 and 1992 studies.

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CHAPTER 1

MARBLED MURRELET HABITAT ASSOCIATIONS ON THE SOUTHERN KENAI PENINSULA

INTRODUCTION

The primary nesting habitat of the marbled murrelet (*Brachyramphus marmoratus*) throughout most of its range is old-growth coniferous forest, where it lays a single egg, typically on a moss-covered branch (Singer et al. 1991; Hamer et al. 1991; Hamer and Nelson 1995; Naslund et al. 1994). Although ground nests have been found in Alaska, the at-sea distribution of marbled murrelets during the breeding season in Alaska shows the majority occurring offshore of forested regions and suggests that a small percentage of the population breeds in treeless regions (Piatt and Ford 1993). Marbled murrelet surveys in Prince William Sound (PWS) have shown the amount of dawn activity to be highest in forested, especially high volume forests, as opposed to non-forested or sparsely forested areas (Kuletz et al. 1994a; Marks et al. 1994).

The southern Kenai Peninsula and the nearby Barren Islands are in the *Exxon Valdez* oil spill zone, and comprise one of the few places where marbled murrelets have been found nesting in non-forested areas (Simons 1980, Hirsch et al. 1981, Rice 1991, J.H. Hughes pers. comm., this study). In addition to ground nesting birds, Kenai Fjords National Park (KFNP) on the southern Kenai Peninsula (Figure 1-1) appeared to support tree nesting murrelets as well, based on observations of murrelets flying into forested areas (M. Tetreau pers. comm.). Prior to 1991, no systematic inland surveys had been conducted along the Kenai Peninsula, although preliminary surveys were conducted in Aialik Bay and McCarty Fjord by KFNP biologists (Rice 1991). These were boat-based surveys using 10-40 minute observation periods. Although 78% of their observations were of murrelets flying over the ocean, they found the highest murrelet dawn activity in forested areas, but also recorded moderately high activity in non-forested, but vegetatively 'mature' areas (those glacier-free since at least 1900).

In addition to high volume forests having high murrelet activity, surveys in PWS indicated that stations in protected bays had higher murrelet activity than those along open shoreline (Kuletz et al. 1994a; Marks et al. 1994). Most of these stations were in forested areas; it was not determined if murrelet activity in non-forested areas was affected by location relative to bays.

In addition to providing additional habitat and murrelet activity information to our spill zone database (see Chapter 2, this report), this study was designed to investigate murrelet use of forested and non-forested areas on the Kenai Peninsula and to examine murrelet activity and habitat characteristics at the heads of bays in both forested and non-forested areas.

The specific objectives of this study were to:

1. Determine if murrelet activity is different between forested areas and non-forested areas.

2. Determine if sites in protected bays have significantly higher levels of murrelet activity at dawn than those located along more open shoreline.

METHODS

Study Area

The southern Kenai Peninsula is comprised of steep coastlines, extensive bays and deep fjords. The heads of fjords typically have retreating glaciers extending out from the massive Harding Ice Field, which runs along the crest of the >1800 meter high Kenai Mountains. About 45% of KFNP is ice covered (Rice 1987). Northern portions of Harris and Nuka bays (Figure 1) were glacier-covered at the end of last century (Post 1980a, b) and, to a lesser extent, Aialik Bay also exhibits the barren, vegetatively sparse nature of recently deglaciated areas.

The southern portion of KFNP faces into the Gulf of Alaska and wind and sea conditions on the outer coasts can be extreme. In general, the southern parts of the peninsulas have more extensive forests than the more recently deglaciated northern areas. Mixed forests of mountain hemlock (*Tsuga mertensiana*) and Sitka spruce (*Picea sitchensis*) occupy the southern coasts of the peninsula in a mosaic of forested and non-forested areas. Treeline is typically at about 300 m elevation and, due to the steep grade, coniferous forests are largely restricted to within 500 m of the ocean.

The climate of the Kenai Peninsula is characterized by cloudiness, frequent fog, heavy precipitation and strong winds. Mean minimum and maximum temperatures (at sea level) for July are approximately 9°C and 17°C, respectively. Precipitation averages approximately 200 cm per year (Selkregg 1974). For the duration of the study in 1993, weather was unusually mild, with fewer than average cloudy days, warmer than average air temperatures and below average precipitation.

Kittlitz's murrelets (*B. brevirostris*) also occur on the Kenai Peninsula in low numbers; the ratio of marbled to Kittlitz's murrelets in KFNP has been estimated at 95:5 (Rice 1991). Kittlitz's murrelets are known to nest on the ground, generally above treeline, in areas of sparse vegetation (Day et al. 1983).

Data Collection

Surveys were conducted in KFNP between 8-29 July 1993 (Figure 1-1). The effects of habitat and location relative to bays was examined using survey stations selected with a stratified random sampling scheme. The four strata examined were: bay/forested, bay/non-forested, open shore/forested, open shore/non-forested. Ten sites were randomly selected in each strata. We used high altitude (1:65000) infrared photographs to determine forested and non-forested areas. Only sites with ≥12 ha (the approximate area of a 200 m radius circle) of contiguous forested or non-forested habitat were designated as potential sites. Non-forested sites could contain Sitka alder (*Alnus crispa sinuata*) and willow (*Salix* sp.), but few or no coniferous trees. Using 1:63360 topographic maps we defined "bay" as any bay or cove with a length greater than the width at the mouth. Bays with mouths >1 nautical mile across were not designated bays, since less protection is afforded from weather (particularly wind) in large bays. "Open shore" was defined as any stretch of shore longer than 0.5 nautical miles, that was relatively straight or formed a point, and was not within a bay.

A 21 m vessel served as a base of operations from which two sites were surveyed each morning. In most cases, an attempt was made to travel inland for the dawn watch. Steep topography usually made it difficult if not impossible to get inland; only two watches were conducted >500 m inland. Due to cliffs or poor options for vantage points, two surveys were done from the large vessel approximately 20 m offshore, and four surveys were done from an inflatable boat <10 m from shore.

<u>The Dawn Watch Survey</u>.--The basic sampling method was the intensive inventory survey (Ralph et al. 1993, hereafter referred to as a 'dawn watch'), with modifications for southcentral Alaska (i.e., beginning 105 min before sunrise and lasting until 15 min after sunrise; for details see Kuletz et al. 1994b). Dawn watches monitor murrelet pre-dawn activity, when birds fly from foraging areas to inland nesting areas. A 'detection' is the unit of observation defined as "the sighting or hearing of a single bird or a flock of birds acting in a similar manner" (Paton et al. 1990). The location of the observer during the dawn watch was the 'station', where observers recorded observations with hand-held recorders. Data collected for each detection included time, number of birds, distance from observer and types of behaviors, vocalizations and wing sounds. Behavior categories included those identified as 'occupied' (below canopy flights, landing or attempting to land on branches, or calling from stationary locations in forested areas), which indicate nearby nesting (Ralph and Nelson 1992). Occupied sites were those with at least one recorded occupied behavior. We used the term 'unknown status' for sites where no occupied behavior was observed, because a single visit was not sufficient to determine if a site was unoccupied (see Ralph et al. 1993). Occupied behaviors observed in non-forested areas have not been defined. In non-forested areas we noted the bird's height above ground and considered very low flights (<4 m from ground vegetation) as occupied behavior. Observers were trained to

identify murrelet vocalizations and behaviors and to estimate distances by personnel with several years experience conducting dawn watches. Trainees were evaluated by comparing their data to those collected concurrently by the trainer. During training surveys, distances of murrelets that were seen and heard were used to estimate distances to murrelets that were only heard.

Our observations indicated that vocalizations of Kittlitz's murrelets on the water and at active nests sound different from, and are made much less frequently than those of marbled murrelets (pers. obs.; Naslund and Piatt, unpubl. data). However, the presence of Kittlitz's murrelets on the Kenai Peninsula could potentially complicate observations. Special attention was paid to vocalizations and flight behavior, especially in non-forested areas, in an attempt to identify behaviors not typical of the marbled murrelet.

Surveys in PWS show a marked increase in murrelet activity around 10 July followed by a rapid decrease in early August (Kuletz et al. 1994b). Although surveys in the KFNP did not begin until 8 July, we examined seasonal effects. We also attempted to minimize seasonal effects on murrelet activity by conducting surveys in each of the four categories throughout the survey period.

Vegetation and Habitat Plots.--A 50 m radius plot was surveyed for vegetation characteristics at every dawn watch station >50 m in from the vegetative edge of the shoreline. The plot usually surrounded the station, but when the dawn watch was conducted from a boat, the vegetation plot was centered in the nearest habitat most visually representative of the area adjacent to the dawn watch site. At two stations, topography restricted access, and resulted in slightly smaller plot sizes. At forested sites, the data collected included: 1) plot elevation, slope and aspect, 2) percentage forest cover and percentage cover of dominant understory species (including alder and willow), percentage canopy cover and approximate canopy height within the 50 m plot, and 3) diameter at breast height (DBH), percentage epiphyte cover, and the number of platforms of the ten most central upper canopy trees (trees with crowns that are part of, or above, the predominate canopy). Platforms were any flat horizontal surface more than 10 m above the ground, with a diameter ≥15 cm in diameter (including moss) on a tree branch. Use of this definition rarely results in >1 platform per limb in the study area. Data collected in non-forested areas included: 1) percentage cover of trees and shrubs, 2) dominant plant species, 3) percentage cover of cryptograms (including ground moss and lichen), 4) percentage rock (including bedrock and loose rock) cover, and 5) general topographic features (elevation, slope and aspect). Besides alder and willow, dominant shrubs included blueberry (*Vaccinium* spp.), salmonberry (*Rubus spectabilis*), rusty menziesia (*Menziesia ferruginea*) and devil's club (*Echinopanax horridum*). Ground platforms were not quantified in non-forested areas.

For weather, we estimated percentage cloud cover and height of ceiling (designated as above or below the closest dominant ridge), wind speed, presence of fog, and presence of precipitation.

To test for an effect of glaciation on murrelet activity, we used Rice's (1991) definition for sites as 'disturbed', those that were still glaciated in the early 1900's, or 'mature', those ice-free since at least the early 1900's. Designations were based on geological survey charts delineating the historical boundaries of individual glacier fields (Post 1980a, b).

Data Analysis

We recorded all detections of murrelets, including those flying over land or water as well as murrelets on the water. Of the total number, for analysis, we only used those detections of murrelets that flew over land <200 m of the observer; these observations should most closely relate activity with habitat surrounding the survey stations. Preliminary analysis showed an increase in the numbers of detections after 19 July. The number of detections were significantly different before and after this date at forested sites (see results), so we standardized numbers of detections (Miller and Ralph 1995). Standardized numbers of detections, unless otherwise stated, were used for all analyses.

A general linear model (SAS Institute, Inc. 1988) was used to test for relationships between surveys conducted in forested, non-forested, bay and open shore on number of detections, and to examine the effect of observers and weather variables on numbers of detections. Sample sizes were equal and numbers of detections were log transformed to equalize variance. While numbers of detections were not normally distributed, the F test is robust under these conditions (Neter et al. 1990). We used Kruskal-Wallis procedure (SAS Institute, Inc. 1988) to test for differences in murrelet activity between early and late July, and between disturbed and mature sites. We also used Kruskal-Wallis to test for differences in habitat characteristics between forest/non-forest and bay/open shore sites.

RESULTS

Site Characteristics

Elevation, slope, and slope aspect were not significantly different between bay sites and open shore sites, nor between forested and non-forested sites (Table 1-1). General site characteristics for each of these four groupings were almost identical.

Forested sites were predominately covered with coniferous trees and were 94% forested, on average (SD=12.7). The remaining 6% consisted of peatland ('muskeg'), ponds, and steep rocky slopes. Non-forested sites had few, if any coniferous trees and were 50.5% (SD=21.0) covered by alder on average (vs a mean of 1.5% alder in forested sites). Excluding alder and willow, non-forested sites had a much lower shrub coverage than forested sites ($\bar{x}$= 21.0% and 69.6%, respectively) and had an average of 17% bare ground, a feature that was very rare in forested areas. Measurements of tree and forest characteristics (percentage forest and canopy cover, canopy height and average dbh, number of platforms, percentage epiphytes, percentage alder cover and percentage shrub cover) at forested sites revealed no significant differences between sites in bays and open shore sites (Table 1-1). Non-forested sites did not differ in alder and shrub cover between bays and open shores.

Murrelet Activity

We did not record any murrelet calls that could not be identified as marbled murrelets. We concluded that few, if any Kittlitz's were mistakenly recorded as marbled murrelets.

Observers estimated distance for 95% of the detections over land; detections of murrelets flying over land within 200 m of the observer accounted for 60% of the total number of observations. Differences in unstandardized detections for surveys before 19 July ($\bar{x}$=19.8, SD=19.6) and those after 19 July ($\bar{x}$=50.0, SD=46.6) approached significance (X^2=3.53,df=1, P=0.060). Unstandardized detections at forested sites were significantly different between early and late July (X^2=4.21, df=1, P=0.0401), but differences among the non-forested sites were not (X^2=0.057 ,df=1, P=0.881).

The total number of (standardized) detections for all 40 surveys conducted in KFNP averaged 32.8 (SD=31.2) per dawn watch. Surveys at forested stations had an average of 48.1 (SD=34.3) detections, and those at non-forested stations averaged 17.4 (SD=18.1). The number of detections was significantly different between forested and non-forested sites (F=12.23, df=1, P=0.001), but not between bay and open shore (F=1.94, df=1, P=0.172). Observer and weather variables did not produce significant results (P>0.8) or affect the significance of the other variables. The mean number of murrelet detections was highest at the forested/bay stations (54.9 per site) and lowest in the non-forested/open shore stations (10.7 per site; Figure 1-2). There was no significant interactive effect between forested/non-forested and bay/open shore categories (F=0.54, df=1, P=0.466).

Occupied behaviors were detected at 11 of the 20 forested stations and three of the 20 non-forested stations. Forested sites averaged 6.85 occupied behaviors per survey (SD=11.5) compared to 0.25 (SD=0.72) for non-forested sites. The number of occupied behaviors varied less between bay and open shore sites ($\bar{x}$=4.6 and 2.6 occupied behaviors, respectively). Six of 20 bay sites and eight of 20 open shore sites were occupied. For forested sites, 64% of the occupied behaviors were at bay sites and 36% at open shore sites. Only five detections of occupied behaviors were observed at non-forested sites; three at a bay site and two at an open shore site. Non-forested occupied behaviors included: 1) one bird making a very low pass and disappearing behind boulders, and 2) one bird flying to within one meter of a clump of alders. These areas were checked for signs of nesting, but none were found. Three occupied behaviors were birds making very low passes to within 4 m of the ground.

Eight of our stations were in areas defined as glacially disturbed. Only one of these was forested. While counts of murrelet detections at mature non-forested sites (n=13) numbered less than half of those from forested stations, mature non-forested sites had much higher activity than disturbed non-forested sites ($\bar{x}$=24.5 and 4.1 detections, respectively; $X^2=7.74$, df=1, $P = 0.005$). Two of the mature stations were identified as occupied.

At one non-forested, recently deglaciated site, on a steep rock and alder-covered slope, a marbled murrelet nest was discovered while hiking along a crevice (Appendix B). Only five audio detections were observed (all over land) during a dawn watch conducted <500 m from the nest site. Murrelets detected during this survey exhibited vocalizations and behaviors (primarily circling) similar to those normally observed in forested areas.

DISCUSSION

Murrelet activity in KFNP was significantly higher in old-growth forested habitat. Occupied behaviors in non-forested areas are not well defined, and other factors affecting the observation of ground-nesting marbled murrelets (e.g., different vocalizations and flight patterns) may influence the number of detections in these areas. Nonetheless, there was a significant difference in the number and types of behaviors seen in forested and non-forested areas. Although nesting occurs in non-forested areas, ground nests are much more likely to be discovered accidentally than tree nests. The low levels of activity and of occupied behaviors at non-forested sites suggests that nesting activity in non-forested areas is much less prevalent than in forested areas. These results are in agreement with the breeding season distribution of murrelets throughout their range, which shows most of the population along the forested areas of the eastern Pacific (Piatt and Ford 1993).

Unlike PWS, bay sites did not appear to have significantly greater murrelet activity than open shore sites, although the trends were in the same direction within forested and non-forested habitat. In KFNP, the presence of old-growth forest appears to be more important than the topography of bay versus open shoreline. Because variation in murrelet activity was high among surveys, our sample size may have been too small to determine a bay effect in the KFNP. In addition, the KFNP topography may be unique in the distribution of forested and non-forested habitat. Because much of the habitat is only recently ice-free and undergoing changes in vegetative cover, larger differences in habitat might exist between the southern and northern sections of the coastline, than between bays and exposed coasts. The more recently deglaciated heads of bays tended to be unforested, whereas the more exposed coastline near bay mouths and outer peninsulas were often forested. The steep topography throughout the KFNP may also provide some of the attributes, such as protection from wind, that bays provide in other areas.

Plant succession and forest development is limited by glacial activity in this area and there may be features present in mature habitat, forested as well as non-forested, that makes these areas acceptable to nesting murrelets. For example, in forested areas, larger trees may be found in areas uncovered >500 years, where soil has accumulated. In non-forested areas, more recently exposed areas lack moss and lichen cover. Moss cover, while not an essential nest material in ground nests (B. Rice, J. H. Hughes, pers. comm.) is often an important nest substrate in forested areas (Hamer and Nelson 1995; Naslund et al. 1994) and might be important to murrelets in mature non-forested areas. The ground nest found in KFNP during our surveys had a thick bed of moss as the nest substrate (Appendix B). However, moss and lichen cover averaged only 4% in non-forested areas, by our crude estimates, and did not differ significantly between mature and disturbed sites.

Forested areas may provide more potential nest sites than relatively two-dimensional non-forested areas. Microclimate conditions within a forest stand often promote the growth of abundant moss platforms, compared to the relatively sparsely vegetated non-forested areas. Furthermore, although both ground and tree nests may be concealed, a secretive approach to the nest may be easier in forested habitat. Trees provide an elevated platform from which to take off, and even the ground nests discovered in non-forested areas have been at the edge of cliffs or on a slope. Appropriate ground nest platforms may be less abundant than tree branch platforms.

In addition to the advantages of vegetation in mature areas, established nesting areas for these apparently semi-colonial birds (Naslund et al. 1994), probably have a tradition of occupation; disturbed habitat only recently made available for nesting may have not yet been discovered by breeding birds. Also, mature non-forested areas are often closer to forested areas (areas with high dawn activity) than disturbed sites, and the proximity of forests might contribute to murrelet activity observed at mature sites.

Finally, predation in nesting areas has been a key factor in shaping marbled murrelet ecology. Eggs, nestlings, and adults are vulnerable to both avian and mammalian predators (Singer et al. 1991; Nelson and Hamer 1995; Marks and Naslund 1994). Predators are common in forested and non-forested habitat in Alaska (Naslund et al. 1994); their local abundance likely has an important role in selection of nest sites. Differences in predation pressure between habitat types are unclear at this time.

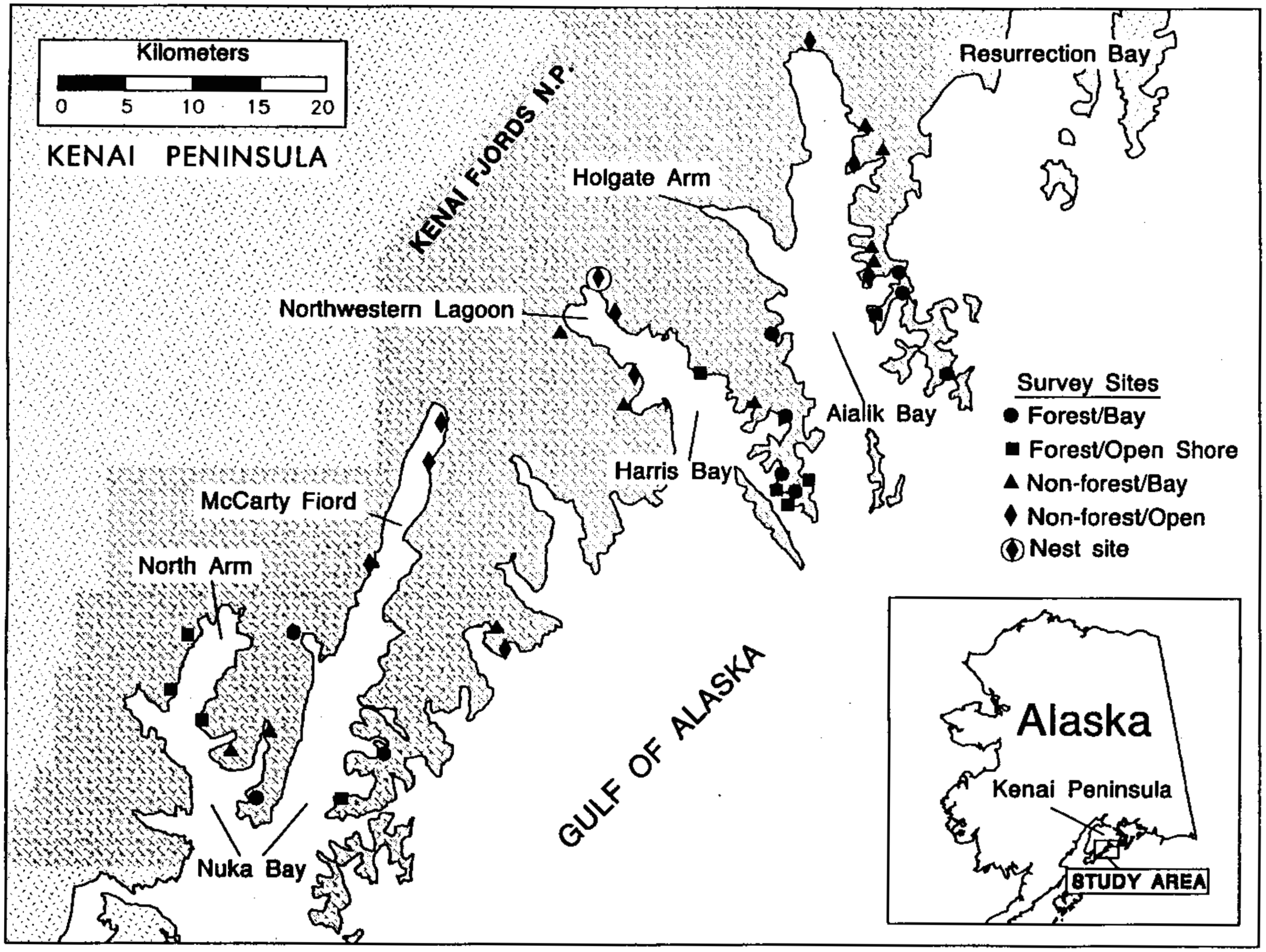

Figure 1-1. Location of marbled murrelet dawn watch stations in Kenai Fjords National Park, Alaska (N=40). Dawn watches were conducted 8 July-29 July 1993. The nest site was a ground nest of a marbled murrelet discovered on 11 July 1993.

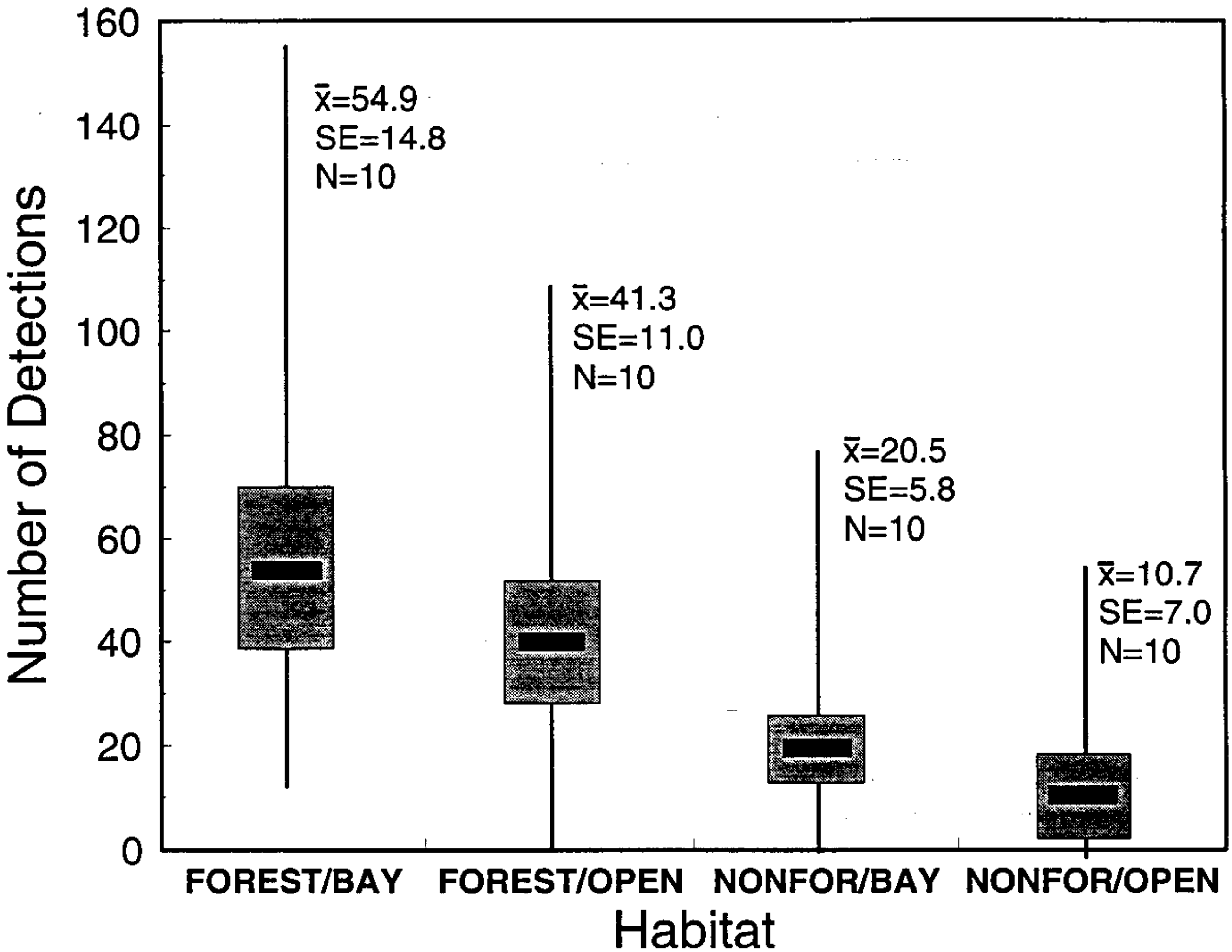

Figure 1-2. Means (± SE) and ranges for the number of marbled murrelet detections at sites surveyed in Kenai Fjords National Park, Alaska, between 8 - 29 July 1993 (N=40). Sites were equally divided into four strata: forested sites in bays (FOREST/BAY), forested sites near open shoreline (FOREST/OPEN), non-forested sites in bays (NONFOR/BAY) and non-forested sites near open shoreline (NONFOR/OPEN).

Table 1-1. Means and standard deviations for site and habitat charcacteristics for forested, non-forested, bay and open shore dawn watch sites in Kenai Fjords National Park in 1993.

	Means for habitat variables (± SD)			Means for habitat variables (± SD)		
Variable	Forested Sites	Non-forested Sites	P	Bay Sites	Open Shore Sites	P
Elevation (m)	27.1 ± 18.1	39.2 ± 70.9	0.184	31.3 ± 34.8	35.0 ± 64.8	0.538
Slope (degrees)	27.5 ± 12.8	27.5 ± 19.9	0.849	26.5 ± 13.4	28.5 ± 19.5	0.765
Aspect (degrees)	203.8 ± 76.8	216.0 ± 81.3	0.568	231.8 ± 76.5	188.0 ± 77.6	0.118
% Forest	94.0 ± 12.7	NA	NA	93.0 ± 16.4	95.0 ± 8.5	0.929
% Canopy cover	72.7 ± 19.3	NA	NA	69.5 ± 25.5	75.8 ± 10.6	0.989
Canopy height (m)	18.7 ± 6.1	NA	NA	19.7 ± 7.8	17.7 ± 4.0	0.896
DBH (cm)	57.3 ± 18.2	NA	NA	56.8 ± 18.2	57.8 ± 19.1	0.977
Platforms per tree	3.9 ± 3.1	NA	NA	4.2 ± 3.2	3.6 ± 1.0	0.836
% Epiphyte cover	51.2 ± 20.5	3.1 ± 3.9[1]	NA	47.5 ± 21.4	54.9 ± 20.0	0.616
% Alder cover	1.5 ± 2.3	50.5 ± 21.0	<0.001	24.8 ± 29.5	27.2 ± 29.0	0.653
% Shrub cover	69.6 ± 31.3	21.0 ± 27.6	<0.001	48.0 ± 36.7	42.5 ± 40.3	0.516

[1] % cryptograms (ground moss and lichen)

CHAPTER 2

QUANTIFICATION OF HABITAT FEATURES RELATED TO NESTING OF MARBLED MURRELETS IN SOUTHCENTRAL ALASKA

INTRODUCTION

The goal of this study was to develop a means of quantitatively ranking lands considered for protection according to their value to nesting marbled murrelets (*Brachyramphus marmoratus*). In previous analyses of the 1991 and 1992 surveys, we identified several habitat features associated with high murrelet activity and with actual nest sites. Murrelet dawn activity was highest in forests of large, old trees with high epiphyte cover (Kuletz et al. 1994a; Kuletz et al. 1994b). Murrelet nests found on Naked Island, Prince William Sound (PWS), Kodiak and Afognak islands (N = 14) were on moss platforms on the branches of large conifers with high epiphyte cover, in old-growth stands of large trees (Naslund et al. 1994).

However, habitat varies considerably throughout the spill zone and murrelets are known to nest on the ground in non-forested habitats. At least 10 marbled murrelet ground nests have been documented in southcentral Alaska (Day et al. 1983; J.Hughes, pers. comm.; B. Rice, pers. comm.; P. Mickelson, pers. comm., Appendix B, this report). It is unclear, however, how important ground nesting is to the marbled murrelet population. It is possible that ground nests of the Kittlitz's murrelet (*B. brevirostris*) have been mistaken for those of marbled murrelets. Additionally, ground nests are more easily discovered than tree nests, possibly inflating their relative numbers.

Marbled murrelet nesting habitat is not easily identified because murrelets are not colonial, are secretive when nesting and may nest up to 100 km inland (Carter and Morrison 1992). Two methods have been used to identify nesting habitat: intensive searches for nests, and dawn surveys (hereafter referred to as 'dawn watches'; Ralph et al. 1993) in which murrelets' dawn flights to their inland nests are monitored. Intensive nest searches have been used in California, Oregon, Washington, and British Columbia, where despite great expense and effort, few nests were found. In Alaska, surveys are limited by logistic considerations, due to great distances and inaccessibility of coastal habitats, and by the relatively short time available for breeding surveys (approximately late May through early August). Therefore, intensive nest searches were not feasible in our study area, and instead we used dawn watch surveys to identify nesting habitat.

During a dawn watch (see Chapter 1, this report), an observer counts each occurrence of murrelet(s) that is seen or heard as a 'detection'. Murrelet activity is considered a good indication that murrelets are nesting in the area (Ralph et al.

1993). In this study we assumed that dawn activity was positively related to nesting activity. We recognize, however, that no quantitative relationship between dawn activity and numbers of nesting murrelets has been defined, and conclusions about relative use of different habitats are tentative.

Four studies that investigated murrelet activity in relation to habitat features in Alaska were combined for this report. In 1991 we surveyed Naked Island, which was considered representative of forested habitat in PWS. In 1992 we surveyed throughout western PWS to investigate the use of boat-based and shoreline-based dawn watches, and to include a greater range of habitats (Marks et al. 1994). In 1992 the Division of Realty (USFWS) conducted surveys on Afognak Island in the Gulf of Alaska, to assess land parcels considered for habitat acquisition by the Trustee Council (Cody and Gerlach 1993; USFWS 1993). In 1993, we surveyed Kenai Fjords National Park (KFNP) to expand our coverage of the spill zone and to examine effects of forest cover and location relative to heads of bays on murrelet activity.

Despite differences in study design among the four studies, they provided a substantial basis for relating habitat variables to murrelet activity. We combined data from these studies to develop a broad-based model of murrelet activity in relation to weather, season, and habitat variables, that would apply throughout the spill zone. Specific objectives were to:

1. Develop a descriptive multiple regression model using weather, season, and habitat variables measured on-site to explain observed variation in levels of murrelet activity.

2. Develop a discriminant function to define characteristics of sites where occupied behaviors (indicating nesting), or high murrelet activity occur.

METHODS

Study Area

Surveys.--The study area encompasses western PWS, the Kenai Fjords National Park and two sections of Afognak Island (Figure 2-1). Naked Island, in central PWS, was surveyed between 10 June - 11 August, 1991 (N = 69). Other sites in PWS were surveyed between 15-18 July, 1991 (N = 9) and 12 June - 3 August, 1992 (N = 68). Afognak Island was surveyed on 4 June - 5 August, 1992 (N = 76). KFNP was surveyed on 8 - 29 July, 1993 (N = 40).

Murrelet Population Estimates for Regions.--The estimated *Brachyramphus* murrelet population for PWS is approximately 100,000 birds (Klosiewski and Laing 1994); approximately 7 % of identified murrelets were Kittlitz's murrelet (*B. brevirostris*). The waters within 5 km of Naked, Storey and Peak islands in central PWS, are estimated to have about 3000 murrelets, with < 1 % of identified murrelets being Kittlitz's murrelets (Kuletz et al. 1994c). At-sea surveys of the KFNP have been restricted to shoreline surveys (within 200m of shore) and complete counts in some bays. In 1989 there were an estimated 2000 *Brachyramphus* murrelets in this area in June, and 6500 murrelets in August; between 7-11% of identified murrelets were Kittlitz's murrelets (USFWS and KFNP, unpubl. data). At-sea surveys of Afognak Island in 1992 produced estimates of 2200 murrelets off the northern section and 2000 murrelets off the southwest section; no Kittlitz's murrelets were identified during these surveys (Fadely et al. 1993).

General Habitat.--PWS, the northernmost portion of the study area, is characterized by protected waters, numerous islands and bays, and deep-water fjords. Forested areas of mixed hemlock-spruce forests (*Tsuga mertensiana, T. heterophylla, Picea sitchensis*) are interspersed with muskeg meadows, alpine vegetation and exposed rocks (see Islieb and Kessel 1973, for a detailed description of habitats and vegetation). Tree line ranges from 30-600 m in elevation (Islieb and Kessel 1973). The fjords typically have tidewater glaciers at their heads. Glaciers and exposed rock are typical above 300 m.

The Kenai Fjords, on the southern Kenai Peninsula, are characterized by steep, rugged coastline, with protected waters and tidewater glaciers at the heads of fjords, and exposed coasts near the mouths, facing south or southeast into the Gulf of Alaska. Numerous islands extend from the mouth of the fjords and bays on the outer coast (see Bailey 1976 for detailed description). Large glaciers cover > 50% of KFNP (Selkregg 1974). Because receding glaciers expose new land toward the fjord heads, the forests are primarily in the outer, more exposed headlands and islands. Tree line is typically 300 m, and few areas beyond 500 m from shore are forested. Tree species are similar to PWS, and ground cover in unforested areas is dominated by alder shrubs. Excluding ice, the ratio of unforested to forested acreage is greater in KFNP than in PWS.

Two areas of Afognak Island were surveyed, both owned by Afognak Joint Venture Corporation. The northern parcel faces north into the Gulf of Alaska, and is characterized by one large bay and several small bays of forested slopes and no glaciers. Tree line ranges from 100-300 m. Sitka spruce is the only conifer on Afognak Island, and trees tend to be larger than on the Alaska mainland.

The second land parcel, on the southwest side of Afognak, faces west into Shelikof Straight and is characterized by two large bays of moderately steep slopes. Forests of Sitka spruce are scattered along river valleys and the heads of bays, but the majority of land is unforested, and dominated by alder, willow, low alpine growth or exposed rock.

Data Collection

Dawn Watch Surveys.--Murrelet activity was quantified using the intensive inventory (Paton et al. 1990), as defined in Chapter 1. We recorded windspeed, wind direction, precipitation, percentage cloud cover, cloud ceiling (none, above the ridge, below the ridge), and temperature for each dawn watch (see Chapter 1 for details).

Habitat Variables.--At each dawn watch station a vegetation plot was sampled (see Chapter 1). Forty of the PWS vegetation plots were done by the USFS. Otherwise, FWS biologists conducting the dawn watch also did the vegetation plot.

Study Design, Sampling and Analyses

Study designs and survey methods varied among areas. At Naked Island, we used stratified random sampling, where strata were USFS forest types defined by tree diameter (DBH) and volume of the stand. The 69 stations were located inland, although 21 were < 50 m from the shoreline. Survey stations were distributed equally among the four forest types (see Kuletz et al. 1994a).

In western PWS, 77 shoreline sections were randomly selected from established USFWS transects, and a station established near the midpoint of the transect (see Marks et al. 1994). Forty-six surveys were done from a boat, 23 from shore-based stations, and 8 stations were > 200 m inland.

At KFNP, sampling was stratified random in four habitats: forested heads of bays, forested open shoreline, non-forested heads of bays, non-forested open shoreline. The 40 survey stations were equally distributed among the strata. Twenty-one stations were surveyed from shore locations, 8 from boats and 9 from inland sites (see Chapter 1, this report).

At Afognak Island, 76 stations were arbitrarily selected and surveyed, although we attempted to distribute them equally throughout the two parcels. The northern area was predominantly forested and the southern area was predominantly non-forested. Two survey stations were located on shore and 74 were inland.

Sites were not randomly located within the entire spill zone. Therefore, our statistical results apply directly only to the sampled sites and caution should be used when making inferences about other areas. Application of results to the entire area is based on the assumption (supported by our observations) that the study sites were representative of habitat types throughout the spill zone. Our total sample size was 262 surveys, however, sample sizes varied among analyses due to missing records for the variables included in each analysis.

Because epiphyte cover and platforms were not recorded at Naked Island, we used Naked Island data for univariate analyses, and for initial multivariate regressions, but not for the final multivariate analyses. For analyses, we used detections over land $\leq$200 m from the observer because it produced stronger relationships with predictor variables in preliminary analysis of portions of the data set. Data from boat- and shore-based surveys were combined with inland survey data because these data are highly correlated (see Kuletz et al. 1994b). Data from all areas were grouped because preliminary analyses indicated that within-site trends were similar to trends exhibited for all sites combined.

Multiple Regression Analyses.--Our initial set of predictor variables were factors known or suspected to be associated with high activity or nesting of marbled murrelets, based on previously conducted analyses (Kuletz et al. 1994a; Marks et al. 1994) and known nests in Alaska (Naslund et al. 1994). These variables were examined with univariate statistics across the four study areas (except epiphyte cover and number of platforms per tree which were not measured in the Naked Island area) to determine the strength of their relationships with the observed number of detections. We used Kruskal-Wallis nonparametric analyses of variance to test categorical variables for significant effects on the number of detections. We calculated Pearson correlation coefficients between continuous variables and the number of detections, and between each pair of continuous variables. To control for colinearity, only one of a pair of variables with $r > 0.80$, whichever had the strongest correlation with the number of detections, was included in the same regression analysis.

Because categorical and continuous variables were included in the multiple regression model, we used a General Linear Model procedure (SAS Institute Inc., 1988) to examine variation in murrelet detections. Because untransformed data produced strong patterns in regression residuals we natural log transformed the number of detections and square-root transformed percent data (canopy cover, forest cover, alder cover, and slope) to stabilize residuals. Our initial regression model used all sites and included all significant ($P < 0.05$) categorical variables and those continuous variables which were measured across all four study areas. We ran a second regression model that included data from the 3 areas for which variables directly related to marbled murrelet nest site selection (epiphyte cover and platforms per tree) were estimated, and included all variables in the initial regression and epiphyte cover. Epiphyte cover and platforms per tree were highly correlated ($r = 0.84$) so only epiphyte cover was included. We reduced our final model to include variables with $P < 0.25$ in the original model. This criterion was selected because our objective was to include all variables that explained variation in murrelet activity. Standardized parameters (parameter estimates divided by their standard error) indicated the relative importance of variables included in the models (SAS Institute Inc., 1988).

Discriminant Analyses.--We used univariate tests and stepwise logistic regression to identify variables that could predict the probability of detecting occupied behavior at a survey site, or separate high from low activity sites. This analysis included a test of how well the logistic model performed in classifying individual observations. We tested frequencies of classes of categorical variables for differences between occupied sites (where one or more occupied behaviors were observed) and sites of unknown status using chi-square; and for differences in rank sums of continuous variables between occupied and sites of unknown status, using the Wilcoxon 2-Sample Test (procedure NPAR1WAY, SAS Institute Inc., 1988).

Significant variables ($P < 0.05$) in these tests were entered into two stepwise logistic regression models (procedure LOGISTIC, SAS Institute Inc., 1990). The initial model included all significant ($P < 0.05$) categorical variables and those continuous variables which differed ($P < 0.05$) between occupied and sites of unknown status, and were measured in all 4 study areas. Our final model was developed for the 3 areas for which variables more directly related to marbled murrelet nest site selection (epiphyte cover and platforms per tree) were estimated.

Logistic regression has the advantage over discriminant analysis that it is appropriate for categorical data and for continuous data that are not normally distributed. The logistic equation has the form:

$$P(y = 1) = EXP(G)/(1 + EXP(G))$$

where $P(y = 1)$ is the probability that a site will be occupied, and G is a regression equation, i.e.

$$G = A + B_1X_1 + ... + B_{iN}X_{In}$$

where A is constant; X_{i1}, X_{In} are the first and ith predictor variables in the model; B_1, B_N are the parameters for the first and nth terms of the model; and i = 1,2,3,4,...N are individual survey sites (Clutton-Brock et al. 1992). Inclusion and retention of variables in the stepwise logistic analysis were allowed at $P < 0.10$. We included platforms per tree in the final model because it performed marginally better than one including epiphyte cover. Standardized parameter estimates were estimated by dividing the parameter estimate by the ratio of the standard deviation of the underlying distribution to the sample standard deviation of the explanatory variable, and indicated the relative importance of variables in the model (SAS Institute Inc., 1990). The classification error rate was calculated using a jackknife approach to reduce the bias of classifying the same data from which the classification criterion was derived (SAS Institute Inc., 1990).

Univariate and logistic regression analyses were repeated using high activity sites versus low activity sites as the binary response variable. Relative activity of sites was determined by running a cumulative frequency distribution of number of detections for all surveys, and dividing it into thirds. Low sites were those with number of detections in the lower third of all surveys, and high activity sites were those with number of detections in the upper third of all surveys. Sites in the middle third were excluded to obtain the best separation between categories.

RESULTS

Marbled Murrelet Activity Relative To Weather, Survey Period and Habitat

Activity level of marbled murrelets differed by study area, with the greatest level of activity occurring at Afognak Island, the least at Naked Island, and intermediate levels in western PWS, and KFNP (Table 2-1). Activity was greater during late summer (11 July - 31 August) than during spring and early summer (1 May - 10 July; Table 2-1). Activity was greater when the cloud ceiling was low (below the nearest ridge) than when there was a high ceiling, or clear conditions (Table 2-1). Activity was also greater at survey sites located at the heads of bays, than at sites located on bays but not at the heads, or sites on exposed shorelines (Table 2-1). Survey method (by boat, from shore or inland), and windspeed did not significantly affect measures of murrelet activity (Table 2-1).

Correlation coefficients between marbled murrelet activity and continuous weather, topographic, and vegetation variables measured in all four areas varied from -0.16 for alder cover to 0.39 for DBH (Table 2-2). The largest correlation coefficients were between murrelet activity and epiphyte cover or platforms per tree (Table 2-2).

Our final multiple regression model was developed for western PWS, KFNP, and Afognak Island where epiphyte cover and platforms per tree were measured. Our reduced model explained 52% of the total variation in murrelet activity (Table 2-3). Parameters for survey period, location relative to the head of a bay, and epiphyte cover were highly significant ($P = 0.0001$). Based on ratios of parameters to their standard errors (Table 2-3), epiphyte cover, survey period, and location relative to the head of a bay, were the most important predictors of murrelet activity.

Identification of Occupied Sites and High Activity Sites

Occupied Sites.--The probability of observing marbled murrelet behaviors indicating nesting (occupied behaviors) was significantly greater at Afognak Island than at other areas, during inland surveys than during boat or shore surveys, during days with clouds than during clear days, and in bays (especially at heads of bays) than at exposed sites (Table 2-4). The probability of observing occupied behaviors did not vary with survey period or windspeed (Table 2-4). Cloud cover, forest cover, canopy cover, canopy height, DBH, epiphyte cover, and platforms per tree were significantly greater at occupied sites than at sites of unknown status (Table 2-5). Alder cover was greater at sites of unknown status than at occupied sites (Table 2-5).

For the three areas where all variables were measured, four variables that differed significantly between occupied and sites of unknown status (DBH, location relative to the head of a bay, survey method and platforms per tree) were incorporated into the final logistic regression model using $P < 0.10$ as the inclusion criterion (Table 2-6). Standardized parameter estimates (Table 2-6) indicated that DBH and platforms per tree were the most important predictors of occupied sites. The logistic function correctly classified 78.9% of observations in a jackknife procedure; 82.7% of occupied sites and 74.6% of sites of unknown status were correctly classified.

High Versus Low Activity.-- Probability of observing a high level of marbled murrelet activity was greater at Afognak Island and KFNP, intermediate in PWS and least at Naked Island. Murrelet activity was greater during late summer compared with spring-early summer, on days with a high percentage clouds compared with clear days, and on bays (especially at heads of bays) compared with exposed shore sites (Table 2-7). Cloud cover, forest cover, canopy height, DBH, epiphyte cover, and platforms per tree were greater at high activity sites than at low activity sites (Table 2-8). In contrast, alder cover and elevation were lower at high activity sites than at low activity sites. Probability of observing high murrelet activity did not vary with survey method or windspeed, when all sites were included (Table 2-8).

For variables that differed ($P < 0.05$) between high and low activity sites and that were estimated at all four study areas, survey period, location relative to the head of a bay, elevation, forest cover, and DBH were included in the first model at $P = 0.10$. For the three areas where all variables were measured, those variables that were significantly related to marbled murrelet activity ($P < 0.05$; Tables 2-7, 2-8), and epiphyte cover were entered into the initial model, and the final model included survey period, location relative to the head of a bay, elevation and epiphyte cover. Standardized parameter estimates (Table 2-9) indicated that epiphyte cover was the most important predictor of high activity. The logistic function correctly classified 86.5% of observations in a jackknife procedure; approximately 86.5% of both high activity and low activity sites were correctly classified.

Comparison of Discriminant Functions for Predicting Occupied Sites and High Activity

Although models using occupied sites and activity levels as binary response variables had elements in common, there were important differences between them. In univariate tests, most variables differed similarly between classes of both response variables. However, several did not. Survey period and elevation differed significantly between sites with high and low activity but not between occupied and sites of unknown status. Survey method and canopy cover differed significantly between occupied and sites of unknown status but not between sites with high and low activity. DBH and location relative to the head of a bay were included in logistic discriminant functions for both response variables. However, area and survey method were included only in logistic functions predicting occupied sites; and survey period, elevation, and forest cover were included only in logistic functions predicting high activity.

DISCUSSION

We conducted the two types of analyses, multiple and logistic regressions, because they served different management needs. The multiple regression examined the continuum of murrelet activity levels relative to independent variables, and examined the interactive effects of those variables. It also described the amount of variation explained by the model. For example, results suggested that the combination of head of bay, steep slope, northerly aspect, low elevation and large trees provide the best habitat for nesting murrelets. However, slope and aspect were not important across all survey areas and were likely localized effects dependent on prevailing weather patterns. Nonetheless, these features may be substantial contributing factors within a given area.

The logistic regression examined the features and conditions which separated areas in which occupied behavior were observed and areas in which they were not observed or high and low activity areas; it may be more useful for general management purposes over a large geographic area. This analysis included a test of how well the discriminant function performed in classifying individual observations.

Habitat Predictors Of Murrelet Use

Murrelet activity levels.--Several variables were consistent predictors of high murrelet activity, based on both multiple and logistical regression analyses. Correcting for survey dates (murrelet activity was highest in late summer), activity was highest at the heads of bays, at low elevations, and in areas with high forest cover and large diameter (DBH) trees. The most important habitat variables across all study areas were location relative to heads of bays and tree size (DBH). Where epiphyte cover and platforms per tree were estimated, these variables were the best predictors of murrelet activity.

The importance of tree size, platforms per tree and the seasonal timing of surveys was consistent with results from other studies and with attributes of nest trees found in southcentral Alaska (Hamer et al. 1991; Hamer 1995; Naslund et al. 1994). The importance of location relative to heads of bays was noted in earlier analyses of the PWS data (Kuletz et al. 1994a; Marks et al. 1994), but has not been reported elsewhere. Further, KFNP did not show a significant within-site trend for a bay effect (Chapter 1, this report). It is possible that high detection rates result from murrelets funneling through bay heads, using them as flyways. However, the consistency of high activity at bay heads throughout most of the study area, combined with the high proportion of occupied sites at bay heads, suggests otherwise.

High activity at bay heads may be a result of larger contiguous forests at bay heads, although stand size relative to landform has not been investigated for these areas. Marks et al. (1994) found that murrelet activity was positively correlated with stand size in western PWS. High activity levels of murrelets were also associated with large stand size in California (Paton and Ralph 1990). Large tracts of contiguous forest reduce habitat fragmentation, and may thereby reduce potential predators (Andren et al. 1985; Wilcove 1985; Andren 1992). Predators are an important cause of murrelet nesting failure (Singer et al. 1991; Nelson and Hamer 1995; Marks and Naslund 1994; Naslund 1993).

Microclimate and minimal exposure to weather at bay heads may contribute to the formation of features associated with known murrelet nesting habitat, including: epiphyte cover, potential nesting platforms on trees, and large tree size. Across all four areas combined, tree DBH ($X^2 = 7.58$, df = 2, P = 0.02), number of potential nesting platforms ($X^2 = 7.08$, df = 2, P = 0.03), and percent epiphyte cover ($X^2 = 6.73$, df = 2, P = 0.03) were greater at sites located at heads of bays than at more exposed sites. These trends were not evident at KFNP, likely due to the recent deglaciation of many of the bay heads (see Chapter 1).

The importance of tree size and elevation in predicting murrelet activity has been suggested in other studies. Murrelets typically nest in old-growth stands where trees tend to be relatively large (Hamer and Nelson 1995; Manley and Kelson 1995; Nelson 1989; Paton and Ralph 1990). Hamer et al. (1991) and Rodway et al. (1993) found that murrelet activity was highest in low elevation forests in California and British Columbia. In northern latitudes, larger trees are found at lower elevations (Viereck and Little 1972). Kuletz et al. (1994a) found a significant negative correlation between tree DBH and elevation measurements on Naked, Storey and Peak islands, where the highest elevation was only 460 m. Thus, the contribution of elevation to the model was likely due to its effect on patterns of vegetation.

Conversely, it is also possible that murrelets were detected more frequently at low elevations, as they moved from marine to terrestrial areas, because low elevation habitat tends to be closer to shore. Murrelets must pass over the shoreline to reach sites further inland. However, in some areas, murrelets leave the water and rapidly gain altitude before flying to distant inland sites (van Vliet, pers. comm.), and would not be detected along the shoreline.

Responses of murrelet activity to variation in slope, aspect and canopy cover were not consistent and may have been influenced by local geography. Activity was positively related to northerly aspect in regression models, reflecting findings of earlier analyses within one of the study regions. At Naked Island, murrelet activity tended to be higher on northerly slopes, possibly due to more high-volume forests on these slopes, or the prevalence of southeast winds (Kuletz et al. 1994a). Nests were found on Naked, Kodiak, and Afognak islands in stands that tended to face westerly or northeasterly (Naslund et al. 1994). Although canopy cover was positively correlated with activity in univariate analyses, it was negatively related to activity within multiple regression models. These results may reflect positive effects of canopy cover for nesting and negative effects on the observability of murrelets in forested areas (i.e., murrelets may be more difficult to see and hear in more dense canopies; Kuletz et al. 1994a).

Occurrence of occupied behaviors.--The influence of habitat features on the occurrence of occupied behaviors was similar to their influence on murrelet activity levels. In particular, the size of trees and the number of potential nest platforms were good predictors for observing murrelets exhibiting occupied behaviors. This is consistent with Alaskan tree nests that have been documented; most were located on large moss-covered platforms, often on the largest trees in an area (Naslund et al. 1994). Our results could be biased in that occupied behaviors in non-forested habitats have not been well defined. However, few behaviors obviously indicative of nesting were observed in non-forested areas.

Epiphyte cover, number of potential nest platforms, and tree size were clearly related. Therefore, inclusion of epiphyte cover or number of platforms resulted in similar models and these variables sometimes replaced DBH in models. It may be appropriate to measure only one of these variables in future studies. However, collecting data on all variables will insure compatibility with other studies in which only one variable has been measured. Further, collecting a variety of data may also be useful when interpreting other factors important to nesting murrelets (e.g., heads of bays) that are not well understood. In addition, the importance of some habitat features to nesting murrelets may vary geographically. For example, epiphyte cover may be important in Alaska, but not in other areas. Some murrelet tree nests at lower latitudes did not have moss as the primary nest substrate (Singer et al. 1991). Naslund et al. (1994) suggested that moss is more important as insulation in Alaska's severe climatic conditions. Additionally, moss increased platform size, which could be important where small trees predominate.

Nesting clearly occurs in non-forested areas (Day et al. 1983). However, the extremely low levels of general activity and of occupied behaviors at non-forested sites suggests that nesting activity in non-forested areas is less common than in forested areas. We conclude that murrelet nesting density is low in sparsely forested or non-forest areas. However, it is possible that differences in murrelet activity levels and behaviors in non-forested and forested habitats may not reflect actual differences in murrelet abundance. For example, murrelets may be more vulnerable to predation in open areas and therefore less active around ground nests.

Effects of Survey Methods

Survey method did not affect observation of murrelet activity, however, significantly more occupied behaviors were observed when surveys were done from inland sites rather than from the shoreline or a boat. In general, occupied behaviors cannot be observed at distances >100 m, due to the difficulty in discerning murrelets flying into or below canopy level (Naslund, unpubl. data). Thus, occupied behaviors may be hard to detect during surveys conducted from a boat because the observer may be 50-100 m from forest habitat. However, occupied behaviors were equally low in frequency during shoreline surveys (done from the beach), and it may be that these results reflect real habitat use, i.e., birds do not typically use trees close to the shoreline. Although murrelets sometimes nest within a few hundred meters of the shore (Naslund et al. 1994; Appendix B, this report), they may use areas along the shoreline less frequently than those further inland (Hamer 1995). While perspective is often very good from a boat or the shore, observers have more forested habitat around them in most inland areas, possibly increasing the chance of noticing an occupied behavior. In addition, effect of survey method was confounded with effect of survey area, because boat-based and shore-based surveys predominated at PWS and KFNP, while inland surveys predominated at Naked Island and Afognak Island. The latter had very high activity levels and large trees and the high occupied status rate could have been due to truly higher nesting densities.

Sources of Unexplained Variation

Our best multiple regression model explained 52% of the variation in murrelet activity. There were many potential sources of unexplained variation. Because sites were only surveyed once, day to day variation within the same area could have contributed to incorrect estimation of general activity level of a given site. Weather affects the activity level of murrelets at a given site (Kuletz 1991; Kuletz et al. 1994b; Naslund and O'Donnell 1995), and conditions which dampen murrelet activity or detectability, such as clear skies, bright moonlight, and high winds, might increase variability in activity between similar habitats. However, these effects were less important than habitat factors when years and areas were pooled. In addition, seasonal influences on murrelet activity have been documented throughout the murrelet's range (Nelson 1989; Kuletz 1991; Manley et al. 1992; O'Donnell 1993, O'Donnell et al. 1995).

Observer variability is often a source of variation in measuring murrelet activity (Kuletz et al. 1994b; C.J. Ralph, pers. comm.). We did not account for observer variability and because each area was generally surveyed by different observers, area effects could be partially due to observer variability.

The size and geographic range of the study area itself likely contributed to the variation in murrelet activity we observed. Weather, local topography and vegetation patterns varied throughout the spill zone. In addition, murrelet nesting distribution may vary with population size and availability of suitable habitat. For example, murrelets may be more dispersed in PWS if prime nesting habitat is widespread, whereas nesting density may be higher in good habitat on the Kenai Peninsula if suitable habitat is sparse. Thus the lower activity levels in PWS relative to KFNP, may reflect differences in habitat availability rather than suitability, between the two areas.

A major factor not considered in our models was the adjacent marine environment; availability of foraging habitat must ultimately determine the use of suitable nesting habitat. Thus, the apparent increase in murrelet dawn activity from PWS southwest along the Kenai Peninsula to Afognak Island may actually be a reflection of large-scale differences in prey availability. It is perhaps noteworthy that seabird colonies increase in frequency and size from PWS to the Kenai Peninsula and south along the Shelikof Strait (USFWS Seabird Colony Catalog database), presumably due to increased prey abundance. Information on the foraging ranges of nesting murrelets, and the distribution of the forage fish they depend on, would enable us to delineate important marine areas associated with murrelet nesting habitat.

CONCLUSIONS

These models primarily serve as descriptive tools until they can be tested with independent data. However, we were able to explain 52 percent of the total variation in Marbled Murrelet activity levels based on temporal, topographic, and habitat characteristics. Further, our results suggest an 83 percent success rate of classifying murrelet nesting habitat in the areas examined on the basis of occupied behavior. The features indicative of murrelet nesting habitat include low elevation locations near the heads of bays, with extensive forest cover of large old-growth trees. In some areas, such as the Kenai Fjords, location relative to bay heads may be less important. The best predictors of nesting habitat in forested areas are high epiphyte cover and large numbers of potential nesting platforms on trees. The most important predictors of murrelet activity were consistent with results of other studies in Alaska and at lower latitudes.

Some features, such as landform, topography, and forest cover, can be identified from topographic maps and timber type data, available on geographic information systems for some areas. The best predictors, high epiphyte cover on trees and large numbers of potential nesting platforms on trees, require on-site measurements, and could be used to evaluate among several similar land parcels.

Our results were derived from surveys designed to estimate murrelet use of forested habitat. Potential variation in murrelet behavior associated with habitat type (i.e., forest or non-forest) has not been adequately examined and could influence interpretation of our results. Therefore, caution should be exercised when extrapolating observed trends on a broad scale across the landscape.

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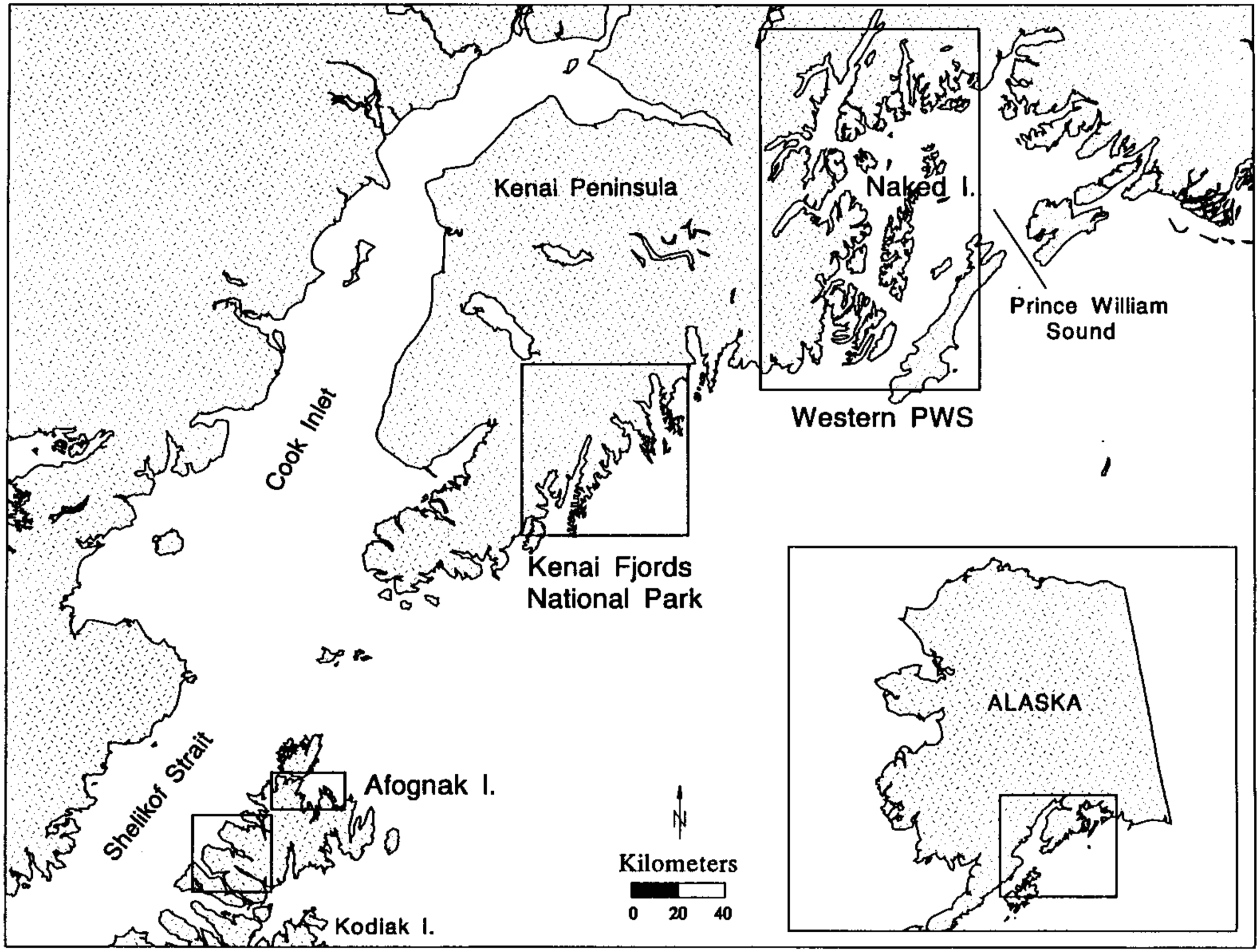

Figure 2-1. Map of southcentral Alaska, showing the four study areas included in the analysis of murrelet / habitat associations.

Table 2-1. The number of marbled murrelet detections for categorical variables considered for inclusion in multiple regression analyses. A Kruskal-Wallis nonparametric analysis of variance tested the null hypotheses that murrelet activity did not differ between (or among) classes of each variable.

Variable	Classes (N)	Number of Detections Mean (SE)	Chi-Square	DF	P
Area	Naked Island (69)	15.81 (2.27)	10.12	3	0.0175
	Prince William Sound (77)	23.79 (3.11)			
	Kenai Fjords (38)	29.92 (5.78)			
	Afognak Island (76)	38.41 (5.27)			
Survey Period	Early (May 1-Jul 10) (113)	18.06 (2.84)	11.03	1	0.0009
	Late (Jul 11-Aug 31) (147)	33.59 (2.96)			
Survey Method	Boat (54)	27.98 (3.62)	2.48	2	0.2890
	Shore (67)	23.61 (4.32)			
	Upland (139)	27.96 (3.10)			
Cloud Ceiling	None (26)	15.35 (4.05)	6.44	2	0.0398
	Above ridge (103)	35.10 (4.09)			
	Below ridge (68)	18.63 (2.90)			
Wind Speed	0 km/h (123)	31.07 (3.51)	6.51	3	0.0893
	1-8 km/h (103)	23.56 (2.86)			
	9-16 km/h (15)	11.47 (4.14)			
	>16 km/h (18)	28.61 (8.86)			
Headbay	Exposed shore (59)	16.61 (3.45)	27.75	2	0.0001
	Bay (106)	21.07 (2.62)			
	Headbay (95)	39.64 (4.28)			

Table 2-2. Pearson correlation coefficients between continuous variables considered for inclusion in multiple regression model, and murrelet activity (over-land detections <200 m from observer).

Variable	N	Pearson Correlation Coefficent	P
Percentage cloud cover	260	0.14	0.023
Elevation (meters)	229	-0.14	0.039
Percent slope	228	0.08	0.237
Degrees from north	228	-0.03	0.607
Degrees from east	227	-0.01	0.860
Percentage forest cover	224	0.24	0.0003
Percentage canopy cover	222	0.12	0.080
Canopy height (meters)	223	0.24	0.0004
Diameter at breast height (cm)	227	0.39	0.0001
Percentage alder cover	218	-0.16	0.020
Percentage epiphyte cover[a]	154	0.48	0.0001
Platforms per tree[a]	154	0.43	0.0001

[a]Not estimated at Naked Island

Table 2-3. Multiple regression model relating activity of marbled murrelets[1] to survey period, weather, topographic, and vegetation variables at three study areas: western Prince William Sound, Kenai Fjords National Park, and Afognak Island. Categorical variables were entered into the regression as dummy variables.

Parameter Model	Variable	Levels of categorical variables	Estimate (SE)	t^2	P	Standardized estimate
F = 15.21	Intercept		2.326 (0.421)	5.53	0.0001	
df = 10, 140						
$\underline{R}^2 = 0.52$	Period	Early	-0.851 (0.19)	-4.38	0.0001	4.39
		Late				
$\underline{P} = 0.0001$	Headbay	Exposed	-1.028 (0.281)	-3.66	0.0004	3.66
		Bay	-0.820 (0.200)	-4.10	0.0001	4.10
		Headbay				
	Elevation		-0.005 (0.002)	-3.03	0.0029	2.50
	Slope[3]		0.131 (0.053)	2.47	0.0148	2.47
	Degrees from north		-0.003 (0.002)	-1.86	0.0648	1.50
	Forest cover[3]		0.121 (0.070)	1.72	0.0700	1.73
	Canopy cover [3]		-0.120 (0.072)	-1.67	0.0964	1.70
	DBH		0.010 (0.006)	1.73	0.0863	1.67
	Epiphyte cover		0.018 (0.004)	4.73	0.0001	4.50

[1]Variable was natural log transformed.
[2]Tested null hypothesis that coefficient estimate = 0.
[3]Variable was square root transformed.

Table 2-4. Univariate tests for differences in frequencies of classes of categorical variables between occupied sites (where behaviors indicating nesting were observed) and other sites (where behaviors indicating nesting were not observed).

Variable	Class (N)	Proportion of occupied sites	Chi-square	DF	P
Area	Naked Island (69)	0.22	42.08	3	0.0001
	Prince William Sound (77)	0.22			
	Kenai Fjords (38)	0.32			
	Afognak Island (76)	0.66			
Survey period	Early (May 1-Jul 10) (113)	0.34	0.23	1	0.629
	Late (Jul 11-Aug 11) (147)	0.37			
Survey method	Boat (54)	0.24	14.56	2	0.001
	Shore (67)	0.24			
	Upland (139)	0.47			
Cloud ceiling	None (68)	0.23	7.74	2	0.021
	Above Ridge (103)	0.44			
	Below Ridge (63)	0.41			
Windspeed	0 Km/h (123)	0.37	1.704	3	0.636
	1-8 Km/h (103)	0.38			
	9-16 Km/h (15)	0.33			
	>16 Km/h (18)	0.22			
Headbay	Exposed shore (59)	0.22	9.42	2	0.009
	Bay (106)	0.35			
	Headbay (95)	0.46			

Table 2-5. Means, standard errors, and univariate tests for differences in rank sums of continuous variables between sites where one or more occupied behaviors (behaviors indicating nesting of marbled murrelets) were observed (occupied sites) and sites where no behaviors indicating nesting of marbled murrelets were observed (other sites).

Variable	Occupied sites			Other sites			Z[1]	P
	N	Mean	(SE)	N	Mean	(SE)		
Cloud cover	94	80.85	(3.76)	166	68.75	(3.33)	2.06	0.04
Elevation	87	51.65	(4.61)	140	71.70	(6.81)	-0.62	0.53
Slope	88	21.25	(18.52)	140	22.15	(12.89)	-1.30	0.19
Degrees from north	88	91.25	(5.53)	140	91.29	(4.51)	-0.05	0.96
Degrees from east	88	99.77	(6.00)	140	99.14	(4.61)	0.12	0.90
Forest cover	88	74.64	(2.64)	136	60.34	(3.00)	2.69	0.008
Canopy cover	88	63.26	(2.46)	134	49.69	(2.86)	2.54	0.01
Canopy height	88	26.71	(1.25)	135	17.31	(1.19)	7.94	0.0001
DBH	87	57.11	(1.98)	140	33.70	(1.77)	7.94	0.0001
Alder cover	86	3.03	(0.70)	132	10.90	(1.86)	-3.08	0.002
Epiphyte cover	72	54.57	(3.88)	82	16.78	(2.18)	7.06	0.0001
Platforms per tree	72	7.36	(0.67)	82	2.06	(0.38)	6.95	0.0001

[1] Wilcoxon 2-Sample Test

Table 2-6. Logistic regression model to predict probability of occupied sites of marbled murrelets (sites where one or more behaviors indicating nesting were observed) for the three study sites: western Prince William Sound (1992), Kenai Fjords National Park (1993) and Afognak Island (1992), Alaska (N = 152 sites total).

-2 Log L Chi-Square	df	P	Variable	Parameter Estimate (SE)	Chi-square	P	Standardized estimate
73.513	4	0.0001	Intercept	4.918 (0.903)	29.633	0.0001	
			Method	-0.679 (0.257)	6.970	0.0083	0.31
			Headbay	-0.559 (0.306)	3.331	0.0680	-0.26
			DBH	-0.040 (0.012)	11.320	0.0008	-0.56
			Platforms	-0.138 (0.057)	5.776	0.0162	-0.41

Table 2-7. Univariate tests for differences in frequencies of classes of categorical variables between sites where activity was high (upper one-third of numbers of detections), and sites where activity was low (lower one-third of numbers of detections). Observations with numbers of detections in the middle one-third for all observations were excluded from analysis.

Variable	Class (N)	Proportion of Sites With High Activity	Chi-Square	DF	P
Area	Naked Island (48)	0.35	7.94	3	0.047
	Prince William Sound (49)	0.49			
	Kenai Fjords (24)	0.58			
	Afognak Island (53)	0.62			
Period	Early (66)	0.35	10.52	1	0.001
	Late (108)	0.60			
Survey Method	Boat (39)	0.61	43.31	2	0.191
	Shore (39)	0.41			
	Upland (96)	0.50			
Cloud Ceiling	None (44)	0.36	6.84	2	0.033
	Above ridge (71)	0.61			
	Below ridge (40)	0.58			
Windspeed	0 km/h (81)	0.57	4.15	3	0.246
	1-8 km/h (65)	0.48			
	9-16 km/h (11)	0.27			
	>16 km/h (16)	0.44			
Headbay	Exposed shore (43)	0.30	19.83	2	0.0001
	Bay (65)	0.43			
	Headbay (66)	0.71			

Table 2-8. Means, standard errors, and univariate tests for differences in rank sums of continuous variables between sites where activity was high (upper one-third of numbers of detections), and sites where activity was low (lower one-third of numbers of detections). Observations with numbers of detections in the middle one-third of all observations were excluded from analysis.

Variable	High Activity			Low Activity			Z[1]	P
	N	Mean	(SE)	N	Mean	(SE)		
Cloud Cover	88	79.94	(3.96)	86	67.09	(4.80)	-2.19	0.028
Elevation	78	48.79	(4.57)	77	84.36	(10.09)	2.14	0.032
Slope	79	23.63	(1.75)	77	20.25	(1.61)	-1.31	0.190
Degrees From North	79	91.52	(6.16)	77	97.92	(6.00)	-0.68	0.498
Degrees From East	79	92.91	(6.06)	77	93.12	(6.25)	0.02	0.984
Forest Cover	79	77.04	(2.82)	73	55.41	(4.12)	-4.00	0.0001
Canopy Cover	79	61.92	(2.54)	71	48.41	(4.23)	-1.57	0.116
Canopy Height	78	24.78	(1.28)	73	17.36	(1.79)	-3.89	0.0001
DBH	79	53.17	(2.20)	77	31.79	(2.39)	-6.01	0.0001
Alder Cover	78	4.21	(1.25)	70	13.62	(2.93)	2.55	0.0106
Epiphyte Cover	62	51.83	(4.13)	43	14.58	(2.22)	-6.50	0.0001
Platforms/Tree	62	6.86	(0.71)	43	1.43	(0.49)	-6.26	0.0001

[1] Wilcoxon 2-Sample Test

Table 2-9. Logistic regression models predicting probability of observing high activity (upper one-third of number of detections) of marbled murrelets at an observation site in western Prince William Sound, Kenai Fjords National Park, and Afognak Island (N = 104).

-2 Log L Chi-Square	df	P	Variable	Parameter Estimate (SE)	Chi-Square	P	Standardized Estimate
73.655	3	0.0001	Intercept	4.133 (1.088)	14.416	0.0001	
			Period	-1.979 (0.721)	7.526	0.0061	-0.52
			Headbay	-1.693 (0.519)	10.636	0.0011	-0.71
			Elevation	0.014 (0.008)	2.760	0.0967	1.66
			Epiphyte	-0.074 (0.018)	17.332	0.0001	-4.16

APPENDIX A

Feasibility of Using Boat-based Marine Radar to Survey the Dawn Activity of Marbled Murrelets in Alaska

ABSTRACT

In July 1993 we conducted a pilot study to assess the use of a boat-based radar to study marbled murrelets (*Brachyramphus marmoratus*) in Alaska. Observations with a Furuno model FCR-1411 marine radar were made from a 24 m vessel at six sites in Kenai Fjords National Park, Alaska and were compared to standard murrelet surveys conducted from the deck of the boat or from a nearby shore. Errors in identification of murrelets on radar was extremely low. Topographic, vegetative, and weather constraints usually did not prevent radar sampling, although light rain on one morning did interfere. Radar detected 1.7 times more murrelets than human observers, but more data is necessary to refine a correction factor. The daily cost of radar surveys is higher than that for using observers, but radar covered more area in a single survey and may be cost effective. Radar could not detect murrelets once they flew inland; rather, it monitored their near shore activity and point of land entry. Thus, radar would be most effective for focusing intensive ground survey efforts inland and identifying high-density nesting habitat. A boat-based radar system could benefit murrelet studies in Alaska, given the coastal distribution of the species and the fact that many nesting areas are accessible only by boat.

INTRODUCTION

Murrelets are typically detected during the dawn activity period with both visual and auditory cues, and the data are used to determine if an area has nesting activity (Paton et al. 1990; Ralph et al. 1993). Because of poor viewing conditions during the dawn activity period and because of the species' cryptic coloration, small size, and rapid flight speed, most of the murrelet detections are auditory only. Thus, while relative dawn activity is an important indicator of murrelet nesting activity, it does not provide the true number of birds.

Radar has been used in ornithological research since the 1950's (Eastwood 1967). In 1992, a pilot study in northern California was conducted to determine if a modified marine radar system could be used to collect information that the standard survey technique could not provide (Hamer et al. 1993). These researchers used radar to monitor murrelet abundance, attendance patterns, flight paths, flight speeds, flight direction, and, occasionally, flight altitude at several timbered nesting areas. The ability of radar to discriminate murrelets from other species and to provide estimates of abundance was assessed by comparing radar data to simultaneous detections by ground observers. Using radar at inland sites, 2.2% of the bird targets were misidentified. At coastal sites, there were large numbers of shorebirds that had similar radar profiles to murrelets, and so the identification error rate was higher (12%). Radar could monitor murrelet movements regardless of light conditions, fog, or background noise, and did not have the bias of variability in the skill levels, hearing abilities, or visual acuity of ground observers. On average, radar detected murrelets 1.8 times more often than did ground-based observers. Radar detected murrelets out to 1.3 km and could survey an area 42 times as large as a ground-based observer.

Radar had three limitations. First, the identification error was unacceptably high at coastal sites. Second, some sites were not suitable for radar observation because of the surrounding topography and vegetation. Large areas of ground clutter, which is created by echoes from surrounding hillsides and vegetation, can obscure echoes of murrelets on the radar monitor. In general, wide valleys, with low relief and some openings in the vegetation, were the most suitable for radar observation. Third, while radar could be used to observe murrelets circling over a stand, it could not distinguish the 'occupied behaviors' listed in the survey protocol (e.g., flying below the canopy, landing, or calling from a stationary location; Ralph et al. 1993).

In 1993, USFWS conducted a study in Kenai Fjords National Park (KFNP) as part of the marbled murrelet restoration project. This pilot study was undertaken to determine if a boat-based radar system could collect useful information on marbled murrelets under Alaskan conditions. Surveys using standard protocol are limited over large areas, and a boat-based method that could cover the spill zone would assist in mapping murrelet nesting habitat.

OBJECTIVES

The specific objectives of this pilot study were:

1. Determine if a boat-based radar system could be used to monitor murrelet activity in steep, coastal areas.

2. Determine if radar data could be used to calculate a correction factor for converting dawn watch counts into estimates of absolute abundance.

3. Compare the coverage, accuracy and cost-effectiveness of radar to human observers.

METHODS

We made observations from a 24 m vessel, at six sites in KFNP, between 21-27 July 1993 (Fig. 1). These six survey sites were randomly chosen as part of the murrelet habitat study (see Chapter 1, this report), rather than being chosen as ideal radar observation sites. Thus, the study sites probably were representative of realistic survey conditions in Alaska.

We used a Furuno Model FCR-1411 marine radar, which has been used for other bird studies (Cooper et al. 1991). It transmitted at 9410 Mhz (i.e., X-band) through a slotted waveguide 2 m long; the peak power output was 10 Kw. This radar could be operated at a variety of ranges from 0.5 km to 133 km. Pulse length could be set at 0.08, 0.6, or 1.0 msec, depending on the range setting used. At the shorter pulse lengths, echo definition is improved (i.e., greater accuracy on target location and distance), whereas at longer pulse lengths, echo detection is improved (increasing the probability of detecting a target). (Note: a target is one or more flying birds; an echo is a picture of a target on the video screen.) This Furuno radar has a digital, color display with color-coded echoes (to differentiate the strength of return signals), on-screen plotting of a sequence of echoes (to depict flight paths), and True North correction for the display screen. A plotting function records the location of a target at selected intervals (15 or 30 sec or 1, 3, or 6 min). Because time intervals are fixed, ground speed is directly proportional to the distance between consecutive echoes and can be measured with a hand-held scale. In addition, an alarm function can be set to sound when echoes above a certain signal strength appear on the screen.

There was no space to mount the Furuno radar antenna on the superstructure above the vessel, so we mounted it on the railing of the foredeck. In this position, a 24° shadow zone behind the vessel was created by the wheelhouse. The ship's generator was loud and precluded observers from conducting dawn watches, so we used two 12-V batteries hooked in series to power the radar. The battery system we normally use will power the radar for approximately 14 h. However, the batteries used during this study only provided 0.5-1.5 h of power.

During the first day of sampling, we used the ship's radar to determine if it also could be used to monitor murrelet movements. The Goldstar Turbo 951 transmitted at 9410 Mhz through a slotted waveguide 0.5 m long; the peak power output was 5 Kw. This radar could be operated at ranges from 0.5 km to 66 km. Pulse length is 0.08 or 0.65 msec, depending on the range setting used. The Goldstar radar, which has a nine-inch, monochrome display, was powered by the vessel's 12-v power supply, and the antenna was mounted above the wheelhouse.

Whenever energy is reflected from the ground, surrounding vegetation, and other objects that surround the radar unit, a ground clutter echo appears on the display screen. Ground clutter can be caused by field stubble as little as 0.5 m high. Because ground clutter can obscure bird targets, we attempted to minimize it by elevating the forward edge of the antenna and by using a ground clutter reduction screen, as described in Cooper et al. (1991). Clutter also can be reduced by placing the radar in locations that are closely surrounded by trees, buildings, or low hills. These objects act as a radar fence that shields the radar from low-lying objects farther away and produces only a small amount of ground clutter in the center of the display screen.

Maximal distances of detection of birds by the Furuno radar depends on body size, flock size, flight profile, atmospheric conditions, and, to some extent, the amount and location of ground clutter. Single marbled murrelets usually are detectable to 1.3 km (Hamer et al. 1993).

One of the limitations of radar is that it frequently is difficult to identify targets to species. By using a combination of target speed, target size, and flight behavior, we usually can determine the species group represented by the target (e.g., waterfowl vs. raptor), but identification to species is impossible unless that species has flight characteristics unique to birds in that area (for a more in-depth discussion, see Cooper et al. 1991).

We operated the radar 0.5-1.75 h/day between 21-27 July. We could not collect data during rain, because the adjustments required to remove the echoes of the precipitation from the display screen also removed bird-caused echoes. A standard dawn watch (following Ralph et al. 1993, see Chapter 1, this report) was conducted from the deck of the boat, concurrently with radar observations. On four days, dawn watches also were made concurrently from a nearby shore.

Each morning, we operated the radar at the 1.4-km range for as long as the power source lasted during the peak of the dawn activity period. For each target that we observed on the screen, we recorded the following information: date, time, species (as determined by the radar observer; any target flying $\geq$ 48 km/h was considered to be a murrelet), species (as determined by the boat-based observer), and flight behavior (straight, circling, or erratic). When possible, we also recorded direction of flight, flight speed (measured with radar), and distance to bird (measured with radar and estimated by the boat-based observer). We recorded the total number of detections recorded by the boat-based and ground-based dawn watch observers during the radar sessions.

RESULTS

The vessel's Goldstar radar was not suitable for monitoring murrelets. Although we detected several Glaucous-winged Gulls out to approximately 400 m on this radar, it was not powerful enough to detect murrelets consistently (it is possible the unit once may have been able to detect murrelets, but lost sensitivity as the magnetron wore out with use). On 21 July, we detected murrelets only four times using this radar, whereas the boat-based observer detected murrelets 123 times (Table 1).

During surveys with the Furuno radar, weather was excellent and we had only one day on which the rain made radar sampling impossible. Large, choppy waves also can make radar sampling difficult by obscuring marine areas with wave clutter. The small waves and smooth swells that we experienced did not cause any problems with radar sampling. Although waves could be a serious hindrance to radar sampling on the outer coast, they were not a major problem in the sheltered fjords and bays.

For those radar observations with a confirmed identity (N=51), the error rate was low. All targets that were observed both on the radar and by ground observers, and called murrelet targets on the radar, were murrelets. Additionally, of the 11 radar targets that we called non-murrelets, five were Black-legged kittiwakes (*Rissa tridactyla*), two were Glaucous-winged Gulls (*Larus glaucescens*), and four were unidentified gulls. The mean flight speed (±SD) of known marbled murrelets was 66 ± 4 kph (range = 56-72 kph; N = 19 targets).

When we compared the estimated distance to birds to actual distance measured on radar [where % difference = ((distance measured on radar - estimated distance)/distance measured on radar)*100], the mean percent difference was 0% ± 31% (range = -69% to +50%; N=15). This means that distances estimated by humans were usually within 31% of distances measured by radar; observer estimates for birds ≤200 m away were usually within 62 m of the distance measured by radar.

The performance of the Furuno radar in detecting murrelets was better than humans at every location (Table 1). On average, radar observed 3.4 ±2.5 (range= 1.7-9.1; N= 8) times as many murrelet targets than did human observers. The greatest difference between human observers and radar occurred at James Lagoon (9.1 times as many on radar). At this site, many of the murrelets detected by radar were flying up the east arm of Nuka Bay and not into James Lagoon, and they may not have been within audio range of observers. All other sampling locations were in the heads of bays, where we did not observe many transient birds.

To calculate a preliminary correction factor for the standard dawn watch counts, we compared those radar targets within approximately 500 m of the boat with the total number of detections on concurrent dawn watches by human observers. We did not include the data from James Bay to calculate the correction factor, because of the large number of transient birds there. The radar counted a mean of 1.7 (±0.9; range= 1.2-3.4; N=6) times as many targets within 500 m of the radar as did human observers.

DISCUSSION

Our results indicate that boat-based radar surveys can be used to study murrelet activity at most sheltered marine locations in Alaska. Our locations were probably representative of the area, but they were not ideal for observing murrelet movements, by radar, over land. Most of the land was steep and thus obscured by ground clutter; marine areas were clutter-free. To use the radar to detect murrelets over land, it would have been necessary to position the boat carefully to minimize ground clutter.

The error rate in identification of murrelets on radar was extremely low, and topographic, vegetative, and weather constraints usually did not prevent radar sampling in this study. Radar monitored murrelet movements regardless of light conditions, fog, and background noise. Several alcid and waterfowl species with flight speeds similar to murrelets occur in KFNP. However, only a single Pigeon Guillemot was observed during the sampling period. The dawn activity period of murrelets does not appear to coincide with other alcid activity in the area, reducing the identification error of radar targets.

More data will be necessary to refine a correction factor but, on average, the radar had 1.7 times as many murrelet detections than did human observers. Although in KFNP steep terrain limited radar range, in Washington (Hamer et al.

1993) radar could detect murrelets as far away as 1.3 km, and could survey an area approximately 42 times as large as a ground-based observer. Because the radar did not always detect birds that flew only over land, it could underestimate birds as well. However, because signals of circling murrelets were sometimes lost, it is possible that an individual bird was counted more than once on radar. For these reasons, the correction factor cannot be used to calculate an absolute count, but may more closely estimate the actual numbers of murrelet detections in an area than can human observers. However, because most human observations are ≤200 m from the observer (Kuletz et al. 1994), a more accurate correction factor would need to take into account the area within 200 m of the radar. This refinement will require further work.

In California, Hamer et al. (1993) compared the number of radar targets within 700 m to the number of ground-based detections and calculated a correction factor of 1.5X. We suspect that the correction factor was lower in California because ground observers were located near the only nesting stand in a particular area, which concentrated the birds and made them relatively easy to detect and count. In KFNP, both murrelets and murrelet habitat are more widespread, making censusing more difficult. Although our sample size was low, our results indicate that human observers were reasonably accurate, in detecting murrelets and their distances, for our needs.

The murrelet flight speeds we observed were similar to other areas. In California, the mean flight speed was 77 kph (range = 56-105 kph; N = 134 targets; Hamer et al. 1993). Burger and Dechesne (1994) used radar and found marbled murrelet speeds to be 66.0 + 14.1 km/h (range 30-100; N=46).

It is difficult to compare the cost effectiveness of radar versus human observers because cost will vary with different applications. However, assuming that a standard dawn watch survey requires two people (for safety reasons) at ~$100 per day, cost is ~$200 per survey. This is in addition to vessel, crew and provisioning costs, which should be approximately equal for both methods. The rental cost of the radar plus a radar technician was $550 per day. Thus, on a survey by survey basis, radar is more expensive. However, if coverage is taken into consideration, radar may be less expensive given that several surveys, with human observers, may be needed to cover the same area as one radar survey. Other considerations may be days lost to weather and sea conditions (see discussion of radar clutter) and technical failures, of which radar is more vulnerable.

The purpose of the restoration study, of which this work was a small part, was to delineate high-density marbled murrelet nesting habitat. This pilot study has shown that radar techniques could supplement such a study. For example, at the sites where terrestrial movements could be monitored with radar, one could overlay habitat information on the radar display screen and count the number of murrelets flying into or out of each habitat type within approximately 1.3 km of the boat. These data would provide information on habitat associations (if one assumed that birds flying into an area used it for nesting). Small bays could be monitored from a single location, rather than with several ground-based observers.

In areas where terrestrial movements could not be observed with radar, one would have to assume that most of the murrelets flying over water towards land would use the adjacent terrestrial habitat near the point of entry and then use these over-water counts as an index of terrestrial use. Field tests in areas where both terrestrial and overwater movements could be monitored with radar would be necessary to validate this assumption. In all areas, radar could be used to focus intensive ground survey efforts at the most likely inland sites, based upon the amount of overwater dawn activity.

A boat-based radar system may be especially appropriate for murrelet studies in Alaska, given the coastal distribution of the species and the fact that many of the nesting areas are accessible only by boat. Additionally, with further study, radar might be applied to address the following:

1) to monitor morning attendance patterns throughout the breeding season to determine whether seasonal fluctuations in dawn watch counts occur because of changes in the numbers of birds or their behavior (i.e., do birds call or circle more often during the July peak?);
2) to monitor the frequency of silent, nocturnal visits during chick rearing;
3) to determine the maximum distance that observers can see and hear murrelets, in a various habitats, to determine if the dawn watch survey protocol could be modified to increase the area that a ground-based observer could sample from a single point;
4) to determine how many calls/detection are required for a ground-based observer to accurately determine the flight direction of a flying murrelet.

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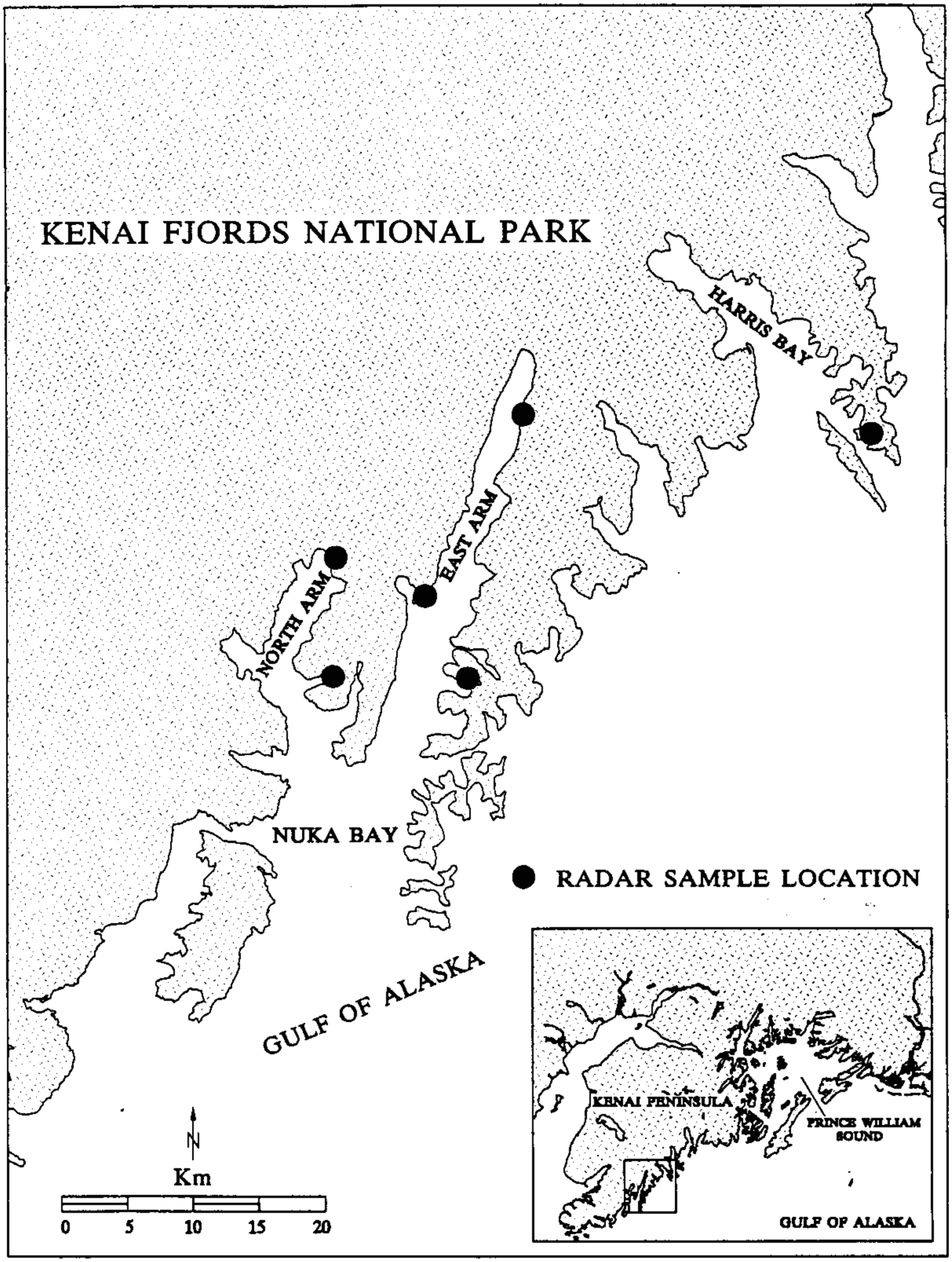

Figure A-1. Sampling locations for radar observations of marbled murrelets in Kenai Fjords National Park, Alaska, during July 1993.

Table A-1. Sampling locations, dates, and times and number of murrelet detections by radar, boat-based observers, and ground-based observers at each location in Kenai Fjords National Park, Alaska, during July 1993.

			Number of Detections			
			Boat-based Radar		Boat-based Observer	Ground-based Observer
Date	Location	Time(s)	within 1300 m	within 500 m	within 500 m	within 500 m
21 July	Fire Cove	0345-0530	4[a]	4[a]	123	ND[b]
22 July	Fire Cove	0407-0516	439	439	128	ND[b]
23 July	Moonlight Bay	0400-0610[c]	134	83	69	68
24 July	James Lagoon	0345-0512	338	138	37	82
25 July	McCarty Glacier	ND[d]	ND[d]	ND[d]	7	1
26 July	N.Arm Nuka	0439-0535[c]	211	118	74	ND[b]
27 July	Quartz Bay	0406-0428	51	41	29	30

[a]The ship's radar (Goldstar) was used on this date.
[b]No data (location of ground observers was beyond the range of the radar).
[c]A portion of the radar session was canceled due to rain or power failure.
[d]No radar sampling possible due to of rain.

APPENDIX B

Discovery Of A Marbled Murrelet Nest In Kenai Fjords National Park, Alaska

INTRODUCTION

Although marbled murrelets (*Brachyramphus marmoratus*) appear to nest in the forested areas of the KFNP (Chapter 1, this report; M. Tetreau, unpubl. data), several ground nesting marbled murrelets have been discovered in non-forested areas along the southern Kenai Peninsula and nearby Barren Islands (Simons 1980, Hirsch et al. 1981, B. Rice pers. comm., J. Hughes pers. comm.). While conducting dawn surveys in July of 1993 for marbled murrelet activity as part of Restoration project 93051B, we discovered and documented a marbled murrelet ground nest in the Kenai Fjords National Park (KFNP) on the southern Kenai Peninsula in southcentral Alaska. Here we report on the discovery and status of the nest, and describe nest and habitat.

STUDY SITE

The nest was located in Northwestern Lagoon, in upper Harris Bay on the southern coast of the KFNP (Figure B-1). The lagoon is set off from Harris Bay by a moraine left by the retreating Northwestern Glacier, which covered the entire lagoon in 1894. Several steep glacial valleys with retreating glaciers at their heads still occupy the lagoon. The nest (59° 48' 13.1" N, 150° 0' 39.5" W) was found at the mouth of the Northeastern Glacier valley, located toward the head of Northwestern Lagoon. The valley was only recently deglaciated, sometime between 1942 and 1964 (probably much closer to 1964; Post 1980). Large stands of mature mountain hemlock (*Tsuga mertensiana*) and Sitka spruce (*Picea sitchensis*) are found in KFNP, but conifers are small and extremely sparse in this valley. Rice (pers. comm.) reports that only Sitka spruce is found here. Sitka alder (*Alnus sinuata*) and willow (*Salix* spp.) are the predominate tree species in the area.

NEST DESCRIPTION AND STATUS

The nest was discovered on 11 July 1993 when an adult murrelet was disturbed and flushed from the nest. The nest was located approximately 30 m from the ocean at 20 m elevation, near the edge of a steep rock ledge on a 45° slope that faced southeast. A 50-m radius plot, with the center ~10 m from the nest site, showed the slope to be approximately 60% covered with vegetation, about 50% of which was Sitka alder, 3-5 m in height. Other plants included small willow (1-3 m tall) and fireweed (*Epilobium* sp.). Moss and lichens covered 10% of the ground in a 25 m radius plot around the nest, leaving 35% of the slope bare rock. There were only traces of soil and plant litter present on the slope. The steep rock wall had cobble and boulders (0.1 m to >1 m diameter) perched on the ledges and gentler sloping pitches.

The nest cup was concealed by alder and willow branches and leaves surrounding it. The cup was 10 x 4 cm and consisted of a 3 cm deep, well-formed cup in a thick (4-5 cm) bed of moss overlying the bedrock of the slope. Additional moss appeared to have been placed at the front of the nest making the cup 4 cm deep at the front. The following day, an adult marbled murrelet was on the nest (and photographed). The adult bird was virtually invisible on the nest from <10 m away. However, with binoculars, the brown back, marbling and dark cap extending below the eye was visible.

When first discovered, the nest contained an egg. The 5.5 x 3.4 cm yellowish-green egg had dark blotches up to 6 mm across which were more dense and formed a thick ring toward the large end of the egg. No sign of pipping was visible. We returned to check the nest on 21 July. A 122 g downy chick was present in the nest. The down was mottled brown and gold over most of the body, turning to gray on the belly. Measurements were taken with dividers and a ruler, to the nearest 1 mm. Tarsus length was 18 mm, wing chord length 50 mm and culmen length 11 mm. Primary feathers were 90-95% in the shaft. The chick appeared healthy and energetic, occasionally biting and trying to free itself when being handled for measurements. A fecal ring was present and covered almost the entire circumference of the nest.

We checked the nest again on 30 July. There was no sign of the chick or its down on or around the nest and there was no fecal ring on the moss platform.

DISCUSSION

The nest appeared to be very similar to several other marbled murrelet ground nests, where the nest itself was placed on a platform of vegetation. The nest was also similar to tree nests found in Alaska in that a thick moss platform served as the nest platform and the nest was well concealed by overhanging tree branches. Additionally, it had a high perch with a steep drop to the ground and water below (Naslund et al. 1994).

The yellow-green on the egg had brownish markings and was typical of marbled murrelet eggs previously described (Kiff 1981; Day et al. 1983; Singer et al. 1991; Nelson and Hardin 1993; Kuletz and Naslund, unpubl. data). Because of our observations of the adult on the nest, and of the egg and chick, we are certain this was a marbled murrelet nest. Photographs of the nest and chick are on file at USFWS, 1011 E. Tudor Rd., Anchorage, AK 99503.

In other alcids that have been observed, hatching can occur over several days. In two species of *Synthliboramphus* murrelets hatching occurs on the second to the fifth day after the first cracks in the egg shell appear (Sealy 1976; Murray et al. 1983) Since the egg was not yet pipping on 11 July, the age of the chick on 21 July was probably less than 9 d. Growth appeared to occur rapidly between the first and second visit, when a 122 g chick was present. This weight is slightly greater than that recorded for a 10 day old chick (100 g) at another ground nest in Alaska, and only 25 g less than observed fledging weights of 140-150 g (Hirsch et al. 1981). Nestling weight can fluctuate widely due to feedings, which can be up to 50% of an alcid chick's body weight per day (Bradstreet and Brown 1985). The time from the earliest possible hatching date of 12 July to the final check on 30 July was 18 d, far fewer than the 27-28 d observed for fledging dates at previous nests (Simons 1980; Hirsch et al. 1981). While fecal rings may disappear quickly after fledging (Nelson 1991), the lack of a fecal ring on the last nest check suggests that the chick had not recently occupied the nest. Also, there was no down evident in or around the nest. Because marbled murrelet chicks pluck all their down off prior to fledging, it is unlikely this chick fledged.

It is possible that the disappearance of the chick prior to the expected fledging date was due to predation. No predators were seen in the immediate area during this our visits, but predatory birds-- bald eagles (*Haliaeetus leucocephalus*), common ravens (*Corvus corax*), northwestern crows (*Corvus caurinus*), black-billed magpies (*Pica pica*), glaucous-winged gulls (*Larus glaucescens*) and mammals-- mink (*Mustela vison*), river otters (*Lutra canadensis*), wolverines (*Gulo gulo*), coyotes (*Canus latrans*) and black bears (*Ursus americanus*) occur in Harris Bay and throughout the Kenai Peninsula.

Only two detections were observed over land during the single dawn survey conducted (12 July) in the area, <500 m from the nest site. This is considerably less than the numbers of detections recorded in forested areas ($\bar{x}$=48.1) and non-forested areas ($\bar{x}$=15.6), in KFNP (see Chap. 1, this report). The two detections during this watch were similar in vocalizations and behaviors (primarily circling) to those observed in forested areas. Although the behaviors of ground nesting marbled murrelets are relatively unknown and may differ from tree-nesting birds, our observations did not indicate a substantial difference in dawn behavior at this ground nest site. The low amount of activity suggests low nesting density at this site.

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Figure B-1. Location of marbled murrelet (*Brachyramphus marmoratus*) nest site discovered on 11 July 1993 in Kenai Fiords National Park, Alaska.

APPENDIX C

Mosses and Lichens Found on Trees Used by Marbled Murrelets and In Marbled Murrelet Nest Stands In Alaska

Samples of epiphytes were collected from coniferous trees on Naked Island, Prince William Sound, and on Kodiak and Afognak islands, Alaska, in 1991 and 1992 (see Naslund et al. 1994; Kuletz et al. 1994). Trees sampled included those that marbled murrelets used for nesting or landing as well as other trees that were searched for nests but where nests were not found. Tree climbers collected samples of epiphytes from nest cups, nest branches, and landing branches. Climbers attempted to collect representative samples of all species that appeared different to the naked eye. Climbers also collected any apparently different species that they encountered elsewhere on the tree. Therefore, samples reflect general species composition of epiphytes but do not represent relative abundance. In addition, because some species of epiphytes appear very similar to others, these species may have not been collected and may not be accurately represented.

Samples were stored in paper bags until time of identification. They were then removed from bags, sprayed down with water (mosses) or soaked in water (lichens), separated by species, and pressed overnight. Dana Bruden (National Biological Survey), Dr. Marilyn Barker (Department of Biology, University of Alaska, Anchorage), and Dr. William Louis Culberson (Department of Botany, Duke University) identified all moss and lichen samples. Samples were carefully identified based on morphology and habitat. A compound microscope was used for identification when necessary.

Antitrichia curtipendula was the most common moss on trees in nesting habitat and provided nest substrate for all murrelet nests (where nest cups were sampled) on Naked (N = 6) and Kodiak (N = 2) islands (no data were available for Afognak island nest trees; Table C-1). *A. curtipendula* was also the primary moss cover on Naked Island nest branches (N = 3) where nest cup contents were not sampled. *Dicranum* spp. occurred in one Naked Island nest cup. A wide variety of lichens were found on Naked Island trees, whereas lichens were not found on Kodiak and Afognak islands. On Naked Island, there were no apparent differences in lichen species found on nest and landing trees or on other trees in nesting habitat.

A. curtipendula was also the most common epiphyte found on five of six nest branches used by marbled murrelets in British Columbia (Burger 1994). In California, *A. californica* was found in nests or on nest branches of two marbled murrelet nests (Singer et al. 1991). In contrast to one of the California nests, Naked and Kodiak island nest cups did not contain lichens. However, the California nest was unusual in that it appeared to be the abandoned nest of a Band-tailed Pigeon (*Columba fasciata*) and was constructed of twigs with lichens attached. Nest trees in both Alaska and California supported *Hypogymnia* sp. and *Parmelia* sp. lichens.

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Table C-1. Species composition of moss and lichen found on nest trees (NT), landing trees (LT) and other trees (OT) in marbled marbled murrelet (*Brachyramphus marmoratus*) nesting habitat, on Naked, Kodiak, and Afognak islands, Alaska, during 1991-1992.

				Moss species					Lichen species										
Location	Tree ID	Source	AC	DF	DS	UM	UO	AS	BR	CL	HY	LO	PS	PA	PN	PT	SQ	UL	
Afognak	LT	Tree	X																
Kodiak	NT	Nest cup	X																
Kodiak	NT	Branch	X																
Kodiak	NT	Nest cup	X																
Naked	NT 1	Branch	X	X				X						X					
Naked	NT 1	Tree							X		X								
Naked	NT 1	Nest cup	X																
Naked	NT 2	Branch	X															X	
Naked	NT 3	Nest cup	X		X											X	X		
Naked	NT 3	Branch						X											
Naked	NT 3	Tree										X					X		
Naked	NT 4	Nest cup	X																
Naked	NT 6	Branch	X																
Naked	NT 6	Tree						X	X								X		
Naked	NT 7	Nest cup	X																
Naked	NT 7	Branch	X			X			X									X	
Naked	NT 8	Branch	X							X									
Naked	NT 8	Nest cup	X																
Naked	NT 10	Nest cup	X																
Naked	NT 11	Branch	X		X			X	X									X	

Table C-1. Continued.

			Moss species					Lichen species										
Location	Tree ID	Source	AC	DF	DS	UM	UO	AS	BR	CL	HY	LO	PS	PA	PN	PT	SG	UL
Naked	LT 2	Branch			X										X	X		
Naked	LT 4	Branch	X					X	X				X				X	X
Naked	LT 5	Branch	X		X		X	X	X									
Naked	LT 8	Branch			X		X										X	
Naked	LT 9	Branch	X						X									X
Naked	LT 11	Branch	X		X			X	X								X	
Naked	OT 3	Branch			X			X	X	X							X	
Naked	OT 4	Branch						X	X								X	
Naked	OT 5	Branch			X		X			X				X				X
Naked	OT 6	Branch			X	X		X	X								X	X
Naked	OT 14	Branch		X														
Naked	OT 21	Branch	X					X	X								X	
Naked	N1003	Branch	X															
Naked	N3003	Branch	X															

Lichen Species List:
AS= *Alectoria sarmentosa*
BR= *Bryoria spp.*
CL= *Cladonia spp.*
HY= *Hypogymnia spp.*
LO= *Lobaria spp.*
PS= *Parmelia saxatilis*
PA= *Peltigera aphthosa*
PN= *Platismatia norvegica*
PT= *Ptilidium spp.*
SG= *Sphaerophorus globosus*
UL= unidentified lichen

Moss Species List:
AC= *Antitrichia curtipendula*
DF= *Dicranum fuscescens*
DS= *Dicranum spp.*
UM= unidentified moss
UO= unidentified other