Multi-Scale Studies of Populations, Distribution and Habitat Associations of

Marbled Murrelets

in Clayoquot Sound, British Columbia

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Edited by
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Flores Island west coast. Clayoquot Sound has the combination of rich waters for feeding and intact old-growth forests for nesting Marbled Murrelets. The Clayoquot Sound Scientific Panel for Sustainable Forest Practices provided direction for inventory and planning related to Marbled Murrelets. Their recommendations are based upon the principal of maintenance of ecological integrity. (Trudy Chatwin)

Introduction and Overview of the Clayoquot Sound Study

by Trudy A. Chatwin and Alan E. Burger

According to Nuu-chah-nulth elders, the story of Clayoquot Sound is one of forest and sea. Indeed, the connection between land and water is found throughout the natural history of Clayoquot Sound's multitude of species, from the tiniest invertebrates, fungi and lichens through to the salmon, birds, bears and whales. No bird species exemplifies this connection between sea and forest better than a small, rather mysterious seabird, the Marbled Murrelet.

Marbled Murrelets are unique among seabirds in nesting far inland in old-growth forests. Their coloration, body form (morphology) and behaviours have evolved in response to the combination of living in nearshore seas and nesting in ancient forests. These adaptations have important consequences for their conservation and management. As a diving seabird that uses its wings to "fly" underwater in pursuit of prey, the Marbled Murrelet's wings are small but powerful. Their wing-loading (ratio of body mass to wing area) is among the highest in the bird world. When breeding, they daily fly to nest sites up to 80 km inland, and can reach speeds of over 120 km/hr. Their high wing-loading means that Marbled Murrelets are not particularly adept at making flying manoeuvres within the complex and dense forest canopy where they nest. Their legs are set far back on the body and they have webbed feet to facilitate diving. These adaptations make it almost impossible for murrelets to take off from level ground, and therefore they need to find an elevated platform for nesting. In most cases this platform is a broad, mossy limb high above the ground in an old-growth tree, but occasionally they use mossy ledges on cliffs.

As long-lived birds with low reproductive capability, Marbled Murrelets are particularly sensitive to predation and show many adaptations for reducing predation. Their nests are widely dispersed, making them difficult for predators to locate. They fly silently to their nests in the dark twilight, before sunrise and after sunset. Most seabirds have black backs and white bellies, which provides a form of camouflage on and under the ocean. Marbled Murrelets have this plumage in winter and when they fledge as juveniles. When breeding, however, Marbled Murrelets have a mottled brown plumage that blends into the forest background, making them almost invisible when sitting quietly on mossy branches or when flying into the forest. Known or suspected predators of murrelets that are found on Vancouver Island include Steller's Jay (*Cyanocitta stelleri*), Gray Jay (*Perisoreus canadensis*), Northwestern Crow (*Corvus caurinus*), Common Raven (*Corvus corax*), Bald Eagle (*Haliaeetus leucocephalus*), Northern Goshawk (*Accipiter gentilis*), Sharp-shinned Hawk (*Accipiter striatus*), Barred Owl (*Strix varia*), Great-horned Owl (*Bubo virginianus*), Red Squirrel (*Tamiasciurus hudsonicus*) and deer mice (*Peromyscus* spp.).

Marbled Murrelets spend most of their lives in the nearshore waters of the Pacific Ocean, feeding on small marine fish, such as sand lance (*Ammodytes hexapterus*), juvenile Pacific herring (*Clupea harengus*), northern anchovy (*Engraulis mordax*) and immature rockfish (*Sebastes* spp.). Large zooplankton, such as euphausiids, are also eaten. The complex coast of Clayoquot Sound, with protected bays, long inlets, areas of upwelling off rocky reefs, and islets on the open west coast, provides ideal feeding grounds for murrelets.

Just as importantly, undisturbed areas of temperate rainforest provide nesting opportunities for murrelets on the large, moss-laden boughs of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*) and amabilis fir (*Abies amabilis*). Clayoquot Sound, despite its history of conflict over industrial logging, still has large tracts of undisturbed forests, especially in the Megin, Moyeha, Sydney, Clayoquot, Bulson, Ursus and Watta watersheds. Three of the six undisturbed watersheds larger than 5,000 ha on Vancouver Island are in this area (Moore 1991). By contrast, much of the Bedwell, Boat Basin, Cypre, Kennedy and Hesquiaht valleys have been heavily logged, and the Atleo, Tofino Creek, lower Tranquil, and Bedingfield areas have been patchily logged. The abundance of forest habitat and the variety of cutting patterns in Clayoquot Sound provide an unparalleled area for studying the habitat associations of Marbled Murrelets.

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History of Marbled Murrelet Studies in Clayoquot Sound

Quantitative research on the murrelet in Clayoquot Sound began in 1982 when Harry Carter and Spencer Sealy undertook an at-sea census that covered most of the water from Ucluelet to Estevan Point (Sealy and Carter 1984). They estimated a minimum population of 4,500 murrelets on the water during the breeding season. John Kelson and co-workers subsequently repeated these counts in 1992, 1993 and 1996, but reported only 2,704, 2,622 and 2,901 murrelets in each year, respectively (Kelson et al. 1995, Kelson and Mather 1999). This decline since 1982 was attributed to loss of nesting habitat due to logging (Kelson et al. 1995), although Burger (2000) suggested that negative responses by murrelets to warm ocean conditions in the 1990s might also have been a factor.

Inland, pilot audio-visual surveys were done at 16 stations in Clayoquot Sound in 1991 (Savard and Lemon 1994). In 1993, Irene Manley, John Kelson, Stephanie Hughes, Kevin Jordan and Bernard Schroeder did dawn surveys and searched for nests in the lower Megin and Clayoquot River valleys (some data in Burger 1995a). Two nests were found (I. Manley, unpubl. data).

In 1993, protests over the British Columbia government's decision to allow logging in 74% of Clayoquot Sound brought world-wide attention to BC's old-growth forests and to Clayoquot Sound. More than 850 people were arrested in the largest act of civil disobedience in the history of Canada. In response to the protests and intense pressure to address First Nations control of resources in their traditional territories, the provincial government signed the Clayoquot Interim Measures Agreement with the Hereditary Chiefs of the Tla-o-qui-aht, Ahousaht, Hesquiaht, Toquaht and Ucluelet First Nations (Nuu-chah-nulth Tribal Council and Natural Resources Defense Council 2001). The agreement recognized the right of First Nations to manage and preserve their traditional territories for future generations and created the Central Region Board to review plans and resource development proposals that affect Clayoquot Sound.

In addition, the BC government appointed the Clayoquot Sound Scientific Panel, made up of eminent scientists in the fields of forest ecology, botany, ethnobotany, anthropology, hydrology, fish biology, wildlife biology, forest harvest planning and traditional ecological knowledge. The panel's report made 125 recommendations (Clayoquot Sound Scientific Panel 1995). The recommendations were guided by the Nuu-chah-nulth principle of *hishuk ish ts'awalk* (everything is interconnected), with ecosystem and cultural values to be determined and evaluated first. Timber harvesting values were to be considered second, with harvest areas designated only after ecological and cultural reserves had been designated. This ecosystem-based planning was a paradigm shift from the forest practices of the day, in which timber extraction targets were set first, and environment officials struggled to protect resources by attempting to modify logging plans. The provincial government accepted all of the Clayoquot Sound Scientific Panel's recommendations, and in early 1996 the Clayoquot Planning Team was charged with implementing the recommendations.

The BC government's commitment to meet the Scientific Panel recommendations, combined with the identification of the Marbled Murrelet as a priority management species, provided the impetus for our studies (see Box 1). At the time of the protests, the Marbled Murrelet was seldom mentioned. When the Ursus Valley was designated as a Wildlife Management Zone, the BC Fish and Wildlife Branch recognized the Marbled Murrelet as an important species in this zone and began studies there. Alan Burger, Volker Bahn, Andrea Lawrence and Deanna Newsom conducted audio-visual surveys, determined habitat associations and produced a preliminary habitat map (Burger et al. 1995). They also set up a marine radar unit on the estuary of the Bedwell River to count murrelets entering the Bedwell-Ursus watersheds from the ocean (Burger 1997). Both the audio-visual surveys and the radar counts indicated the importance of the Ursus Valley to Marbled Murrelets.

High rates of detections reported from the Megin, Clayoquot River and Ursus valleys, combined with the large populations counted at sea, indicated the provincial importance of Clayoquot Sound to Marbled Murrelets (Sealy and Carter 1984, Rodway et al. 1992, Burger 1995b). Furthermore, the sea-survey data showed a marked decline in the Sound's population of murrelets; loss of nesting habitat from logging was suggested as the reason (Kelson et al. 1995). Wildlife and forest managers recognized that designation of forest reserves to protect nesting habitat would require a more thorough understanding of the size and distribution of the murrelet population and its habitat requirements. This knowledge would have to cover a range of spatial scales, from regional, encompassing all of Clayoquot Sound, right down to the micro-habitat use of trees.

Objectives of the Studies

The Marbled Murrelet is listed as Threatened in Canada (Rodway et al. 1992) and also in Washington, Oregon and California (Ralph et al. 1995). Its status in Alaska is under review. Within BC it is on the Red List (species legally designated or being considered for legal designation as Endangered or Threatened). The murrelet is one of the Identified Wildlife species within the BC Forest Practices Code Act, and the Identified Wildlife Management Strategy (IWMS) mandates the creation of Wildlife Habitat Areas (WHAs) for Marbled Murrelets in areas managed for forestry. Loss of nesting habitat through logging of old-growth forests is the principal threat through the murrelet's range, but oil spills and gill-nets are also recognized as significant threats (Ralph et al. 1995).

Our five-year research and inventory program began in 1995 as part of the BC government's commitment to implement recommendations of the Clayoquot Sound Scientific Panel (1995). Our study was guided by the specific recommendations from the Scientific Panel applicable to a Red-listed species and silvicultural recommendations 3.6 and 3.8 dealing with wildlife and ecological integrity (Box 1).

Box 1

Recommendations of the Clayoquot Sound Scientific Panel (1995) which applied to the Marbled Murrelet and which guided the research in 1995-2000 reported in this volume.

Recommendation 3.6: "to assist in identifying retention areas with significant wildlife resource values"
Recommendation 3.8: "to assist in selecting specific structures and patches to meet ecological objectives and identify ecological sensitivity"
Recommendation 7.2: "to identify suitable ecological land units to form the basis of planning and identifying watershed-level values of biodiversity"
Recommendation 7.3: "to collect appropriate baseline information on biophysical resources and use this information to assess ecological responses to change"
Recommendation 7.16: "map and designate reserves at the watershed level to protect . . . Red- and Blue-listed species"
Recommendation 8.3.2: Monitoring vulnerable and rare indigenous species: "to ensure that particular species known or suspected to be at risk are monitored and their habitats protected"

The study was designed to provide empirical data for management of murrelets, both inland and at sea, and to monitor the effects of changes occurring in Clayoquot Sound. Our study also tested and refined methods that can be applied to the conservation of Marbled Murrelet habitat throughout its range.

The overall objectives of our work were to:

- estimate the total number of Marbled Murrelets found in Clayoquot Sound in summer;
- estimate the numbers entering Clayoquot Sound watersheds during the breeding season and assess the relative importance of each watershed as nesting habitat;
- identify landscape-level features that may determine murrelet distribution and determine which parts of selected watersheds are most important to nesting murrelets;
- identify critical macro- and micro-habitat features and mapped ecosystem or forest vegetation units that provide high quality Marbled Murrelet nesting habitat;
- apply the results of habitat studies in order to model and map suitability classes of Marbled Murrelet nesting habitat;
- determine nest density within various habitat suitability classes and describe nest-stand, tree and micro-habitat characteristics;
- assess the risks of predation to nesting murrelets in a wide range of habitats;
- assess how clear-cut logging, forest fragmentation and other forest practices affect population densities, nest site selection and predation risk of Marbled Murrelets;
- monitor the distribution and densities of murrelets at sea as a first step in explaining their marine habitat use;
- assess the recruitment of juveniles at sea in each season to provide baseline data for comparison with other studies and with future data from Clayoquot Sound;
- assess seasonal and annual variations in all measurements, the factors causing these variations and the effects of the variations on inventories and management decisions; and
- make recommendations for a reserve network that will set aside both an adequate quality and quantity of habitat to sustain Marbled Murrelets.

More detailed objectives of each study are given in each specific chapter.

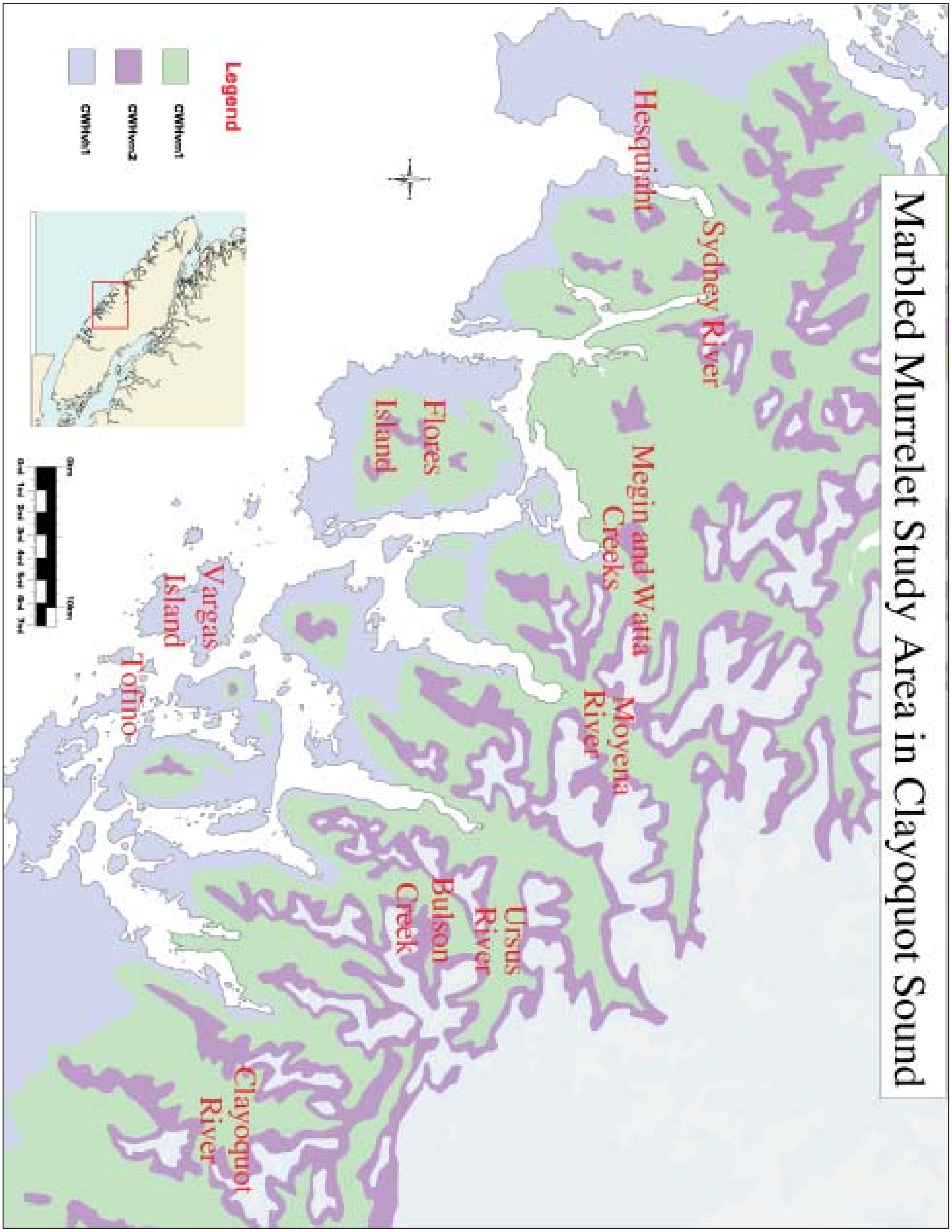

Figure 1-1. Map of Study Area

Overview of the study area in Clayoquot Sound

Clayoquot Sound (Figure 1-1) is located in on the west coast of Vancouver Island, British Columbia (latitude 49º00'–40º30' N, longitude 125º20'–126º35' W). The area is a maze of islands, inlets and temperate rainforest watersheds. The terrestrial ecosystems are predominantly within the Coastal Western Hemlock (CWH) and Mountain Hemlock (MH) biogeoclimatic zones (Green and Klinka 1994) and the Windward Island Mountains ecosection (Demarchi et al. 1990). This is the rainiest zone in British Columbia, with cool summers and mild winters (Meidinger and Pojar 1991). Mists are an almost ever-present feature in Clayoquot Sound, promoting dense epiphyte growth of mosses, lichens and liverworts on the trees.

The feeding grounds for Clayoquot Sound's murrelets are the rugged, windward, outer coast of the Pacific Ocean, with upwellings from the continental shelf. Broiling waters around rocks and islets provide nutrient-rich, shallow waters for feeding. Long, deep, fjord-like inlets seem to provide poor feeding habitat for murrelets, but provide access to the forested watershed nesting areas. The sea-survey study area ranged from Portland Point around Vargas Island, through the Bartlett Island group and around the entire coast of Flores Island.

The rainforest of Clayoquot Sound is legendary: a blanket of green, enveloped in mist. The forests we sampled ranged in elevation from 0 to 900 m, but mountains here reach 1,700 m. The forest is comprised of dense conifers, often more than 50 m tall and 2 m in diameter. The understory is characterized by dense tangles of shrubs, deadfall trees, ferns and moss.

Our study covered three subzones of the Coastal Western Hemlock (CWH) biogeoclimatic zone (Green and Klinka 1994). The very wet southern hypermaritime (CWHvh1) subzone occurs on the outer coast up to 150 m in elevation and is dominated by mixtures of western hemlock, western redcedar and Sitka spruce, with variable amounts of yellow-cedar (*Chamaecyparis nootkatensis)*. Sitka spruce dominates well-drained floodplains on the exposed coastal zone and reaches 50 m or more in height. Poorly drained flat areas have mixtures of shore-pine (*Pinus contorta)*, spire-topped western redcedar and western hemlock. Bogs are common. Well-drained slopes have mixtures of western redcedar, western hemlock and some amabilis fir. The understory of this subzone is dominated by salal (*Gaultheria shallon*), Alaska blueberry (*Vaccinium alaskense*), red huckleberry (*Vaccinium parviflorum*) and deer fern (*Blechnum spicant*). For details on site series descriptions see Green and Klinka (1994).

The very wet submontane maritime subzone (CWHvm1) is the most extensive subzone variant in Clayoquot Sound, occurring from 150 to 600 m on the outer coast and from sea level to 600 m on inland watersheds (Green and Klinka 1994). Moderate slopes are dominated by western hemlock, amabilis fir and western redcedar. Poorly drained sites are dominated by yellow-cedar with some mountain hemlock (*Tsuga mertensiana*). Floodplains are dominated by Sitka spruce. The understory shrubs are dominated by red huckleberry and Alaska blueberry, although dense salmonberry (*Rubus spectabilis*) and devil's club (*Oplopanax horridus*) occur on floodplains. Understory herbs are sparse, but the cryptogam layer is well developed, with step moss (*Hylocomium splendens*) and lanky moss (*Rytidiodelphus loreus*) dominating. This subzone variant contains most of the major streams in Clayoquot Sound and has the largest trees.

The very wet montane maritime subzone (CWHvm2) occurs at elevations from 600 to 900 m in the coastal watersheds (Green and Klinka 1994). Forests are dominated by western hemlock and amabilis fir. As elevation increases, western redcedar, yellow-cedar and mountain hemlock increase in dominance. The understory shrubs have more Alaska blueberry and electrified cat's moss (*Rhytidiopsis robusta*) than in the CWHvm1 subzone.

Summary of the major research and management results

The results of the 1995-2000 studies are presented in the chapters of this compendium. Additional analyses and background data are available in the annual progress reports (Burger et al. 1995, 1997, Chatwin et al. 1999). Some of the material has also been published elsewhere, including a Master of Science thesis by Bahn (1998), and papers by Bahn and Newsom (2000), Burger (1997, 2000, 2001), Chatwin et al. (2000) and Rodway and Regehr (1999, 2000).

The intent in this section is to provide an executive summary in plain English, which highlights the results and implications of each study. The specific chapters that follow provide the details on the methods, analyses and data from each study. All data are archived at the Ministry of Water, Land and Air Protection office in Nanaimo, BC.

At-sea Surveys (Chapter 2, by Adrienne Mason, Alan Burger and Bob Hansen)
Previous at-sea surveys in Clayoquot Sound, beginning in 1982, had used a grid sampling technique, which covered 1-km^2 sampling units (Sealy and Carter 1984, Kelson et al. 1995). Mason and co-workers switched to

linear strip transects, which were consistent with the Resources Inventory Committee (RIC 1997) standards for Marbled Murrelets and more readily repeated within and among seasons. After consultation and field trials, two lengthy transect routes were selected, totalling 148 km. These covered a range of marine habitat types and included areas known to be foraging “hot spots” for murrelets. Boat surveys were done through the breeding seasons in 1996-2000. Due to high seasonal variability, most analysis focused on the core period 14 May through 31 July, which covered the peak densities from mid June to late July. Murrelets emigrated from the area as the breeding season ended in late July and early August.

There was no significant variation in the counts from either transect from year to year. This was a bit surprising, because the study included the El Niño year of 1997 and the transition from the “warm” phase (1978-1998) to the “cool” phase (1999 on) of the Pacific Decadal Oscillation (PDO). Both El Niño and PDO are known to affect the distribution and breeding success of seabirds, and murrelets are thought to be sensitive to exceptionally warm ocean conditions. Due to the high variability within each season, a longer series of data is needed to clearly show long-term variations among years.

In both transect routes, Mason et al. found a consistent spatial distribution from year to year: murrelet densities were consistently high in some sectors and consistently low in other sectors. The researchers lacked the data on currents, bottom substrates, temperature, salinity and, most importantly, prey distribution, needed to explain these distributions. Nevertheless, these results provide a valuable first step in explaining the marine habitat preferences of murrelets. As discussed in the chapter, such information is essential for long-term planning of marine protected areas, contingency planning in the event of a catastrophic oil spill, and reducing conflicts with human activities such as aquaculture, recreational boating and commercial fishing. The waters of Clayoquot Sound are becoming increasingly used by people and some planning is needed to avoid impacting the murrelets at sea.

At sea, newly-fledged juvenile murrelets can usually be distinguished from adults and subadults in their summer, breeding plumage. In Alaska researchers have reported aggregations of juveniles in sheltered “nursery areas.” Mason et al. found no significant differences in the spatial distribution of juveniles and birds in adult plumage, concluding that there were no special nursery areas at the spatial scale analyzed in this study.

Some measure of breeding success and recruitment can be obtained from sea surveys, by comparing the ratios of newly-fledged juveniles to adults (adjusted to account for seasonal trends in both age classes) and juvenile densities (birds per square kilometre) from year to year. Mason et al. reported no clear annual trends in their data, although the juvenile:adult ratios were markedly higher in the cooler years of 1999 and 2000 than in the warmer years 1996-1998. Clearly a much longer series of surveys is needed to detect significant trends in breeding success and recruitment, but these data provide a valuable baseline for future comparisons, and allow comparisons with other areas.

Radar Counts of Murrelets and Macro-habitat Associations (Chapter 3, by Alan Burger)

Trials at the mouth of the Bedwell-Ursus watershed in 1995 showed that murrelets entering watersheds from the ocean could be reliably counted with high-frequency marine radar (Burger 1997). A full-scale sampling program was planned and 20 watersheds were sampled in 1996-1998, using two similar radar units. The long, narrow fjords and steep-sided valleys in Clayoquot Sound were ideal for radar counts because the murrelets were channelled along narrow flight paths as they entered the watersheds. Few birds were likely to be missed at most of the stations. The primary goals of the radar study were to estimate the regional population of murrelets, determine the relative importance of each watershed for murrelets, identify important watershed-level habitat associations and investigate the effects of clearcut logging.

Radar was a new, relatively untested method of studying murrelets at the start of the study and Burger’s intensive research has been important in developing standard protocols. In particular, his research found the following:

- murrelets fly to nests sites at both dawn and dusk, but counts made at dawn were consistently higher and less variable than dusk counts, and were therefore preferred for most analysis;
- some murrelets were evidently making repeated flights to nests on some mornings,and to avoid multiple counts we restricted analysis to the pre-sunrise period;
- dawn and dusk counts were higher on cloudy days than on clearer days, but among cloudy days there was no additional effect of precipitation (thick fog or drizzle);
- counts varied among years and within seasons, but multi-year counts within a core period (mid May to mid July) minimized this variation;
- murrelets sometimes crossed over low ridges from one valley to the next and in such situations the watershed areas needed to be adjusted to include adjacent valleys;

- the study confirmed that audio-visual detections provide a poor measure of murrelet numbers per watershed and that murrelets did not necessarily use streams or valley-bottoms as flight corridors.

The radar counts showed that more than 4,600 Marbled Murrelets (mean of annual mean counts per station), and probably 5,500 (mean of the annual maximum counts), were using the 20 watersheds sampled. These counts included non-breeders. Taking into account the areas not covered by the radar study, the regional Clayoquot Sound population was estimated to be 6,000 to 8,000 murrelets. This estimate is higher than the at-sea census numbers and confirms that Clayoquot Sound is one of the primary breeding sites for murrelets throughout its range. The radar data also allowed the importance of each watershed to be assessed. The highest populations were in the Moyeha, Watta, Megin, Clayoquot River, Kennedy, Bedwell-Ursus, and Bulson watersheds.

One of the most powerful uses of the radar data was in analyzing landscape-level habitat associations and in assessing the impacts of clearcut logging on the murrelet populations. Murrelet counts were compared with a range of habitat measures available on Geographic Information Systems (GIS) in 18 watersheds. Mean and maximum counts of murrelets were found to be positively correlated with total watershed area, area of mature forest (>140 years old), and – most strongly – with areas of mature forest below 600 m elevation. Multiple regression equations showed that the combined positive effects of old-growth availability and negative effects of logged and immature forest explained up to 91% of the variability in dawn counts of murrelets. For management purposes, simple linear regressions based on the area of old-growth forest were found to be reliable predictors of murrelet numbers. Radar studies made on northwest Vancouver Island (Manley 2000) and the Olympic Peninsula, Washington (Raphael et al. in press) have since reported similar results.

The discovery of a correlation between murrelet numbers and areas of old-growth forest is important for several reasons. First, it confirms that murrelets tend to nest at low densities. Radar data from Clayoquot Sound gave a mean of 0.07 birds per ha in low-elevation forest and 0.04 in old-growth across all elevations, which suggests nest densities in the range of 0.01-0.03 nests per ha. Second, the linear relationship between murrelet numbers and existing habitat area indicates that murrelet densities do not increase in remaining old-growth patches as clearcut logging removes habitat. In other words, the murrelets are not packing into the remaining patches in higher densities, but are moving away and perhaps not nesting at all as their habitat is cut. This trend was confirmed by detailed comparisons of logged and unlogged valleys in the Clayoquot Sound samples (see details in the chapter and in Burger 2001).

Obviously, this has important implications for conservation of the threatened murrelet. If confirmed by other studies, this result indicates that populations will decline in proportion to the amount of habitat lost and we should not expect murrelets to nest in higher densities in the reduced habitat available. Murrelet populations in BC may decline significantly if only 10-12% of original suitable habitat is retained in managed forests.

Inland Activity and Forest Structural Characteristics as Indicators of Nesting Habitat (Chapter 4, by Michael Rodway and Heidi Regehr)

Audio-visual surveys, reporting the number of detections of Marbled Murrelets at fixed stations at dawn, have become a standard method to measure murrelet activity and determine occupancy of forest stands. This protocol, refined over many years in both the United States and British Columbia, was used at 177 stations in 14 watersheds in Clayoquot Sound during the 1995-1997 breeding seasons. The objective was to identify important nesting habitats for Marbled Murrelets at landscape and stand scales. Audio-visual detections are indirect measures of activity; the relationships between numbers of detections and actual habitat use by nesting murrelets are not known. To compensate for this uncertainty, standardized habitat measures were made in plots near each survey station. Rodway and Regehr therefore analyzed a combination of data covering murrelet activity, forest structural characteristics (e.g., tree size, availability of potential nest platforms, epiphyte cover on branches), topographical features (e.g., elevation, distance inland) and abundance of potential predators (e.g., jays, crows, eagles, squirrels).

Rodway and Regehr found positive relationships between occupied detections (the subset of detections indicating near-nest activities) and forest structural characteristics, especially density of trees with platforms, density of large trees and mean diameter of all trees. There was thus a general association between murrelet activity thought to be associated with nesting and structural characteristics known to be important to nesting murrelets. They concluded that forest structural characteristics may be more useful than audio-visual detections for differentiating breeding habitats for Marbled Murrelets at small scales within watersheds. Detections of murrelets alone were considered inadequate because of high variability, both temporal (at daily, seasonal and annual temporal scales) and spatial (at survey station, watershed and biogeoclimatic subzone variant spatial scales).

Forests bordering major stream channels provided high-quality nest habitat for murrelets, with large trees, high epiphyte cover and many potential nest platforms. Detections of murrelets were also highest along stream beds, but this might have been partially due to the tendency of murrelets to fly along stream beds en route to other areas. On the other hand, frequencies of potential predators, specifically Northwestern Crows and Bald Eagles, were higher along stream edges than in interior forest. Breeding success by murrelets might therefore be lower at riparian nest sites.

There were no clear indications of consistent differences in the quality of nesting habitat among the three biogeoclimatic variants sampled: CWHvm1, vm2 and vh1 (see descriptions of these variants elsewhere in this introduction). Some measures of habitat suitability (tree diameter, epiphyte cover, and density of large trees) were higher in the low-elevation CWHvm1 than in higher vm2 areas, but density of trees with platforms and total platform density per hectare showed no differences. No differences in murrelet detections were found between these variants, except for higher densities along streams in the low-elevation vm1 areas. Detections of murrelets were lower in the CWHvh1 variant on exposed coasts than in the more inland vm1 and vm2 variants, but structural characteristics suggested that vh1 provided attractive nesting habitat for murrelets. Potential murrelet predators were more abundant at ocean edge than interior stations, but in general the data suggest that only the perimeter coastal strip in vh1 habitat is unattractive to nesting murrelets.

The perimeter coastal forests had lower density of trees with nesting platforms, low detection numbers and higher predator abundance than inland forests. Better quality habitat and higher detections were generally located away from the sea and at intermediate elevations between 50 and 500 m, although some of the trends were weak. Availability of potential nest platforms was highest at intermediate distances from the sea and at elevations below 800 m.

Within each biogeoclimatic subzone, Rodway and Regehr found clear differences in the quality of nesting habitat among site series (stand-level biogeoclimatic units; Green and Klinka 1994). More productive site series with richer soils and intermediate moisture better provided the forest structural characteristics thought to be important to nesting murrelets than poorer site series. Unfortunately, these productive site series are also the most valuable for timber extraction.

The effects of logging and fragmentation of forests were assessed. Lower murrelet activity and higher predator frequencies indicated that areas fragmented by logging provided poorer nesting habitat than unfragmented forest. Increased predator abundance at edges and in stands fragmented by logging is a major concern for murrelet conservation.

Rodway and Regehr concluded that the most important nesting habitats for Marbled Murrelets in Clayoquot Sound were highly productive, unfragmented, multi-aged, old-growth stands located away from ocean and harvest edges in valley-bottom and slope areas below 800 m elevation. These results contribute to setting priorities for the establishment of reserves for murrelets within Clayoquot Sound and provided the basis for the habitat modelling undertaken by Bahn and Newsom (Chapters 5 and 6).

Can Use of Nesting Habitat be Predicted from Mapped Forest Characteristics? (Chapter 5, by Volker Bahn and Deanna Newsom)

Before developing a predictive habitat suitability model (Chapter 6), Bahn and Newsom undertook a study to test whether a habitat variable commonly used in ecosystem mapping could reliably predict suitable habitat and high levels of murrelet activity.

First, they analyzed data from 118 vegetation plots sampled previously in the Clayoquot Sound study. Of the forest and terrain characteristics available on resource maps, tree height was found to be the most useful variable to predict suitability of murrelet habitat. Tree height is readily available on forest cover or timber supply maps and can be interpreted on aerial photographs.

Next, they did a field study comparing audio-visual detections of murrelets at 11 pairs of forest stands. The stands were selected using Vegetation Resource Inventory maps, which use tree height as a key variable. Each pair had one stand with the average height of canopy trees more than 35 m (rated as TALL) and one with average tree height less than 26 m (rated SHORT). They predicted that the TALL stands would show more murrelet activity associated with breeding than the SHORT stands. Each pair of stands had a similar elevation, distance to ocean, slope position and aspect. Teams of observers performed standardized audio-visual surveys at paired stands on the same morning to avoid biases caused by weather and season. They observed significantly higher numbers of occupied detections and subcanopy detections (both thought to be related to nearby breeding) in the TALL stands than in SHORT stands. Bahn and Newsom therefore concluded that Marbled Murrelet breeding activity could be predicted, using a mapped forest characteristic. This result gave support for the development of their more sophisticated habitat model (Chapter 6).

Habitat Suitability Mapping (Chapter 6, by Volker Bahn and Deanna Newsom)

The development of a predictive habitat model or algorithm is a common goal in wildlife management. If habitat important for a target species can be reliably predicted from variables available on maps or GIS databases, this greatly helps in identifying, mapping and managing critical habitat. The problem with Marbled Murrelets is that many of the habitat features known to provide important nest habitat, including the availability of large limbs for nest platforms, moss cover and canopy openings, are not normally included in standard vegetation, forest cover or biogeoclimatic maps. Successful models of murrelet habitat therefore need to find the mapped variables that are the best proxies or indicators of suitable nest micro-habitats. Because a single variable is usually not reliable as a habitat indicator, the models usually combine several variables in a mathematical formula, also known as an algorithm.

Using the wide range of data available from the Clayoquot Sound murrelet studies, Bahn and Newsom developed a Habitat Suitability Index (HSI) model. This was an expanded and updated version of the model developed by Bahn in his Masters thesis (Bahn 1998). The overall goal was to provide a reliable mechanism for evaluating mapped forest polygons as potential nesting habitat for murrelets, which would allow selection of high-quality habitat for reserves and, where possible, direct logging and road-building into less suitable habitat.

First, Bahn and Newsom compared the two types of ecosystem maps available for Clayoquot Sound. They compared the habitat types predicted from the maps with those actually found on the ground in field studies. They also considered the relevance of the mapped information to nesting murrelets. Vegetation Resource Inventory (VRI) maps, which contain detailed land cover information with a focus on forest cover, were determined to be better suited for the model than the Terrestrial Ecosystem (TEM) maps, which contain biogeoclimatic information on vegetation associations.

Second, they sampled habitat variables from vegetation plots in forest polygons randomly selected from VRI maps. Several variables measured in the field came out as important to murrelets; to reduce the complexity of using multiple variables, the significant variables were combined into two factors by a Principal Component Analysis (PCA). These PCA factors, representing habitat important to murrelets, were then compared to variables available for these polygons on VRI maps using regression analyses. Based on the regressions and information from literature, seven mapped variables were selected to be included in the HSI model. These were: distance from the sea; elevation; age of the leading or the second-leading tree species; mean height of the dominant or second-dominant tree species; basal area (square metres per hectare) of all living trees; vertical complexity of the forest canopy; and canopy closure (percent of ground area covered by the vertically projected crowns of the tree cover). The seven variables were combined into a single predictive equation, whose output is a habitat suitability index (HSI) between 0 and 1 for each mapped polygon (see Chapter 6 for full details).

Finally, Bahn and Newsom divided the HSI scores into four categories: “Important-Excellent” (HSI larger than 0.875; also referred to as “Excellent”); “Important-Good” (HSI between 0.78 and 0.875; also referred to as “Good”); “Sub-optimal” (HSI between 0.65 and 0.78); and “Unsuitable” (HSI less than 0.65). These rankings were then applied to 335,127 ha of land area in Clayoquot Sound mapped on VRI maps. The final breakdown of this area was: 34,833 ha (10.4%) rated as Excellent habitat; 40,466 ha (12.1%) Good habitat; 59,388 ha (17.7%) Sub-optimal habitat; and 200,440 ha (59.8%) Unsuitable habitat. More simply, the model identified 75,299 ha (22.5% of land area) as Excellent or Good habitat, and 259,828 ha (77.5%) as Sub-optimal or Unsuitable habitat.

Maps of these suitability rankings are now available for several areas in Clayoquot Sound and these were key components of the management decisions described in Chapter 8. Some support for the habitat rankings comes from the data collected in the tree-climbing study (Chapter 7), although testing the model was not the goal of that study. Some validation of the predictions is also possible using the distribution of nest sites located using radio-telemetry in the Simon Fraser University/Ministry of Forests/Canadian Wildlife Service study presently underway. Preliminary results from nine nests found in 2000 and 2001 indicate that most of the nest sites were in habitat ranked as suitable by the model (L. Waterhouse, pers. comm.).

Estimating Nest Densities in Three Habitat Suitability Categories in the Ursus Valley (Chapter 7, by Catherine Conroy, Volker Bahn, Michael S. Rodway, Laurie Ainsworth and Deanna Newsom)

How much habitat is needed to support a viable population of Marbled Murrelets? This is a frequently asked question, but one which is currently impossible to answer. Knowledge of the nest density of murrelets would greatly help management objectives, especially if nest densities were known for different types of forest habitat. Rough estimates of nest densities might be possible from radar counts, but these counts include non-breeding birds and the ratio of nests to birds is not clearly defined. Locating nests using radio-telemetry is a valuable method for describing nests and their habitat, but cannot provide any estimate of nest density. A more direct approach is to climb randomly-selected trees that have potential nest platforms (usually large limbs) and measure the density of nests per platform tree. Combined with estimates of the number of platform trees per hectare, this can give an estimate of nests per hectare. This was the approach taken by Conroy and her co-workers in the Ursus Valley in 1998-2000. Preliminary results from this study were published by Rodway and Regehr (1999).

The study compared nest densities and habitat characteristics in three habitat suitability categories in the Ursus Valley, ranked as Excellent, Good and Sub-optimal by the Bahn and Newsom model (Chapter 6). The nest densities in each habitat category were estimated by climbing trees with potential nest platforms in randomly-selected clusters in unfragmented old-growth forest. Using measurements made in the tree canopy by the climbers, and in habitat plots sampled on the ground, they were also able to compare the availability of structures considered important for nesting murrelets, such as availability of platforms and epiphyte cover. In total, 467 trees with potential nest platforms were climbed and 44 vegetation plots were sampled.

The data provide some support for the Bahn and Newsom habitat suitability model, although separation of all three rankings was not consistently supported. Vegetation plot data showed that trees in Excellent habitat had thicker epiphyte growth, were taller and had greater diameter at breast height than trees in Good or Sub-optimal habitats. Total tree density was lower and canopy closure was higher in Excellent habitat than in Good and Sub-optimal habitats. Good habitat had higher densities of platforms than Excellent and Sub-optimal, which partially contradicted the model, but both Good and Excellent habitats had higher densities of trees with platforms than Sub-optimal habitat, as predicted by the model. Trees with platforms climbed in Excellent habitat were taller, had larger mean diameter, greater numbers of mossy platforms per tree and more abundant and thicker epiphyte cover than trees with platforms climbed in other habitat classes.

Of 240 trees with potential nesting platforms that were climbed in Excellent habitat, 5 nests were found; no nests were found in Good (n = 139 trees) or Sub-optimal (n = 88 trees) habitats. All nest-site characteristics (e.g., height within the tree, diameter of nest limb, moss thickness) were within the ranges found at other nest-sites from BC. Within Excellent habitat, the five trees with nests had significantly larger stem diameters than 235 trees that had potential nest platforms but no visible nests; no other tree characteristics differed significantly.

The five nests found included one used in the current year and four used in previous years. The density of trees (± SD) with potential nest platforms was 30 ± 14, 37 ± 27 and 12 ± 11 per ha in Excellent, Good and Sub-optimal habitats, respectively. The density of active nests per year was 0 for Good and Sub-optimal habitats, and 0.11 ± 0.12 (SD) per ha for Excellent habitat.

This study is the first to attempt an estimate of nest density from actual field measurements. It revealed that very large numbers of trees need to be climbed in order to find enough nests for analysis. This is both expensive and logistically demanding, but not likely to be more so than the efforts needed to find nests by telemetry. The climbing study also confirmed what the radar counts showed, that murrelets tend to nest in low densities even in apparently optimal habitat. The nest density data were used by Trudy Chatwin in calculating the areas of reserves needed for Clayoquot Sound (Chapter 8).

Management of Marbled Murrelet Nesting Habitat in Clayoquot Sound (Chapter 8, by Trudy Chatwin)

The primary purpose of the research and inventory studies in Clayoquot Sound was to provide information applicable to conservation and management of the threatened Marbled Murrelet. In the final chapter, Chatwin draws upon this information to assess the adequacy of existing reserves in old-growth forest available to nesting murrelets and to propose additions. Her objective was to ensure that the quantity and quality of the reserves would sustain present nesting populations of murrelets. Chatwin focused on four planning units (Bedingfield, Cypre, Flores Island and Tofino-Tranquil).

Chatwin used the Habitat Suitability Model (Bahn and Newsom, Chapter 6) to identify and map habitat ranked as "Important" (Important-Excellent + Important-Good) in the four planning units. She combined population estimates (from radar counts) and nest density data (from the tree climbing study) to evaluate the area of Important habitat needed to sustain the existing population of murrelets in Clayoquot Sound. There was a high degree of uncertainty around the nest density data, which affected the estimate of habitat required. The analysis indicated that a minimum of 21,400-28,600 ha (28-38%) of Important habitat was needed in the four planning units to sustain the present nesting population.

When the four planning units were mapped, more than 38% of Important habitat was in the Existing Reserve Network. The protected area was not, however, within the large patches (at least 200 ha) recommended for Marbled Murrelets by the IWMS. To minimize risk and ensure that 17-26% of the Important habitat was reserved in patches larger than 200 ha, Chatwin proposed additional Marbled Murrelet reserves for the four planning units. The proposed new reserves combined with the smaller existing reserves would protect approximately half of the Important habitat identified in these planning units. Larger reserves should minimize edge-related nest failures and provide some compensation for loss of nesting habitat outside reserves due to forest harvesting.

If, through adaptive management research, it can be shown that Marbled Murrelet populations do not decline when their habitat is fragmented, the inclusion of larger reserves allows later changes in reserve design. However, if, as current research indicates, murrelet numbers decline as their habitat is fragmented, the larger reserves will provide source habitats to help recolonize modified areas. If recently harvested watersheds show declines in murrelet populations despite the inclusion of reserves, then additional reserves will be needed. Reserve design based on these multi-scaled, science-based research and inventory techniques has application to ecosystem management of nesting habitat throughout the Marbled Murrelet's range.

Conclusions

Although our field work is completed, there is still much to be learned about the mysterious ways of the Marbled Murrelet. More work is needed to conserve the murrelet's forest and marine habitats, and our data will help with that task. Our research and inventory has provided valuable baseline data which can be compared with future monitoring to determine if the populations, distribution, habitat use and breeding success of the murrelets change over the years.

Research on Marbled Murrelets is continuing in Clayoquot Sound. A team involving Simon Fraser University, the BC Ministry of Forests and the Canadian Wildlife Service, led by Dr. Fred Cooke, is using radio-telemetry to track murrelets and locate nests in Clayoquot Sound. This work will, in part, test Bahn and Newsom's Habitat Suitability Model (Chapter 6) and provide valuable information on the demography, movements and habitat use of the Marbled Murrelet. Continuing at-sea monitoring is being planned. Management issues concerning murrelets are ongoing.

Much has been learned about Marbled Murrelets over the last 10 to 15 years, due to considerable research in both Canada and the US. Protection of nesting habitat in old-growth forest need no longer be based on guesswork. Despite the millions of dollars of research, many unanswered questions remain, which are critical for conservation and management. How do Marbled Murrelets select their nest sites? Where do murrelets go when their nest sites are clearcut? Is there some form of territoriality that causes them to space out in the forest? What role does food availability play in their distribution and breeding success? Where do murrelets go in the winter? These are all questions of basic biology that will take years of research to answer. The Marbled Murrelet will long remain, in the words of BC ornithologist Charlie Guiguet (1956): "the enigma of the Pacific."

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Many researchers of Marbled Murrelets in other parts of BC and in the US do not appreciate the difficulties of working with this species in Clayoquot Sound. Gaining access to observation and sampling sites through a range of habitats is a logistical nightmare. There are few roads in Clayoquot Sound, especially in the watersheds where most of the suitable murrelet habitat remains. Getting to study sites therefore meant using helicopters, float-planes and boats, usually followed by hours or days of slogging through dense forests and crossing swift, icy streams on foot. Research teams routinely hiked and camped for 5 to 14 days at a time and carried tents and all other supplies on their backs. Then there is the weather! Even on the days when it is not raining, the forest is damp and mists often hide the sun. Soggy clothes, wet tents, dark early mornings, hoards of "no-see-ums" and long treks through the tangle of deadfall and vegetation were a part of each project reported here. It is remarkable to hear the Marbled Murrelet's sharp keer calls, or glimpse the whizzing forms of murrelets flying through the early morning mists to feed their young. It was these experiences that kept the field crews going.

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At-Sea Surveys of Marbled Murrelets in Clayoquot Sound, 1996-2000

by Adrienne Mason, Alan E. Burger and Bob Hansen

Abstract

Vessel strip transects were made in nearshore seas along 148 km of coastline around Vargas and Flores Islands in Clayoquot Sound to sample the distribution and abundance of Marbled Murrelets (*Brachyramphus marmoratus*) and other seabirds. The Tofino Transect (52.7 km) in the Vargas Island area was sampled annually in the breeding season in 1996-2000, and the Flores Transect (95.3 km) in the Flores Island area was sampled in 1997-2000. Densities of Marbled Murrelets in the study area peaked between mid June and mid July and showed a significant decline in August, indicating post-breeding emigration. Most analysis focused on the core period of activity, 14 May to 31 July and we found no significant variation in murrelet densities among years in this period. Marbled Murrelets preferred certain areas in both transect routes and avoided other areas. This spatial distribution was consistent from year to year and high-density aggregations correspond to those found in previous studies in 1982, 1993 and 1996. Preferred areas were in nearshore waters on the exposed outer coast and between Vargas and Flores islands. In general the more sheltered inland channels were used by fewer murrelets. The preferred sites provide a focus for management and conservation plans for Marbled Murrelets in Clayoquot Sound. This information is useful in the event of an oil spill and to assess disturbance from boat traffic, aquaculture and fishing. Most newly-fledged juveniles appeared on the water from late June through August, and our data showed no marked variations in fledging times among years. Juveniles and adults showed similar spatial distributions among the legs of both transects and we found no evidence of separate “nursery areas” such as those used by juveniles in parts of Alaska. Our data provide a baseline for future monitoring of at-sea densities, spatial distribution and juvenile recruitment, and allow comparisons with other areas.

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Introduction

The Marbled Murrelet (*Brachyramphus marmoratus*) is a seabird in the Family Alcidae and is usually found in sheltered or nearshore ocean (Ralph et al. 1995, Nelson 1997). The species is listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and is on the Red List of species at risk in British Columbia. Loss of nesting habitat in coastal old-growth forests is recognized as the principal threat to the species in BC and elsewhere, but mortality from oil spills and entanglement in gill nets is also a concern (Rodway et al. 1992, Ralph et al. 1995, Burger 2002).

The Clayoquot Sound area contains some of the few remaining largely undisturbed areas of old-growth coastal temperate rainforest on Vancouver Island and supports large populations of breeding Marbled Murrelets (Sealy and Carter 1984; Rodway et al. 1992; Burger 1995, 1997, 2002, this volume). Monitoring of vulnerable and rare indigenous species was identified in recommendation 8.2 of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound (Clayoquot Sound Scientific Panel 1995). Our study was therefore established to provide baseline data during five breeding seasons (1996-2000) for monitoring populations of the murrelet at sea in parts of Clayoquot Sound. In addition, our goals were to assess the importance of various marine habitats in Clayoquot Sound to Marbled Murrelets, determine seasonal and annual variations in densities and distribution, and estimate the timing, density and spatial distribution of newly fledged juveniles. Our study forms part of a larger research and monitoring strategy in Clayoquot Sound, which includes several studies in Marbled Murrelet nesting habitat (see other chapters in this volume).

Prior to our study, at-sea surveys of Marbled Murrelets had been conducted in Clayoquot Sound during the breeding seasons of 1982 (Sealy and Carter 1984), 1992-1993 (Kelson et al. 1995) and 1996 (Kelson and Mather 1999). These early studies all used a contiguous grid method of surveying and covered the same areas. Their data indicated a significant decline in the murrelet population in Clayoquot Sound: the 1992-1993 surveys showed a 40% decline from 1982 counts (Kelson et al. 1995) and the 1996 surveys a 22% decline from 1982 counts (Kelson and Mather 1999). Loss of nesting habitat in old growth was suggested as a cause of the decline (Kelson et al. 1995), although Burger (2000) showed that changes due to ocean warming in the 1990s might be partly responsible.

Oil pollution is a significant cause of mortality among seabirds off the west coast of Vancouver Island (Burger 1992). A decade ago, approximately 164 million barrels of oil (1,500 tankers) moved up and down the west coast of Alaska, British Columbia and Washington each year (Burger 1992) and the shipping traffic is probably similar or greater today. Marbled Murrelets are at risk of being oiled, particularly in the summer off southwest Vancouver Island, where high murrelet densities coincide with the greatest volume of tanker traffic and other shipping. Marbled Murrelets are among the most vulnerable of Pacific seabirds to oil spills, because they remain on the sea for most of their lives, forage by diving and prefer marine areas in which there is a large volume of shipping (King and Sanger 1979, Carter and Kuletz 1995). Other concerns in Clayoquot Sound are the growing volume of nearshore boat traffic, continued sports and commercial fishing, and possible increases in aquaculture or gill-net fishing.

Specific objectives of the at-sea surveys were to:

- conduct boat surveys following the Resources Inventory Committee (RIC 1997) standards during the breeding season, which would provide baseline information on the distribution and densities of Marbled Murrelets in selected areas in Clayoquot Sound suitable for long-term monitoring;
- cover a sufficiently large and dispersed area that would include several important foraging areas, allowing us to document movements among marine patches and assess the predictability of preferred foraging areas;
- record seasonal and annual variations in distribution and density of Marbled Murrelets on the transect routes in order to assess temporal variability within and among seasons;
- count newly fledged juveniles to obtain an index for monitoring annual productivity (recruitment) of the local population and to determine the seasonal and spatial variations in juvenile numbers.

Methods

Study Area

Two survey routes were established for repeated strip transect: the Tofino Transect (Figure 2-1), from Tofino south to Portland Point then around Vargas Island, was sampled in 1996-2000; the Flores Transect (Figure 2-2), from Tofino up the east side of Vargas Island, out around Bartlett Island and then around Flores Island and back to Tofino, was sampled in 1997-2000. Both routes were selected to cover a wide range of marine habitats and to include previously observed concentrations of Marbled Murrelets (Sealy and Carter 1984, Kelson et al. 1995). Both routes were subdivided into legs with variable lengths and with waypoints that matched identifiable landmarks to aid navigation (Table 2-1, Figures 2-1 and 2-2). Details on the routes are available from the senior author or from earlier reports (Diggon and Mather 1999, Hansen et al. 2001) and are archived at the Ministry of Water, Land and Air Protection, Nanaimo.

The Tofino Transect was started in 1996, using a route previously surveyed in 1994 by J. Kelson (A. Dorst, pers. comm.), which covered 49.75 km. In 1997 and later years, Legs 4 and 7 of this survey were subdivided into shorter sub-units to give 10 legs, and the transect was lengthened slightly to 52.7 km, covering 15.8 km^2 (Table 2-1, Figure 2-1). The Flores Transect was started in 1997 with 17 legs, covering 82.1 km. In 1998 and later years, Leg 2 was re-routed and subdivided to incorporate areas where additional observations indicated significant seabird activity. The additional legs began at Eby Rock (end point of Leg 1), included a route around Bartlett Island and finished at Shot Island (the beginning of Leg 3). The route surveyed in 1998-2000 had 19 legs with a total length of 95.3 km, covering 28.6 km^2 (Table 2-1, Figure 2-2).

Field Survey Methods

Marbled Murrelets and other seabirds were counted using fixed-width strip transects (RIC 1997). Strip transects were selected because they were easier to navigate and sample in repetitive surveys than the grid-sample method used in previous at-sea surveys in Clayoquot Sound (Sealy and Carter 1984, Kelson et al.

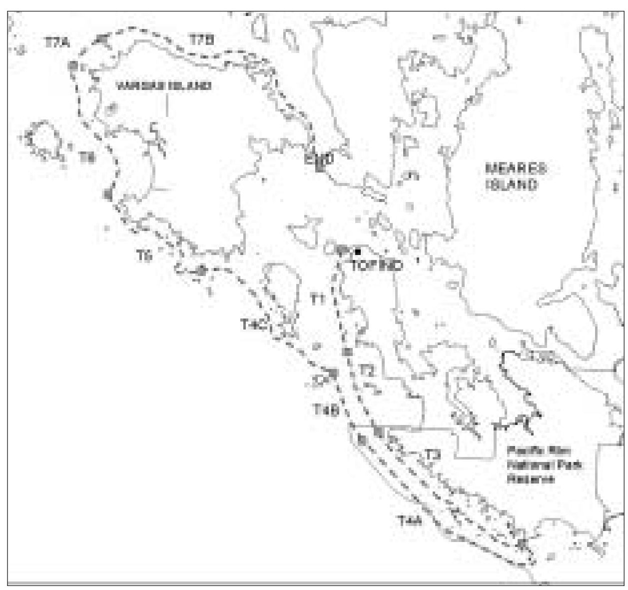

Figure 2-1. Map of the Tofino Transect route, showing the divisions into legs, each separated by a waypoint indicated by a square symbol. See Table 2-1 for details on the legs.

1995, Kelson and Mather 1999). Strip transects also allowed comparison with other surveys using similar methods elsewhere in BC (e.g., Burger 1995, 1997; Lougheed 2000). Line transects using the Distance sampling technique are probably more accurate than strip transects at estimating at-sea densities of murrelets (e.g., Becker et al. 1997) and have become the suggested standard for Marbled Murrelets in BC (RIC 2001). The Distance method is, however, sensitive to observers' abilities to estimate the distance of each bird from the transect line, and does not readily deal with large, scattered flocks of murrelets, as are regularly found in Clayoquot Sound. The Distance method is also more time-consuming and less suitable than strip transects when many species of seabird are being counted. Overall, strip transects provide a reasonably accurate, readily repeatable method suitable for long-term monitoring, where repeatability and precision are more important than accuracy in estimating densities.

Surveys were usually conducted from a 4.5-m inflatable boat powered by 25-hp or 40-hp outboard motors. In 1998, the Flores Route was surveyed using a 5.5-m fibreglass boat powered by a 115-hp outboard. In all boats the observers' eye height was approximately 1.5 m above sea level. We travelled at speeds of 8-12 knots (15-22 km/h), slowing or stopping occasionally to count larger flocks or check the identification of birds. Navigation was by reference to landmarks. A GPS was also used for navigation and as a safety precaution as the area is noted for thick fog.

Birds within 150 m of either side of the vessel were counted (i.e., 300-m-wide strip). Birds seen on the water were recorded separately from those flying. Any

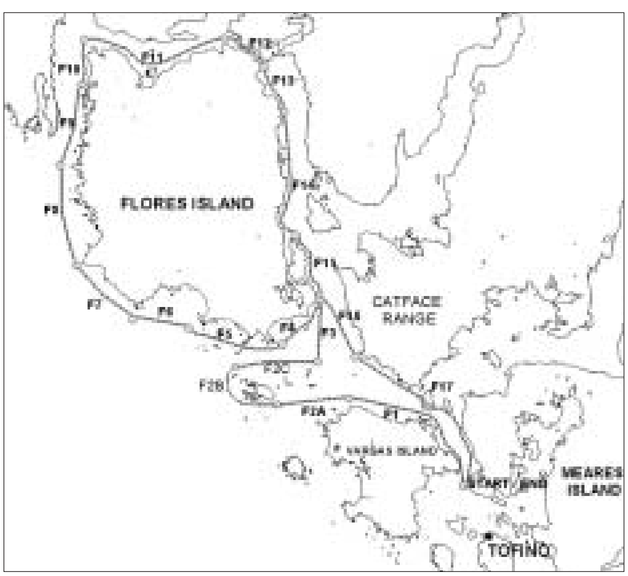

Figure 2-2. Map of the Flores Transect route, showing the divisions into legs, each separated by a waypoint indicated by a square symbol. See Table 2-1 for details on the legs.

Table 2-1. Breakdown of the legs within the Tofino and Flores transects.

Leg Code	Description	Distance (km)
Tofino Transect		
T1	Felice Island to north end of Chesterman Beach (Wickaninnish Inn)	3.60
T2	North end of Chesterman Beach to Cox Point	3.10
T3	Cox Point to Portland Point (inside of Gowland Rocks)	6.90
T4A	Portland Point to Cox Point (outside of Gowland Rocks)	8.80
T4B	Cox Point to Lennard Island	2.50
T4C	Lennard Island to Wilf Rocks (south tip of Vargas Island)	6.00
T5	Wilf Rocks to Ahous Point	5.40
T6	Ahous Point to Hobbs Islet	4.90
T7A	Hobbs Islet to Eby Rock	2.50
T7B	Eby Rock to Schindler Point	9.00
Total for Tofino Transect		52.70
Flores Transect		
F1	Schindler Point to Eby Rock	8.99
F2A	Eby Rock to Bartlett Island	8.48
F2B	Bartlett Island to Tibbs Light	3.88
F2C	Tibbs Light to Shot Islet	3.72
F3	Shot Islet to Yates Point	3.50
F4	Yates Point to Kutcous Point	3.32
F5	Kutcous Point to Red Rocks	5.43
F6	Red Rock to Siwash Cove	3.80
F7	Siwash Cove to Rafael Point	4.40
F8	Rafael Point to Hot Springs marker	5.76
F9	Hot Springs marker to Baseball Bay	4.75
F10	Baseball Bay to Starling Point	2.53
F11	Starling Point to Hayden Passage	8.30
F12	Hayden Passage to Millar Channel	1.38
F13	Millar Channel to Atleo Fish Markers	2.81
F14	Atleo Fish Markers to McKay Light	7.22
F15	McKay Light to Yates Point	3.69
F16	Yates Point to Chetarpe Point	3.96
F17	Chetarpe Point to Schindler Point	9.38
Total for Flores Transect		95.30

identifiable birds outside the transect were noted, but not included in density estimates. Estimates of seabird densities from transects tend to underestimate actual density since birds can be missed when diving or flying in or out of the transect area. Field studies indicate that some murrelets further than 100 m from a boat are likely to be missed, especially if the sea is choppy (Becker et al. 1997, A. Burger unpubl. data) and therefore extending our counts to 150 m on either side of the boat was likely to underestimate densities. This was the standard count distance at the time we started our study (RIC 1997) and inaccuracies were minimized by restricting counts to days when the sea was relatively calm. There are no easy, reliable methods for compensating for the birds missed while they are diving or flying and thus it seems prudent to use only the number of birds recorded on the water as a measure of density (RIC 1997).

Newly-fledged juveniles (also known as hatching-year or HY birds) were separated from adults and subadults (also known as after-hatching-year or AHY birds) on the basis of plumage (Carter and Stein 1995). AHY birds included both mature adults and immature birds one or two years old, but these have identical plumage unless examined in the hand.

Surveys were usually initiated in the mornings unless delayed by weather and/or sea conditions, and took 4 to 6 hours to complete. Sightings were recorded on a cassette recorder, timed to the nearest minute, and later entered into a Microsoft Access database. Sea state, wind conditions and weather were recorded for each survey. Generally, surveys were initiated only when winds were less than 15 knots (28 km/h) with sea swell less than 1 m. Occasionally surveys had to be aborted if weather deteriorated to a state when accurate viewing of birds was not possible.

Measuring Habitat Use and Density Anomalies
The relative use of Marbled Murrelets for each leg of the two transect routes was determined in three ways. Only birds recorded as on the water within the transect strip were used in the calculations. First, the density of murrelets per leg was calculated from the field data of each survey. Second, we calculated a density anomaly for each leg of the transect for each survey, using the equation:

$$\text{anomaly} = (d_i - d_m)/d_m$$

where d_i is the mean murrelet density for a particular leg and d_m is the mean murrelet density for the entire transect. A positive anomaly indicates a higher than average density in the leg, and a negative anomaly indicates avoidance of the leg. A positive anomaly of 1.0 indicates that murrelet density was double the transect average (100% higher). Mean anomalies for each leg were calculated for each year. Finally, the overall mean anomaly was calculated for all years of the study. Density anomalies were also a convenient method for comparing the spatial distribution of juveniles and birds in adult plumage, because these age groups had very different densities.

Estimates of Juvenile Recruitment
The ratio of juveniles (HY) to birds in adult plumage (AHY) is a standard productivity index for estimating annual recruitment or breeding success in Marbled Murrelets (Beissinger 1995, Kuletz and Kendall 1998). There are, however, several problems in estimating and interpreting this ratio. In some areas, juvenile birds remain in the area into which they fledge for just a few days, before migrating elsewhere (Lougheed 2000). In many areas, adult birds emigrate as breeding ends and the AHY counts therefore decline rapidly as the HY birds reach the water, which seriously biases any HY:AHY ratio where both groups are counted concurrently (Kuletz and Kendall 1998). Emigration of adult murrelets late in the breeding season occurs in Clayoquot Sound (this study) and in other areas of southwest Vancouver Island (Burger 1995, 1997).

Kuletz and Kendall (1998) proposed two methods to avoid the bias resulting from concurrent HY:AHY ratios in situations where adults migrated while juveniles were fledging. The first method involved using a temporally adjusted HY:AHY ratio, rather than concurrent counts as a productivity index. The mean counts of HY birds during the period of fledging are used as the numerator, and the mean counts of AHY birds during the incubation phase as the denominator. The Clayoquot Sound counts did not sample the incubation period (May and June) sufficiently, and so we modified the method, using the mean AHY counts from 14 May through 16 July, and the mean HY counts from 15 June through 10 August. Most years were not sampled after 10 August, even though some juveniles certainly fledged after that date, but as breeding ends it becomes difficult to differentiate juveniles from the increasing proportion of moulting adults with similar plumage. The second productivity index proposed by Kuletz and Kendall (1998) is the mean density of juveniles (birds per km^2) measured during the fledging period (15 June through 10 August in our samples). This measure is not affected by counts of adult birds.

The date of the survey has a major effect on the density of adults and juveniles. We therefore tested the effects of different transects and years on adult density, juvenile density and concurrent HY:AHY ratio using a General Linear Model (GLM) analysis with date set as a covariate, and year and transect set as fixed factors. Statistical analysis was done with SPSS 10.0, and the level of statistical significance (alpha) was 0.05.

Results

Data Summaries
We counted 11,080 Marbled Murrelets in all the surveys of the Tofino and Flores transects (Tables 2-2 and 2-3; further details in Appendices 2-1 and 2-2). Of these, only 5% were recorded outside the 300-m transect strip and these were not included in any further analyses. Out of 10,515 sightings of murrelets within the transect, 87.3% were on the water and 12.7% flying. Analysis of densities focused on murrelets on the water within the transects.

Table 2-2. Tofino Transect counts of Marbled Murrelets from 1996 to 2000. The density was calculated from birds on the water within the 300-m-wide transect. Mean values for each year were calculated for the entire survey period and for the core part of the breeding season (14 May through 31 July).

		Murrelets within transect					
Date	Transect distance (km)	On water - Adults	On water - juveniles	Flying	Total = On Water + Flying	Density on water (birds/sq.km.)	Murrelets outside transect
1996							
18-Jun-96	49.75	206	1	43	250	13.87	0
24-Jun-96	49.75	352	12	106	470	24.39	0
4-Jul-96	49.75	204	4	105	313	13.94	5
11-Jul-96	49.75	223	11	30	264	15.68	11
18-Jul-96	49.75	94	9	70	173	6.90	15
24-Jul-96	49.75	32	5	9	46	2.48	0
5-Aug-96	49.75	33	0	17	50	2.21	0
12-Aug-96	49.75	16	3	6	25	1.27	1
20-Aug-96	49.75	30	0	15	45	2.01	0
30-Aug-96	49.75	5	0	4	9	0.34	2
8-Sep-96	49.75	0	0	0	0	0.00	0
17-Sep-96	49.75	8	0	1	9	0.54	0
29-Sep-96	49.75	4	0	0	4	0.27	0
Mean for 1996 (all surveys)		93	3	31	128	6.45	3
Mean for 1996 (core period)		216	7	71	294	12.88	6
1997							
14-May-97	52.7	168	0	18	186	10.63	15
30-May-97	52.7	228	0	50	278	14.42	8
11-Jun-97	52.7	269	0	28	297	17.01	17
19-Jun-97	52.7	129	0	16	145	8.16	4
28-Jun-97	52.7	81	6	3	90	5.50	1
11-Jul-97	52.7	130	8	28	166	8.73	21
22-Jul-97	52.7	103	15	15	133	7.46	27
7-Aug-97	52.7	26	3	6	35	1.83	5
Mean for 1997 (all surveys)		142	4	21	166	9.22	12
Mean for 1997 (core period)		157	5	23	185	10.27	13
1998							
17-May-98	52.7	17	0	3	20	1.08	0
29-May-98	52.7	254	0	26	280	16.07	3
08-Jun-98	52.7	260	0	31	291	16.45	51
17-Jun-98	52.7	293	1	8	302	18.60	71
27-Jun-98	52.7	113	6	15	134	7.53	14
13-Jul-98	52.7	103	5	14	122	6.83	27
24-Jul-98	52.7	43	19	2	64	3.92	17
10-Aug-98	52.7	23	8	1	32	1.96	4
Mean for 1998 (all surveys)		138	5	13	156	9.05	23
Mean for 1998 (core period)		155	4	14	173	10.07	26
1999							
20-Jun-99	52.7	51	1	18	70	3.29	2
11-Jul-99	52.7	120	11	19	150	8.29	0
8-Aug-99	52.7	25	8	6	39	2.09	1
Mean for 1999 (all surveys)		65	7	14	86	4.55	1
Mean for 1999 (core period)		86	6	19	110	5.79	1
2000							
6-Jun-00	52.7	52	0	14	66	3.29	0
24-Jun-00	52.7	36	0	4	40	2.28	0
15-Jul-00	52.7	116	8	18	142	7.84	7
5-Aug-00	52.7	66	9	11	86	4.74	1
Mean for 2000 (all surveys)		68	4	12	84	4.54	2
Mean for 2000 (core period)		68	3	12	83	4.47	2

Table 2-3. Flores Transect counts of Marbled Murrelets from 1997 to 2000. The density was calculated from birds on the water within the 300 m wide transect. Mean values for each year were calculated for the entire survey period and for the core part of the breeding season (14 May through 31 July).

		Murrelets within transect					
Date	Transect distance (km)	On water - Adults	On water - juveniles	Flying	Total = On Water + Flying	Density on water (birds/sq.km.)	Murrelets outside transect
1997							
15-Jun-97	82.1	462	0	69	531	18.8	8
21-Jun-97	82.1	395	0	52	447	16.0	19
16-Jul-97	82.1	214	21	36	271	9.5	28
19-Jul-97	82.1	117	17	30	164	5.4	11
5-Aug-97	82.1	29	16	7	52	1.8	0
15-Aug-97	82.1	57	11	5	73	2.8	0
28-Aug-97	82.1	33	1	2	36	1.4	0
Mean for 1997 (all surveys)		187	9	29	225	8.0	9.4
Mean for 1997 (core period)		297	10	47	353	12.4	16.5
1998							
25-May-98	95.3	107	0	15	122	3.7	0
31-May-98	95.3	287	0	56	343	10.0	27
17-Jun-98	95.3	679	0	32	711	23.7	57
22-Jun-98	95.3	576	2	21	599	20.2	43
27-Jun-98	95.3	151	6	23	180	5.5	3
7-Jul-98	95.3	100	2	24	126	3.6	0
13-Jul-98	95.3	241	30	27	298	9.5	2
21-Jul-98	95.3	188	18	24	230	7.2	0
4-Aug-98	95.3	46	6	8	60	1.8	0
Mean for 1998 (all surveys)		264	7	26	297	9	15
Mean for 1998 (core period)		291	7	28	326	10.4	16.5
1999							
22-Jun-99	95.3	208	0	66	274	7.3	0
10-Jul-99	95.3	263	2	35	300	9.3	6
7-Aug-99	95.3	93	53	6	152	5.1	8
Mean for 1999 (all surveys)		188	18	36	242	7	5
Mean for 1999 (core period)		236	51	287	8.3	3.0	
2000							
7-Jun-00	95.3	52	0	0	52	1.8	0
25-Jun-00	95.3	244	9	14	267	8.8	0
16-Jul-00	95.3	262	24	18	304	10.0	21
6-Aug-00	95.3	121	14	6	141	4.7	2
Mean for 2000 (all surveys)		170	12	10	191	6	6
Mean for 2000 (core period)		186	11	11	208	6.9	7.0

Seasonal and Annual Variations in Density

Marbled Murrelet densities showed strong seasonal trends in all years, with peak densities occurring between late May and mid July, and consistently low counts after the end of July (Figure 2-3). Analysis of Variance showed significant effects of month on murrelet densities in the Tofino Transect but not in the Flores Transect (Table 2-4). The effects of year and the interaction of year by month were not significant in either of the two transects, but the high variability within each season made it difficult to detect significant differences. To minimize seasonal variations we restricted further analysis to a core period (14 May-31 July), which covered most of the surveys but omitted the low counts after 31 July. Within this core period we found no significant difference among years for the Tofino ($F_{4,23}$ = 1.168, P = 0.356) and Flores ($F_{3,16}$ = 0.474, P = 0.705) transects, although there was a trend for lower densities in 1999 and 2000 in both transects (Figure 2-4).

Seasonal Variations in Juvenile Counts

Newly fledged juveniles first appeared in mid to late June (first sightings in each year were 18 June 1996, 28 June 1997, 17 June 1998, 20 June 1999 and 25 June 2000). Peak counts of juveniles were made from the last week of June through mid August (Figure 2-5). The fledging peak might have extended somewhat later in some years, but few surveys were made after 10 August in most years. Our data were too sparse to statistically compare dates of fledging among years, but there were no obvious differences among years, and we could detect no difference in the timing of fledging between the “warm” years of 1996-1998 and the “cool” years of 1999-2000 (Figure 2-5).

Table 2-4. Results of Analysis of Variance (General Linear Model) of murrelet density compared with year and month in the Tofino and Flores transects.

Variable	Type III Sum of Squares	df	F	P value
Tofino Transect (1996-2000)				
YEAR	116.0	4	1.128	0.375
MONTH	419.6	4	4.079	0.016
YEAR * MONTH	300.6	9	1.299	0.303
Total	3288.4	36		
Corrected Total	1423.7	35		
Flores Transect (1997-2000)				
YEAR	14.9	3	0.189	0.902
MONTH	202.0	3	2.560	0.114
YEAR * MONTH	204.6	6	1.297	0.341
Total	2387.6	23		
Corrected Total	848.9	22		

Spatial Distribution Along the Transects

Murrelet densities varied considerably among the legs of the two transects within the core period, but the large standard deviations in most legs indicate considerable variability within the transect as well (Figures 2-6 and 2-7). This within-season variability is due to local movements and seasonal migrations. With densities plotted as anomalies (variations from the average density within the transect), the spatial distribution is more obvious (Figures 2-6 and 2-7). In both transects there was consistency in spatial distribution among the transect legs from year to year – most legs were either consistently well used, consistently avoided or consistently close to the transect average density.

Within the Tofino Transect the preferred legs were T3, T4C and T5, and legs T4A and T7A had densities close to the transect average (see Table 2-1 and Figure 2-1 for details of their location). In the Flores Transect the preferred legs were F2B, F2C, F3, F5, F6, F8, F16 and F17, and legs F2A, F4 and F7 had densities close to the transect average (see Table 2-1 and Figure 2-2 for locations).

Juvenile Distribution

Juvenile densities were too low for detailed analyses of distribution within seasons, but we compared their overall distribution with that of birds in adult plumage using the mean density anomaly for all years (Figure 2-8). The distribution of juveniles across the transect legs was very similar to that of adults, and there was a significant positive correlation between age classes in

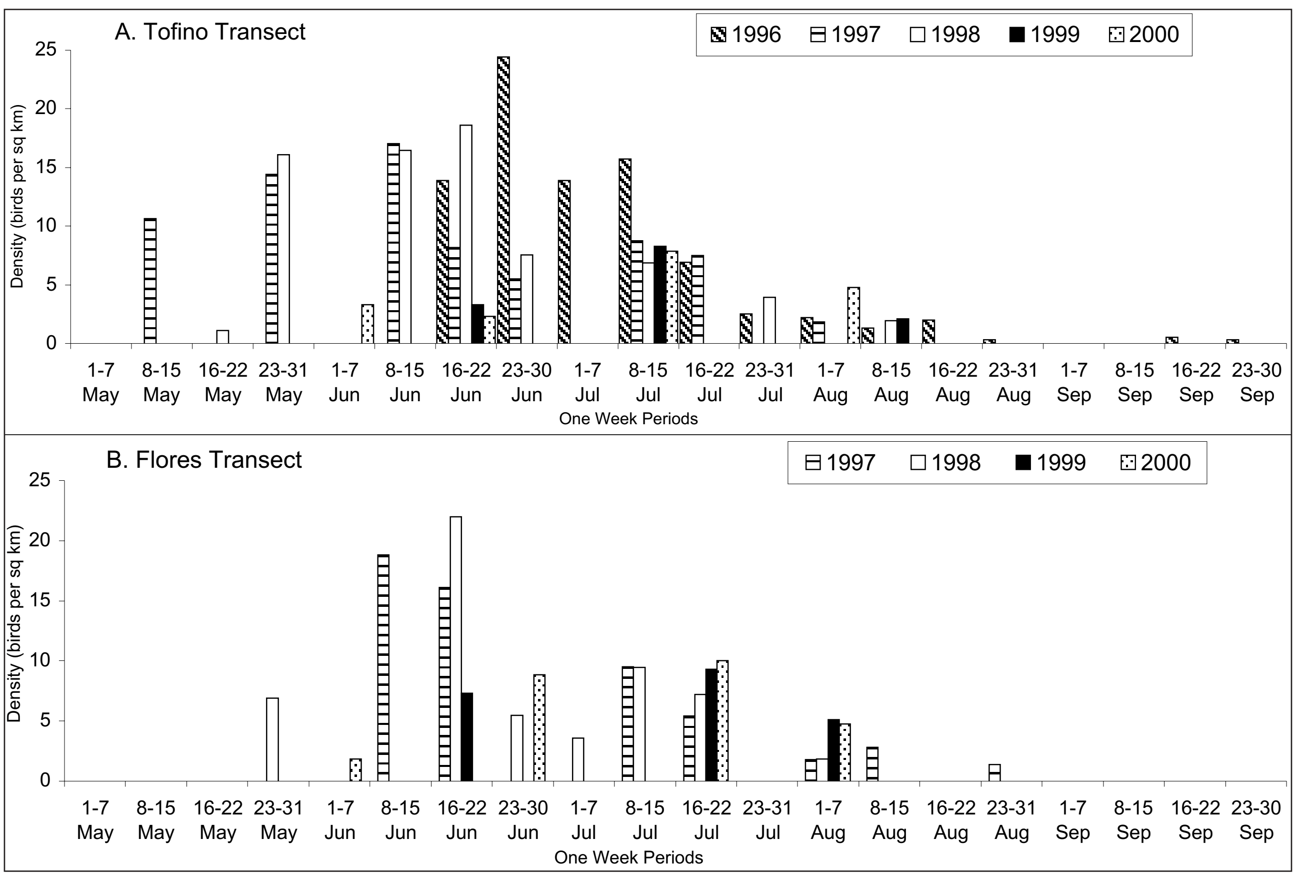

Figure 2-3. Seasonal trends in the density of Marbled Murrelets inside the transect, on the water for the Tofino Transect (upper graph) and the Flores Transect (lower graph). The densities are plotted for one week intervals. When two surveys were done per week (Flores Transect: 16-22 July 1997, 23-31 May 1998, 1-7 May 1998) the weekly mean was plotted.

the ranking of the legs within both transects (Spearman rank correlation; Tofino Transect: $r_s = 0.794$, $N = 10$, $P = 0.006$; Flores Transect: $r_s = 0.854$, $N = 19$, $P < 0.001$).

Densities of Newly-fledged Juveniles and HY:AHY Ratios

Three indices of productivity or juvenile recruitment were calculated for each transect and each year (Figure 2-9): a) the concurrent HY:AHY ratio calculated from the birds counted within each survey; b) the adjusted HY:AHY ratio, using a modified version of the Kuletz and Kendall (1998) method; and, c) the mean density of juveniles per square km during the fledging period.

The concurrent HY:AHY ratios (Figure 2-9A) overestimated recruitment in Clayoquot Sound, because at the time of fledging many adults had already emigrated. These data were provided merely for comparison with other studies that use similar ratios, and to test for differences among years and between transects.

The adjusted HY:AHY ratio was more likely to reflect the actual ratio of fledged juveniles to AHY birds, but might have been biased by unusual movements or distribution of adults. Both the Tofino and Flores transects showed marked increases in this ratio in 1999 and 2000, relative to previous years (Figure 2-9B). This might, however, be an artifact of the small sample size and the low counts of adults in those years (Figure 2-4, Tables 2-2 and 2-3). The adults might have been foraging elsewhere in those years because of changed local ocean conditions. Juvenile densities did not show the same trends in both transects (Figure 2-9C).

Statistical tests showed that adult densities, juvenile densities and concurrent HY:AHY ratios were all significantly affected by date, but with date set as a covariate, there was no significant effect of transect or year (Table 2-5). Adjusted HY:AHY ratios, calculated as a single measure per year could not be statistically tested.

Discussion

Seasonal Abundance

Marbled Murrelets are present year-round in Clayoquot Sound, albeit in low numbers in inlets and protected waters during the winter (personal observations). Numbers within the study area tended to increase through June and into July, peaked from mid June to mid July, and then declined noticeably in August. Similar seasonal patterns have been reported from several other areas on the west coast of Vancouver Island (Carter 1984; Burger 1995, 1997). Although some murrelets appear to overwinter in sheltered inlets on this coast, the bulk of the population appears to leave the area after the breeding season ends in late July. The arrival of birds in the spring is less well documented, but in most years this happened in late April and early May (Carter 1984, Burger 1995, A. Burger, unpubl. data). The continued influx of birds into July likely includes some non-breeders. Counts from the core period 14 May through 31 July therefore captured the bulk of the breeding season activity, but there was still considerable variability in the counts during this period. This was probably due to local movements of the murrelets within the larger Clayoquot Sound area.

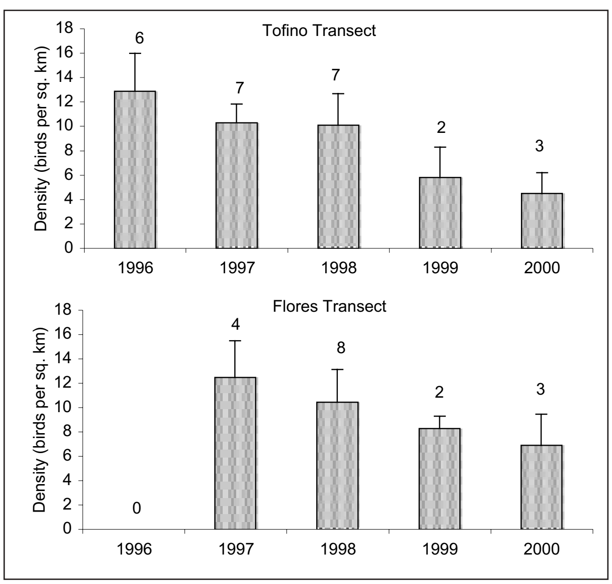

Figure 2-4. Mean (± SE) density of Marbled Murrelets on the water within the Tofino and Flores transects during the core period (14 May - 31 July). The number of surveys within the core period is shown for each year. The Flores transect was not surveyed in 1996.

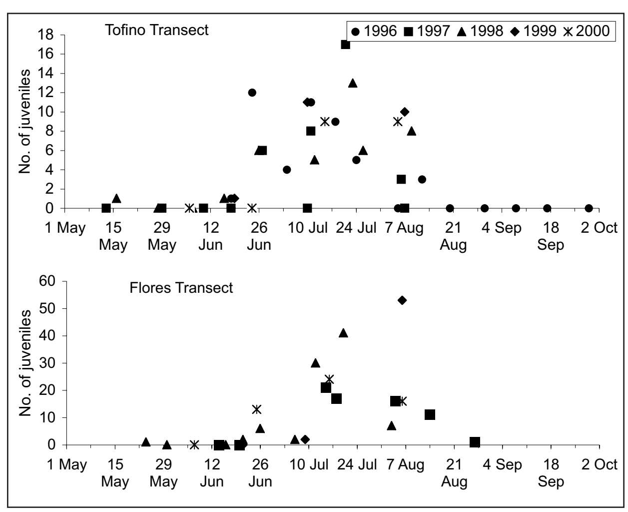

Figure 2-5. Seasonal variation in counts of newly fledged juveniles on the water in the two transects in Clayoquot Sound.

Table 2-5. Statistical tests (GLM model) on adult (AHY) density, juvenile (HY) density, and concurrent HY:AHY ratios. In each analysis the df values were the same. Date was set as a covariate and Transect (Tofino vs. Flores) and Year were set as fixed factors. In each case there was no significant effect of Transect or Year, once the effects of Date were controlled.

		Adult (AHY) density		Juvenile (HY) density		Concurrent HY:AHY ratio	
	df	F	P	F	P	F	P
Model	9	2.280	0.035	3.115	0.006	5.467	<0.001
Date	1	13.797	0.001	22.769	<0.001	36.409	<0.001
Transect	1	1.116	0.297	0.057	0.813	0.099	0.754
Year	4	1.653	0.179	0.112	0.978	1.372	0.26
Transect*Year	3	0.076	0.973	0.431	0.732	1.109	0.356

Variations Among Years and Effects of Ocean Temperatures

Marbled Murrelets appear to be sensitive to the effects of local sea temperatures. Off southwest Vancouver Island, several measures of at-sea density and inland activity of Marbled Murrelets showed negative correlations with local sea temperatures, suggesting that murrelets were negatively affected by warmer than normal temperatures in the spring and summer (Burger 2000). We examined whether our data from Clayoquot Sound fit this pattern by comparing densities and juvenile recruitment with sea surface temperatures.

Temperatures measured at Amphitrite Point were provided by the Department of Fisheries and Oceans (http://www-sci.pac.dfo-mpo.gc.ca/osap/data/lighthouse).

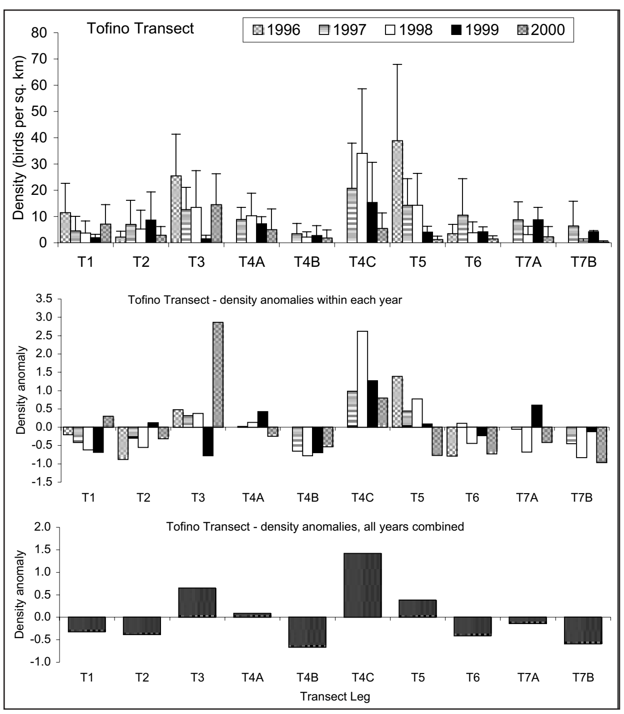

Figure 2-6. Mean density ± SD (upper graph) and density anomalies (lower graphs) per leg within the Tofino transect. Only birds on the water within the 300-m-wide transect strip were included. Anomalies greater than zero indicate positive preference for the leg and negative values indicate avoidance. Note that there were no data from legs T4A-C or T7A-B for 1996.

Mean temperatures were calculated for the period April through July, which covers the period of peak marine productivity and the murrelet's breeding season (Figure 2-10). Local sea temperatures tended to be higher than normal for the 20-year period 1978-1998, with the years before and after having lower than normal temperatures. This pattern matches the large-scale Pacific Decadal Oscillations (PDO) affecting the eastern North Pacific and Gulf of Alaska (Francis et al. 1998, McGowan et al. 1998, Anderson and Piatt 1999). These long-term oscillations, driven by changes in temperature and currents, create "regime-shifts" affecting entire pelagic food webs. Within this prolonged warm phase there were also shorter-term fluctuations in sea temperatures associated with El Niño and La Niña events. From 1978 to 1998, the eastern Gulf of Alaska, including BC, experienced a warm phase, and fish-eating seabirds in many areas were negatively affected by this change (Anderson and Piatt 1999).

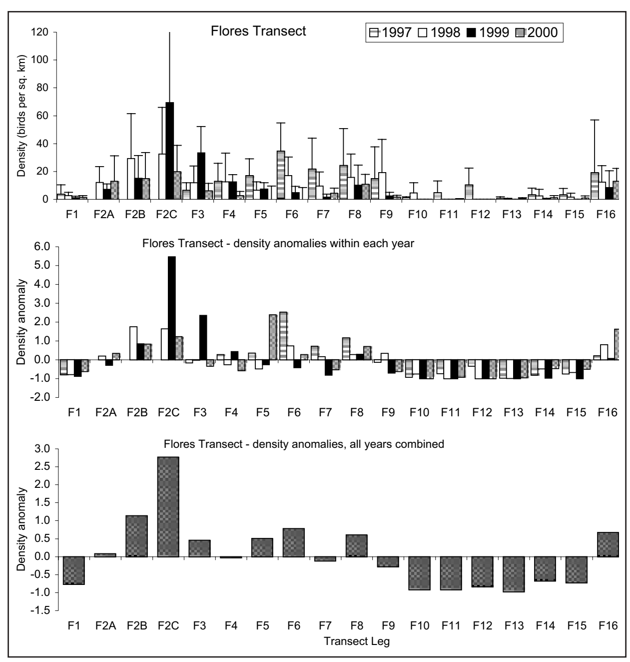

Figure 2-7. Mean density ± SD (upper graph) and density anomalies (lower graphs) per leg within the Flores transect. Only birds on the water within the 300-m-wide transect strip were included. Anomalies greater than zero indicate positive preference for the leg and negative values indicate avoidance. Note that there were no data from legs F2A-C for 1997.

Our surveys in 1996-2000 spanned the transition from the warm to cool regimes and included the 1997 El Niño event. We found no significant differences among the years in densities of murrelets at sea in Clayoquot Sound, once seasonal variations were statistically controlled. Both the Tofino and Flores transects showed lower densities of murrelets in 1999 and 2000, but our sample sizes were small in those years and the differences were not significant. If there were in fact fewer murrelets in Clayoquot Sound during the cooler years of 1999 and 2000 this would contradict the hypothesis that the murrelets avoid the area during warm years (Burger 2000), and might suggest that a decline in numbers was occurring.

The annual trends in juvenile recruitment were somewhat contradictory to the overall density pattern. Adjusted HY:AHY ratios showed a marked increase in recruitment in the cool years of 1999 and 2000, consistent with the hypothesis that conditions are better for murrelets during cooler sea temperatures, but we found no significant difference in the densities of juveniles (birds per square kilometre) among the years. Overall, it seems a much larger sample within and among years is necessary to determine significant variations among years, and to test the effects of ocean temperatures on murrelets off southwest Vancouver Island.

Juvenile Recruitment

In most years, peak counts of newly-fledged juveniles were from late June through mid August and we could detect no obvious variations in the timing of fledging among the years. We found no significant effects on adult (AHY) density, juvenile (HY) density or HY:AHY ratio from transects (Tofino vs. Flores) or years, once the date of surveys was statistically controlled. All three variables were strongly influenced by date, reflecting the dramatic changes as adults moved in and out of the study area through the season, and as juveniles fledged and also seemed to emigrate. More detailed analysis of the movements of adults and juveniles using radio-telemetry would allow a more refined estimate of the numbers of adults and juveniles using the area, and hence better estimates of recruitment or productivity (Lougheed 2000). Annual variations in juvenile counts were discussed in the previous section.

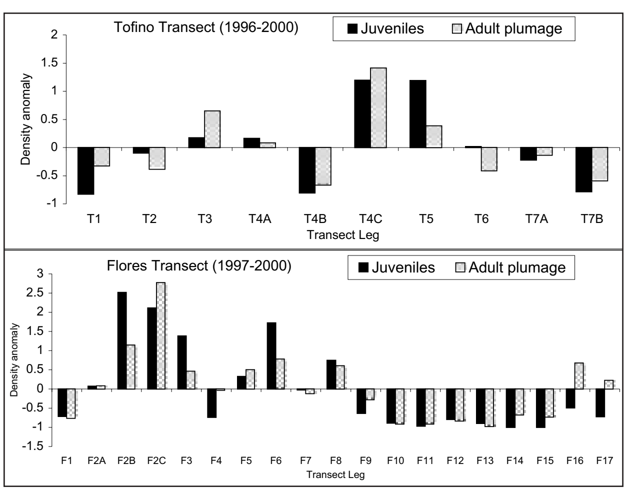

Figure 2-8. Comparison of the density anomalies per transect leg of juveniles and birds in adult plumage (after hatching year birds) in the Tofino and Flores transects.

The adjusted HY:AHY ratios ranged from 0.024 to 0.083 in the Tofino transect and 0.030 to 0.084 in the Flores transect. This suggests a rather low productivity (2.4-8.4%), but is fairly typical of similar measures made in other parts of BC (Lougheed 2000, Burger 2002) and elsewhere in the species range (Beisinger 1995, Kuletz and Kendall 1998). More refined estimates of recruitment require knowledge of the residence time within the study area after fledging by juveniles, migration patterns of adults and juveniles, and the proportions of active breeders within the AHY population. Once these factors are better known, our data can be re-interpreted and compared with data from other years and different places.

These data provide useful baseline data with which to compare productivity in previous years within the same study areas. Kuletz and Kendall (1998) found that juvenile density was a reliable measure of productivity for long-term monitoring within specified study areas and was not affected by seasonal variations in the densities and movements of adults. They concluded that several measures of productivity (e.g., adjusted HY:AHY ratios and juvenile densities) could be applied, since no single method was without some bias or source of error.

Spatial Distribution and Habitat Use

Although Marbled Murrelets tended to move around somewhat throughout the study area over the duration of the study season, some areas were consistently preferred through the years of our study. We recorded consistently high densities in the exposed nearshore seas facing the open ocean off Vargas Island and Flores Island, and in the more sheltered waters between these islands. These preferred sites also concur with those found in grid surveys done in 1982, 1992, 1993 and 1996 (Sealy and Carter 1984, Kelson et al. 1995, Kelson and Mather 1999). This consistent use of these areas, from studies spanning almost two decades and using two different methods, is a strong indicator that murrelets have high foraging site fidelity, despite diurnal and seasonal variations in at-sea locations. Regular use of selected areas has also been found in multi-year surveys from Barkley Sound (Carter 1984, Carter and Sealy 1990,

A. Burger unpubl. data), the West Coast Trail coast (Burger 1997), Desolation Sound (Lougheed 2000), Laskeek Bay off Haida Gwaii (Gaston 1996) and in Alaska (Kuletz 1996, Speckman et al. 2000). Strong et al. (1995), however, found significant shifts in distribution along the Oregon coast from year to year.

The underlying causes for the observed habitat use is difficult to determine. Off southwest Vancouver Island, Marbled Murrelets show a general preference for shallow (<20 m), nearshore waters off outer coastlines and have more variable densities within more protected waters (Carter 1984; Sealy and Carter 1984; Burger 1995, 1997). Shallow, nearshore habitat is likely to provide optimal foraging conditions, including aggregations of sand lance (*Ammodytes hexapterus*) and juvenile Pacific herring (*Clupea harengus*). Along the West Coast Trail, murrelet densities were correlated with the distribution of sandy shores, likely linked with subtidal sandy habitats suitable for sand lance (Burger 1997). Further studies on prey availability, water currents and substrate distribution in Clayoquot Sound are likely to explain the distribution patterns we observed. Disturbance from boats (which are more abundant in protected waters than along exposed shores) is also likely to affect murrelet distribution and habitat use.

Defining Well-used Areas and Exposure to Risk

Defining these well-used marine areas is an obvious priority when considering risks from oil spills, interference from aquaculture facilities, boat traffic and fishing, and for possible marine protected areas. Chronic low-level oil pollution is a persistent cause of mortality among seabirds off the west coast of Vancouver Island, and occasional large catastrophic spills are likely to

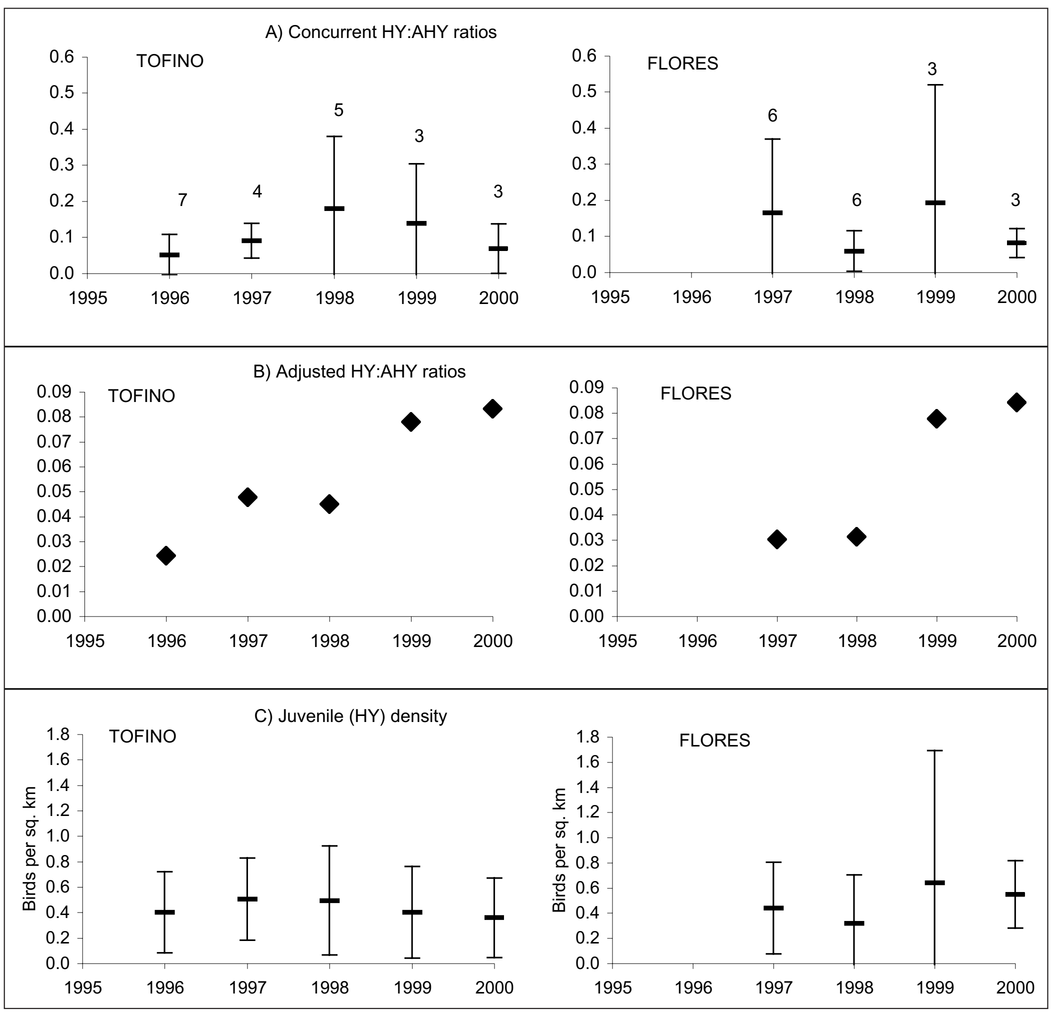

Figure 2-9. Three measures of juvenile recruitment in Clayoquot Sound in 1996-2000. Graphs on the left show the data from the Tofino transect and on the right the Flores transect. Graph A shows the mean (± SD) concurrent ratios of hatching-year (HY) to after-hatching-year (AHY) for surveys between 15 June and 10 August. Graph B shows the adjusted HY:AHY ratio, modified from the Kuletz and Kendall (1998) method, based on the mean HY counts between 15 June and 10 August, and mean AHY counts between 14 May and 16 July. Graph C shows the mean (± SD) density of juveniles per square kilometre in surveys made from 15 June through 10 August. The sample sizes show the mean number of counts between 15 June and 10 August.

occur (Burger 1992). A large oil spill reaching Clayoquot Sound between May and September could be devastating to the Marbled Murrelet population. The preferred marine habitats noted above should be the primary focus of any oil spill contingency plans for the area.

Marbled Murrelets are occasionally caught on fishing lures (Campbell 1967, Carter et al. 1995, Kelson and Mather 1999). Given the high frequency of sports fishing in areas preferred by Marbled Murrelets, particularly off Portland Point and Wilf Rocks on the Tofino Transect, it is likely that some Marbled Murrelets are caught and injured or killed by fishing lures within our study area. Mortality from entanglement in gill-nets is a concern for Marbled Murrelets elsewhere in BC (Carter and Sealy 1984, Carter et al. 1995), but gill-net fishing is currently uncommon in Clayoquot Sound. Disturbance from boaters is likely to affect murrelets. Marbled Murrelets will dive on close encounters with boats, but often fly when approached by a boat at longer range (B. Hansen, personal observation). Piatt and Naslund (1995) assert that persistent boat traffic could prevent murrelets from utilizing important foraging areas and cause the disruption of breeding. Some areas with high densities of Marbled Murrelets in Clayoquot Sound are also favoured locations for sport fishers, kayakers and whale-watching charters. Of particular note are: Leg T3 (Cox Point to Portland Point), which is becoming a very popular route for salmon and halibut fishing charters heading off Portland Point; Leg T4C, which is popular for both sports fishermen (particularly off Wilf Rock and behind Lennard Island) and whale-watching charters (routinely on the west side of Lennard Island to observe seals); Legs F2A-2C (Eby Rock, around Bartlett Island and back to Shot Island), which is frequently used by whale-watching boats going to Cleland Island or Cow Bay, and by kayakers going to Whaler Islet; and Leg F16 (Yates Point to Chetarpe), which is utilized by water taxis, whale-watching charters, other tour boats, fishing boats, aquaculture tenders and private vessels. Heavy boat traffic through Maurus Channel/Calmus Passage on the inside of Elbow Bank close to Vargas Island might explain the low densities of murrelets there (both legs F1 and T7B), compared with higher densities in leg F17 on the opposite side of the channel, which is less frequently used by boats. More work is needed to confirm the effects of boat traffic on murrelets in Clayoquot Sound.

Spatial Distribution of Juveniles

Understanding the spatial distribution of newly-fledged juveniles is important for several reasons. Counts of juveniles at sea are the only known method of monitoring breeding success of Marbled Murrelets over many years. Monitoring breeding success at nest sites is extremely difficult because of the logistical problems and costs involved in locating nests and the disturbance likely to affect their success. At-sea counts of these age classes are, however, likely to be inaccurate and might underestimate or overestimate recruitment if juveniles use significantly different foraging and loafing areas than older birds. Several studies have noted that juveniles tend to prefer more sheltered waters and are more likely than adults to be found in kelp beds (Sealy 1975, Strachan et al. 1995), although some studies found no difference in habitat use by juveniles and adults (Ralph and Long 1995). At a larger spatial scale, there is evidence that juveniles move from day to day after reaching the water and local counts can include

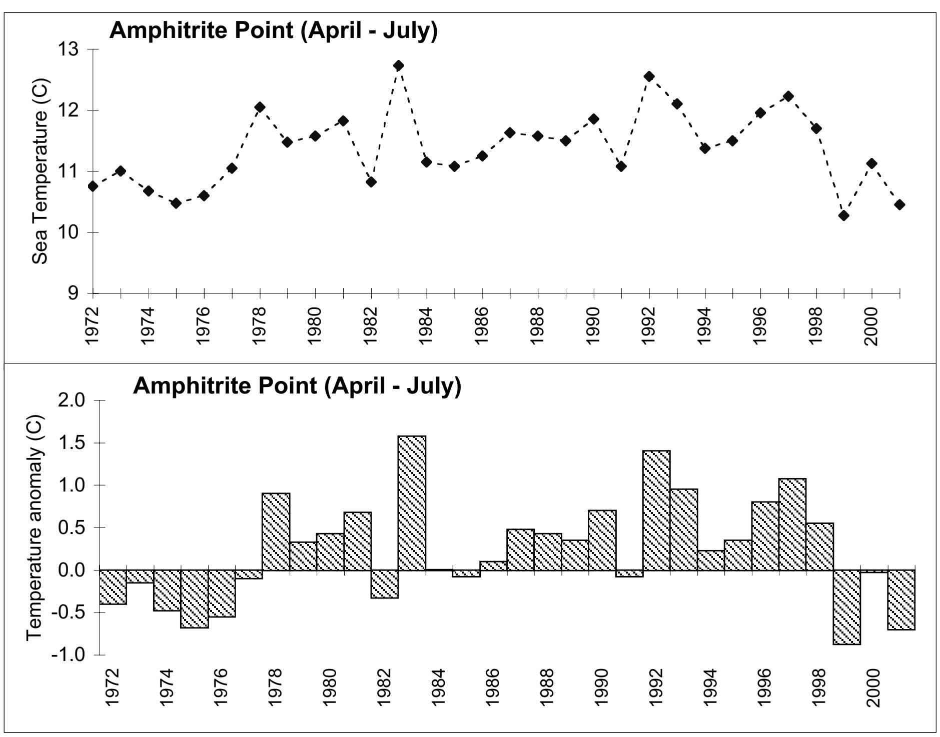

Figure 2-10. Annual variations in sea surface temperature measured at Amphitrite Point lighthouse. The upper graph shows the mean temperatures for April-July (period of peak productivity at sea) for 1972-2001 and the lower graph shows the temperature anomalies (deviations from the long-term average) for the same period.

juveniles that fledged many kilometres away (Lougheed 2000). In some areas, juveniles aggregate in “nursery areas” that are not as well-used by adults (Kuletz and Piatt 1999). Identifying such areas is important for accurate estimates and monitoring of juvenile recruitment

Our data showed no significant differences in the spatial distribution of juveniles and after-hatching-year birds in the legs of both transects when averaged over all the years of the study. At this spatial scale (approximately 1-10 km leg lengths), the juveniles appear to aggregate in the same habitats as older AHY birds. The spatial resolution of our surveys was not fine enough to determine whether juveniles were perhaps using somewhat different habitats (e.g., preferentially using kelp beds) within each leg. It seems that the length and habitat diversity of our transects was sufficient to cover areas likely to be used by all age classes, and we therefore feel confident that these transect routes will be useful for monitoring annual variations in juvenile recruitment.

Conclusions

Peak numbers of Marbled Murrelets in Clayoquot Sound were counted during June and July. The highest densities occurred in generally the same locations in each year in 1996-2000, and in previous studies. No significant population trends have been identified on the Tofino or Flores Transect routes, but our study was probably too short to detect any subtle trends. The decline of average densities of Marbled Murrelets in 1999 and 2000 should be compared to surveys in subsequent years to see if this trend continues, or if it might be due to changes in ocean temperatures. Strip transects should be continued, as they provide valuable, easily repeated surveys for monitoring long-term changes in local populations of Marbled Murrelets. As well, since variables in the study have been fairly consistent from year to year (e.g., survey methods, time of year, observers, negligible logging during study period), continuing at-sea surveys will provide valuable data when one of these variables changes (e.g., when logging resumes in Clayoquot Sound).

Further studies should be done in areas that are preferred by Marbled Murrelets to determine food availability and the possible effects of boat traffic, exposure to ocean waves, tidal currents and benthic substrates. This will help determine why these areas are preferred and any mitigative measures that may be required as a result.

In recent years most attention has been paid to threats to inland nesting habitats of Marbled Murrelets, but the species continues to be at risk from ocean-based impacts, particularly oil pollution and boat traffic. Marine areas preferred by Marbled Murrelets should be considered in oil spill contingency plans and the effects of boat traffic, aquaculture and sports fishing on Marbled Murrelets in Clayoquot Sound should also be examined more closely. Any upland activity that has the potential to impact the areas that Marbled Murrelets frequent should also be monitored carefully to see if there are any impacts on murrelets and other seabirds. Any management plans for the area, including the location of aquaculture facilities, should take special care to consider the marine areas that tend to be favoured by these seabirds.

Recommendations

1. Continue monitoring Marbled Murrelets at sea in Clayoquot Sound to collect data on long-term annual and seasonal patterns and population trends.
2. Increase the numbers of surveys to eight per season per transect to allow stronger statistical analysis between survey years.
3. Pool data with Pacific Rim National Park Reserve’s data on Marbled Murrelets to determine a larger picture for the murrelets at sea on the west coast of Vancouver Island.
4. Investigate prey species and habitat at marine locations preferred by Marbled Murrelets.
5. Investigate disturbance from boat traffic, fishing and aquaculture in marine areas used consistently by Marbled Murrelets.
6. Identify oil spill contingency plans that account for diving seabirds in Clayoquot Sound and incorporate information on areas consistently preferred by Marbled Murrelets into these plans.
7. Where logging occurs in Clayoquot Sound, monitor effects on Marbled Murrelets at sea.

Acknowledgements

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Appendix 2-1. Count of birds on the water within the Tofino transect (excluding flying birds and those outside the transect). Note that legs T4 and T7 were subdivided after 1996.

A) Counts of all birds on the water

Leg	T1	T2	T3	T4	T4A	T4B	T4C	T5	T6	T7	T7A	T7B	Total
Distance (km)	3.60	3.10	6.90		8.80	2.50	6.00	5.40	4.90		2.50	9.00	52.70
18-Jun-96	12	2	39	35	-	-	-	89	14	16	-	-	207
24-Jun-96	35	2	85	101	-	-	-	141	0	0	-	-	364
4-Jul-96	10	6	57	56	-	-	-	66	5	8	-	-	208
11-Jul-96	0	1	89	69	-	-	-	45	6	24	-	-	234
18-Jul-96	12	1	46	12	-	-	-	20	5	7	-	-	103
24-Jul-96	5	0	0	10	-	-	-	16	0	6	-	-	37
5-Aug-96	3	0	18	4	-	-	-	4	1	3	-	-	33
12-Aug-96	3	3	6	5	-	-	-	0	0	2	-	-	19
20-Aug-96	9	0	4	0	-	-	-	9	4	4	-	-	30
30-Aug-96	3	0	0	1	-	-	-	0	0	1	-	-	5
8-Sep-96	0	0	0	0	-	-	-	0	0	0	-	-	0
17-Sep-96	0	0	0	0	-	-	-	6	2	0	-	-	8
29-Sep-96	0	0	0	0	-	-	-	4	0	0	-	-	4
14-May-97	0	2	2	-	26	0	40	36	61	-	1	0	168
30-May-97	1	24	33	-	42	7	24	17	4	-	5	71	228
11-Jun-97	12	0	54	-	21	3	104	30	11	-	12	22	269
19-Jun-97	0	11	37	-	12	2	35	3	7	-	4	18	129
28-Jun-97	14	2	11	-	36	0	10	2	5	-	6	1	87
11-Jul-97	1	5	16	-	10	0	26	46	13	-	15	6	138
22-Jul-97	6	1	29	-	15	6	22	27	7	-	3	2	118
7-Aug-97	1	0	6	-	2	0	2	2	0	-	13	3	29
17-May-98	0	0	3	-	4	0	0	6	2	-	0	2	17
29-May-98	13	19	87	-	51	2	40	39	2	-	0	1	254
8-Jun-98	8	1	39	-	40	4	115	39	9	-	5	0	260
17-Jun-98	0	6	29	-	60	1	120	52	14	-	6	6	294
27-Jun-98	0	5	15	-	13	3	75	5	0	-	1	2	119
13-Jul-98	4	3	17	-	14	0	43	13	12	-	2	0	108
24-Jul-98	3	0	4	-	8	1	36	7	0	-	2	1	62
10-Aug-98	1	2	4	-	0	3	7	8	3	-	0	3	31
19-Jun-99	1	1	1	-	14	0	8	9	4	-	4	10	52
11-Jul-99	3	15	5	-	24	4	47	4	8	-	9	12	131
8-Aug-99	1	4	4	-	2	0	13	6	2	-	1	0	33
6-Jun-00	7	0	8	-	2	4	21	2	3	-	5	0	52
24-Jun-00	0	2	26	-	0	0	8	0	0	-	0	0	36
15-Jul-00	16	6	56	-	37	0	0	4	3	-	0	2	124
5-Aug-00	1	0	19	-	20	0	15	9	7	-	4	0	75

B) Counts of juveniles

DATE	T1	T2	T3	T4	T4A	T4B	T4C	T5	T6	T7	T7A	T7B	Total
18-Jun-96	0	0	1	0	-	-	-	0	0	0	-	-	1
24-Jun-96	0	0	5	0	-	-	-	0	4	3	-	-	12
4-Jul-96	0	0	0	1	-	-	-	3	0	0	-	-	4
11-Jul-96	0	0	2	0	-	-	-	6	0	3	-	-	11
18-Jul-96	0	0	5	0	-	-	-	2	1	1	-	-	9
24-Jul-96	1	1	0	0	-	-	-	3	0	0	-	-	5
5-Aug-96	0	0	0	0	-	-	-	0	0	0	-	-	0
12-Aug-96	0	1	2	0	-	-	-	0	0	0	-	-	3
20-Aug-96	0	0	0	0	-	-	-	0	0	0	-	-	0
30-Aug-96	0	0	0	0	-	-	-	0	0	0	-	-	0
8-Sep-96	0	0	0	0	-	-	-	0	0	0	-	-	0
17-Sep-96	0	0	0	0	-	-	-	0	0	0	-	-	0
29-Sep-96	0	0	0	0	-	-	-	0	0	0	-	-	0
14-May-97	0	0	0	-	0	0	0	0	0	-	0	0	0
30-May-97	0	0	0	-	0	0	0	0	0	-	0	0	0
11-Jun-97	0	0	0	-	0	0	0	0	0	-	0	0	0
19-Jun-97	0	0	0	-	0	0	0	0	0	-	0	0	0
28-Jun-97	0	0	0	-	4	0	1	1	0	-	0	0	6
11-Jul-97	0	0	0	-	0	0	3	3	1	-	0	1	8
22-Jul-97	0	0	1	-	4	1	2	7	0	-	0	0	15
7-Aug-97	0	0	2	-	1	0	0	0	0	-	0	0	3
17-May-98	0	0	0	-	0	0	0	0	0	-	0	0	0
29-May-98	0	0	0	-	0	0	0	0	0	-	0	0	0
8-Jun-98	0	0	0	-	0	0	0	0	0	-	0	0	0
17-Jun-98	0	0	0	-	0	0	0	0	1	-	0	0	1
27-Jun-98	0	0	1	-	0	0	4	0	0	-	0	1	6
13-Jul-98	0	0	0	-	1	0	2	2	0	-	0	0	5
24-Jul-98	0	0	0	-	0	0	13	4	0	-	1	1	19
10-Aug-98	0	2	0	-	0	0	0	2	3	-	0	1	8
19-Jun-99	0	0	0	-	0	0	0	0	1	-	0	0	1
11-Jul-99	0	1	0	-	7	0	0	2	0	-	1	0	11
8-Aug-99	0	4	2	-	0	0	2	0	1	-	1	0	10
6-Jun-00	0	0	0	-	0	0	0	0	0	-	0	0	0
24-Jun-00	0	0	0	-	0	0	0	0	0	-	0	0	0
15-Jul-00	1	0	4	-	4	0	0	0	0	-	0	0	9
5-Aug-00	0	0	1	-	0	0	0	3	4	-	1	0	9

Appendix 2-2. Count of birds on the water within the Flores transect (excluding flying birds and those outside the transect)
Note that leg F2 was modified after 1997 and split into three sections

A) Counts of all birds

Leg	F1	F2	F2A	F2B	F2C	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	Total
Length (km)	8.99		8.48	3.88	3.72	3.5	3.32	5.43	3.8	4.4	5.76	4.75	2.53	8.3	1.38	2.81	7.22	3.69	3.96	9.38	95.3
15-Jun-97	37	14	-	-	-	0	12	56	48	72	3	69	1	43	11	0	5	1	0	90	462
21-Jun-97	0	9	-	-	-	4	2	23	12	17	108	14	1	4	5	2	22	11	90	71	395
16-Jul-97	2	20	-	-	-	12	31	20	66	10	29	1	1	0	0	0	0	0	1	42	235
19-Jul-97	0	19	-	-	-	11	6	12	32	16	27	1	0	0	1	0	0	2	0	7	134
5-Aug-97	1	3	-	-	-	2	6	8	2	4	15	2	0	0	1	0	0	0	0	1	45
15-Aug-97	9	2	-	-	-	0	0	7	13	0	17	1	0	0	0	0	0	0	5	14	68
28-Aug-97	0	3	-	-	-	0	0	0	0	3	3	0	0	0	0	0	1	0	0	24	34
25-May-98	0	-	2	14	3	2	0	2	5	5	0	8	0	0	0	0	29	8	11	18	107
31-May-98	3	-	30	14	7	5	2	15	25	4	8	26	0	0	0	1	9	5	45	88	287
17-Jun-98	10	-	69	35	96	23	58	27	40	9	62	94	7	0	0	0	2	0	14	133	679
22-Jun-98	20	-	24	121	85	28	26	18	26	11	74	65	16	0	0	0	0	0	11	53	578
27-Jun-98	6	-	2	9	2	1	0	5	38	31	42	13	2	0	0	0	0	1	0	5	157
7-Jul-98	0	-	18	19	15	0	3	0	0	0	0	0	0	0	0	0	0	0	23	24	102
13-Jul-98	8	-	80	48	29	10	0	15	10	36	10	8	0	0	0	0	0	0	5	12	271
21-Jul-98	9	-	21	11	52	30	11	2	11	3	22	3	2	0	0	0	0	0	8	24	209
4-Aug-98	6	-	3	14	8	3	2	1	4	1	2	2	0	0	0	0	0	1	2	3	52
22-Jun-99	5	-	11	31	16	21	16	7	9	4	35	6	0	0	0	0	1	0	20	26	208
10-Jul-99	1	-	25	4	139	49	9	17	2	0	0	1	0	0	0	0	0	0	0	18	265
7-Aug-99	14	-	36	10	50	13	1	13	4	0	3	0	0	0	0	0	0	0	0	2	146
7-Jun-00	4	-	0	2	0	0	1	14	2	0	6	2	0	1	0	0	6	3	9	2	52
25-Jun-00	7	-	12	8	42	9	1	35	9	8	20	4	0	0	0	1	1	0	28	68	253
16-Jul-00	0	-	86	42	24	10	6	44	21	9	30	0	0	0	0	0	0	0	9	5	286
6-Aug-00	0	-	26	56	12	8	0	4	3	1	8	3	0	0	0	0	0	0	1	13	135

B) Counts of juveniles

Date	F1	F2	F2A	F2B	F2C	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	Total
15-Jun-97	0	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-Jun-97	0	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16-Jul-97	0	0	-	-	-	0	2	3	7	2	4	1	0	0	0	0	0	0	0	2	21
19-Jul-97	0	2	-	-	-	0	0	0	9	3	2	0	0	0	0	0	0	0	0	1	17
5-Aug-97	0	0	-	-	-	0	0	5	2	3	3	1	0	0	1	0	0	0	0	1	16
15-Aug-97	0	0	-	-	-	0	0	1	5	0	5	0	0	0	0	0	0	0	0	0	11
28-Aug-97	0	0	-	-	-	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
25-May-98	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31-May-98	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-Jun-98	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-Jun-98	0	-	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
27-Jun-98	0	-	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	6
7-Jul-98	0	-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
13-Jul-98	1	-	6	11	2	2	0	2	3	2	1	0	0	0	0	0	0	0	0	0	30
21-Jul-98	0	-	2	3	3	2	1	1	0	1	3	0	1	0	0	0	0	0	2	0	19
4-Aug-98	0	-	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	1	6
22-Jun-99	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10-Jul-99	0	-	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2
7-Aug-99	7	-	7	5	21	2	0	8	2	0	1	0	0	0	0	0	0	0	0	0	53
7-Jun-00	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-Jun-00	0	-	0	0	1	0	0	0	0	0	7	1	0	0	0	1	0	0	2	1	13
16-Jul-00	0	-	5	4	0	1	0	4	3	0	7	0	0	0	0	0	0	0	0	0	24
6-Aug-00	0	-	1	6	1	1	0	1	0	0	2	2	0	0	0	0	0	0	1	1	16
Total juveniles	8	2	22	32	28	8	3	25	36	15	35	6	1	0	1	1	0	0	7	9	239

Marbled Murrelets at sea in Clayoquot Sound in summer plumage (above) and winter plumage (below). (photos by Mark Hobson)

Radar set-up at mouth of Cypre Creek. High frequency scanning radar was used to count incoming birds at 19 stations in Clayoquot Sound. (photo by Andrea Lawrence)

Radar Inventory and Watershed-level Habitat Associations of Marbled Murrelets in Clayoquot Sound, 1996-1998

by Alan E. Burger

Abstract

High-frequency radar was used to count Marbled Murrelets (*Brachyramphus marmoratus*) entering 20 watersheds in Clayoquot Sound in 1996-1998. The primary goals were to estimate the regional population, determine the relative importance of each watershed for murrelets, identify important watershed-level habitat associations and investigate the effects of clearcut logging. Pre-sunrise counts provided the most reliable counts, but dusk counts produced similar ranking of watersheds and proportionate numbers of murrelets. Dawn and dusk counts were higher on cloudy days (≥80% cloud cover) than on clearer days, but among cloudy days there was no additional effect of precipitation (thick fog or drizzle). Counts varied among years and within seasons, but multi-year counts within a core period (mid May to mid July) minimized this variation. Radar surveys at the confluence of the Ursus and Bedwell streams showed that about 75% of the murrelets entering the Bedwell-Ursus watershed were using the Ursus Valley and 25%, the Bedwell Valley. In 1995-1998, the Ursus Valley Special Management Area was used by a mean of 341 (range 249-554) breeding and non-breeding murrelets. The study confirmed that audio-visual detections are a poor measure of murrelet numbers per watershed, and that murrelets did not necessarily use streams or valley bottoms as flight corridors. More than 4,600 Marbled Murrelets (mean of annual mean counts per station), and probably 5,500 (mean of the annual maximum counts), were using the 20 watersheds. These counts included non-breeders. The regional Clayoquot Sound population is likely to be 6,000 to 8,000 birds, and its management is therefore a provincial priority. The annual mean (Dawnmean) and annual maximum (Dawnmax) counts at 18 watersheds were both positively correlated with total watershed area, area of mature forest (>140 years old), and – most strongly – with areas of mature forest below 600 m elevation. Multiple regression equations showed that the combined positive effects of old-growth availability and negative effects of logged and immature forest explained up to 91% of the variability in dawn counts of murrelets.

The numbers of murrelets in Clayoquot Sound watersheds could be reliably predicted from the area of mature forest below 600 m (Matlow) or the total area of mature forest (Mature). Both measures could be readily estimated from GIS, aerial photographs or timber inventories. Linear regressions plotted through the origin were the most useful predictors when small areas were considered.

The resultant equations were:

Dawnmean = 0.0653*Matlow
(SE ± 0.005*Matlow; R^2 = 0.898, df = 17, P < 0.001)

Dawnmax = 0.0770*Matlow
(SE ± 0.006*Matlow; R^2 = 0.892, df = 17, P < 0.001)

Dawnmean = 0.0348*Mature
(SE ± 0.003*Mature; R^2 = 0.892, df = 17, P < 0.001)

Dawnmax = 0.0410*Mature
(SE ± 0.003*Mature; R^2 = 0.887, df = 17, P < 0.001),

with Matlow and Mature measured in hectares. Matlow was preferred to Mature because it compensated better for the effects of clearcut logging. Negative impacts of logging were clear; three of the five watersheds with extensive logging of low-elevation forest (Kennedy, Cypre and Bedwell) had fewer murrelets per area of original forest than unlogged watersheds or those with <10% logged. Murrelets were not packing into the remaining old-growth patches in higher densities in logged valleys, but were likely moving elsewhere to breed or were not breeding. Murrelet populations in BC will decline significantly if only 10-12% of original suitable habitat is retained in managed forests.

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Introduction

Clayoquot Sound supports one of the highest concentrations of breeding Marbled Murrelets (*Brachyramphus marmoratus*) in British Columbia, indeed anywhere south of Alaska (Sealy and Carter 1984; Rodway et al. 1992; Burger 1995, 2002). This is due to the presence of large tracts of old-growth forest suitable as nesting habitat, adjacent to productive nearshore ocean supporting large schools of prey for murrelets. Management and conservation of this murrelet population is thus of provincial and global importance. The murrelet is found in virtually all watersheds in Clayoquot Sound and has become a focal species for conservation management in the sound. It is widely regarded as an "umbrella species" whose conservation will impact many other old-growth dependent species.

High-frequency radar is becoming a standard method for estimating murrelet populations and assessing the importance of watersheds to murrelets (Hamer et al. 1995; Burger 1997, 2001; Cooper and Hamer 2000; Cooper et al. 2001; Raphael et al. in press). A radar unit correctly positioned at the mouth of a watershed allows counts of birds entering the watershed, although a few birds are probably always missed. There are no other methods of obtaining such counts. Watersheds opening into narrow inlets, where murrelets are funnelled through narrow flyways, can be more reliably censused with radar than those with wide coastal access (Burger 1997). Clayoquot Sound, where most watersheds drain into narrow fjords, is ideal for radar counts. This study sampled 19 watersheds (20 if Bedwell and Ursus are considered separately, see below), which included the majority of suitable nesting habitat remaining in Clayoquot Sound (Figure 3-1). Furthermore, these watersheds differ greatly in their size, topography, logging history and distance from the murrelet's foraging areas. This makes them ideal for testing the effects of these macro-habitat features on the numbers of murrelets coming inland.

The primary goals of the radar study in Clayoquot Sound were:

- to count Marbled Murrelets using each watershed, and hence estimate the total population in the Sound;
- to assess the relative importance of each watershed for murrelets, based on the estimated population;
- to compare the numbers of murrelets with macro-habitat features, and hence identify the important landscape-level habitat requirements; and
- to assess the impacts of past and future logging on the numbers of murrelets in the watersheds.

Since radar censusing is a new technique, and there is considerable variation in murrelet activities (Jodice and Collopy 2000), important secondary goals were:

- to document the species and number of birds likely to be confused with murrelets on radar at each radar station;
- to evaluate which of incoming and outgoing, and dawn and dusk counts of murrelets, is most appropriate for censusing;
- to examine diurnal, seasonal and annual variations in murrelet counts and determine the most accurate census protocol;
- to examine the effects of weather on radar counts; and
- to compare radar counts with audio-visual survey data.

I analyzed radar counts made at the adjoining Ursus and Bedwell watersheds. The Ursus Valley was designated as a Special Management Area, with emphasis on wildlife values. Marbled Murrelets were identified as a focal species here, prompting intensive research for four years (1995-1998), including audio-visual surveys, habitat analysis and tree-climbing (Burger et al. 1995, Rodway and Regehr this volume, Bahn 1998, Bahn and Newsom this volume Ch. 6, Conroy et al. this volume). The radar study identified the numbers and flight paths of murrelets using the Ursus Valley, which helps to assess the importance of the valley and the results of other studies.

This chapter should be read in conjunction with the paper by Burger (2001), which focused on factors affecting murrelet counts (weather, seasons, annual variability, etc.) and on habitat associations derived from this study. Key results from Burger (2001) are summarized here, but the details are not repeated.

Methods

Location of Radar Stations

Eighteen radar stations were used to sample the 20 watersheds (Figure 3-1, Table 3-1). Observers were able to simultaneously track murrelets entering the Watta valley and the adjacent unnamed watershed (Watta South) because the birds used distinct flight paths. Murrelets counted at the Bedwell river mouth were using both the Bedwell and Ursus watersheds, but for habitat analysis these watersheds were treated separately, based on separate radar counts made at the junction of these watersheds (details below). The Sydney station was first placed on the estuary in 1996, but in 1997 and 1998 was placed at the Biosphere Cabin, which improved detectability of incoming murrelets. Radar data from the estuary station were excluded. In 1997, high water levels in Kennedy Lake forced us to relocate the Clayoquot River station to a location 1 km SSW of the river mouth, which covered the same flight path and produced similar counts.

Radar Census Methods

The methods followed those in Burger (1997). We used two mobile 10 kW marine surveillance units, a Furuno FR-7111 and a Furuno FR-810D, which both use 9410 MHz (X-band) transmitted through a 2-m scanner (additional details in Burger 2001). Each scanner was tilted upward and scanned a vertical arc of 25º. The two units were compared using simultaneous surveys at the Bedwell station in 1998.

The scanners were usually mounted on platforms 2.5 m above the ground and positioned to provide a clear view across the expected flight path of the murrelets, at or near the mouth of each watershed. At two sites exposed

Table 3-1. Code names of the 20 watersheds, and locations and scanning radii of the 18 radar stations used in Clayoquot Sound in 1996-1998. The UTM coordinates are all given for zone 10 but on some maps the grid lines refer to zone 9 and should be ignored.

Watershed	Code	UTM (zone 10)		Location of radar station	Scanning radius (km)
Atleo	AT	5472000	276900	On shore 500 m S of Atleo River	1.0
Bedwell	BE	5471350	298100	On level platform E of Bedwell River and 50 m NE of bridge. Also for Ursus birds.	1.0
Boat Basin (Hesquiat)	BB	5483450	252350	On beach in front of Boat Basin Farm cottage	1.5
Bulson	BU	5459800	301400	On estuary meadow 20 m E of river and S of clump of large trees	1.5*
Clayoquot River	CR	5450600	315100	On sandy vegetated beach 50 m SE of river mouth	1.0
Cow Bay (Flores I.)	CB	5460100	272000	On SE extreme of beach with scanning circle offset to cover Cow Bay	1.5*
Cypre	CY	5462300	288500	On rocky bluff 600 m ENE of river mouth (incorrectly shown on charts)	1.5
Flores #6	F6	5466600	275650	On drift logs above tide line 150 m NE of river mouth	1.5*
Hesquiat Point Creek	HP	5476200	255150	On high gravel beach 100 m NW of creek mouth	1.5
Kennedy River	KE	5443600	320000	On N shore at narrows 2 km W of mouth of Upper Kennedy River	1.5
Lemmen's Inlet (Meares I.)	LI	5455000	289900	Floathouse in NE portion of inlet, radar offset to cover inlet	1.0*
Megin	ME	5479850	277000	On rocks in front of cabin 50 m SE of river mouth	1.5
Moyeha	MO	5477100	288600	Estuary at mouth of small creek W shore, 1 km SW of Moyeha R.	1.5
Pretty Girl	PG	5483650	266200	On open estuary meadow 20 m NW of tidal protion of the river	1.5
Sydney (Cabin)	SY	5486400	261500	Platform built in front of cabin on shoreline	1.0
Tofino Creek	TC	5456300	310700	On W side of inlet, mouth of small creek, 400 m SW of river mouth	1.0
Tranquil	TR	5454350	305850	On E side of estuary on low ridge at forest edge, among old logging equipment	1.0
Ursus	UR	-	-	Estimated 75% of the count made at Bedwell mouth (see text)	-
Watta	WA	5479350	280600	On shore 20 m N of unnamed creek 1600 m SE of Bacchante Bay narrows	1.5*
Watta South	WS	-	-	Same as Watta, birds entering the unnamed valley E of the radar station recorded as Watta South.	-

* When the Furuno 711 unit was used the scanning area was offset.

to choppy seas (Hesquiat Point and Megin) the radar scanner was positioned on the ground, with a low barrier of logs built around it, to screen out the reflections from waves. The observers kept a safe distance from the scanner, behind a protective barrier. Interference from waves was not a problem in the protected waters at the other sites.

The scanning radius was set to 1 km at most locations, and 1.5 km at stations where the murrelet flight path was beyond 1.0 km (Table 3-1). Murrelets were easily detected within 1.8 km. The scanning area of the Furuno 7111 unit could be offset from the centre to facilitate scanning flight paths that were >1 km from the radar station. Both rain and sea scatter suppressers were turned off and the gain turned up to near-maximum to give maximum sensitivity to the signals. At these settings, murrelets, smaller birds such as swallows, and bats were easily detected. Images of Marbled Murrelets could be distinguished from those of other birds and bats by their size (bats and smaller birds produced small images), flight path (few birds, other than murrelets, flew between the ocean and interior, and few had fairly straight paths) and speed (murrelets generally flew much faster than most birds; see Hamer et al. 1995; Burger 1997, 2001; Cooper et al. 2001). During radar surveys an audio-visual observer, positioned within 50 m of the scanner, recorded the presence of any species likely to be confused with murrelets on the radar and performed a standard audio-visual survey following the Resources Inventory Committee (RIC 1997) protocol. Between surveys the radar crews also recorded the maximum daily count of such birds in the vicinity of the radar stations.

Two types of flight path were considered for counting murrelets (Burger 1997, 2001): incoming (direct landward flight from the ocean or inlet); and outgoing (direct seaward flight towards the ocean or inlet). Birds circling over the ocean or forest were ignored in this analysis.

The protocol was to visit each station at least twice per season, with each visit lasting 2 to 3 days and involving dawn and dusk surveys on each day. Heavy rain, equipment failure and logistical problems sometimes resulted in cancelled visits or reduced numbers of surveys per visit. Dawn surveys started 90 min before sunrise and ended 60 min after sunrise, or 15 min after the last murrelet was recorded. Dusk surveys began 40 min before sunset and sampled 2 h. Sunrise and sunset times for Tofino were obtained from the Dominion Astrophysical Observatory (www.hia.nrc.ca/services/sunmoon/).

Standardized weather observations were made at the start and end of each radar survey, and notes were made of any changes likely to affect radar detections, such as the onset and cessation of rain squalls, which obscured bird images. All surveys in which rain obscured most of the screen for >10 min during periods of peak activity were omitted from analysis. Weather during surveys was categorized as: clear (cloud cover <80%); cloudy (cloud cover ≥80%, but no precipitation); and drizzle/fog (cloud cover ≥80%, with thick fog and/or drizzle). Audio-visual surveys show an increase in inland murrelet activity above 80% cloud cover (Rodway et al. 1993, Naslund and O'Donnell 1995).

The apparent size of each flock of murrelets was recorded. Observers felt confident in distinguishing single birds, and also the number of birds in flocks detected four or more times on the screens. Birds in close-flying flocks detected only 2-3 times were more difficult to count. Observers were more likely to underestimate flock size (e.g., two birds recorded as one), so our estimates of numbers of birds were highly conservative. In addition, some of the murrelets probably missed detection if they flew close to the treetops on the slopes of inlets. All counts, even maximum counts, therefore underestimated the true numbers entering watersheds.

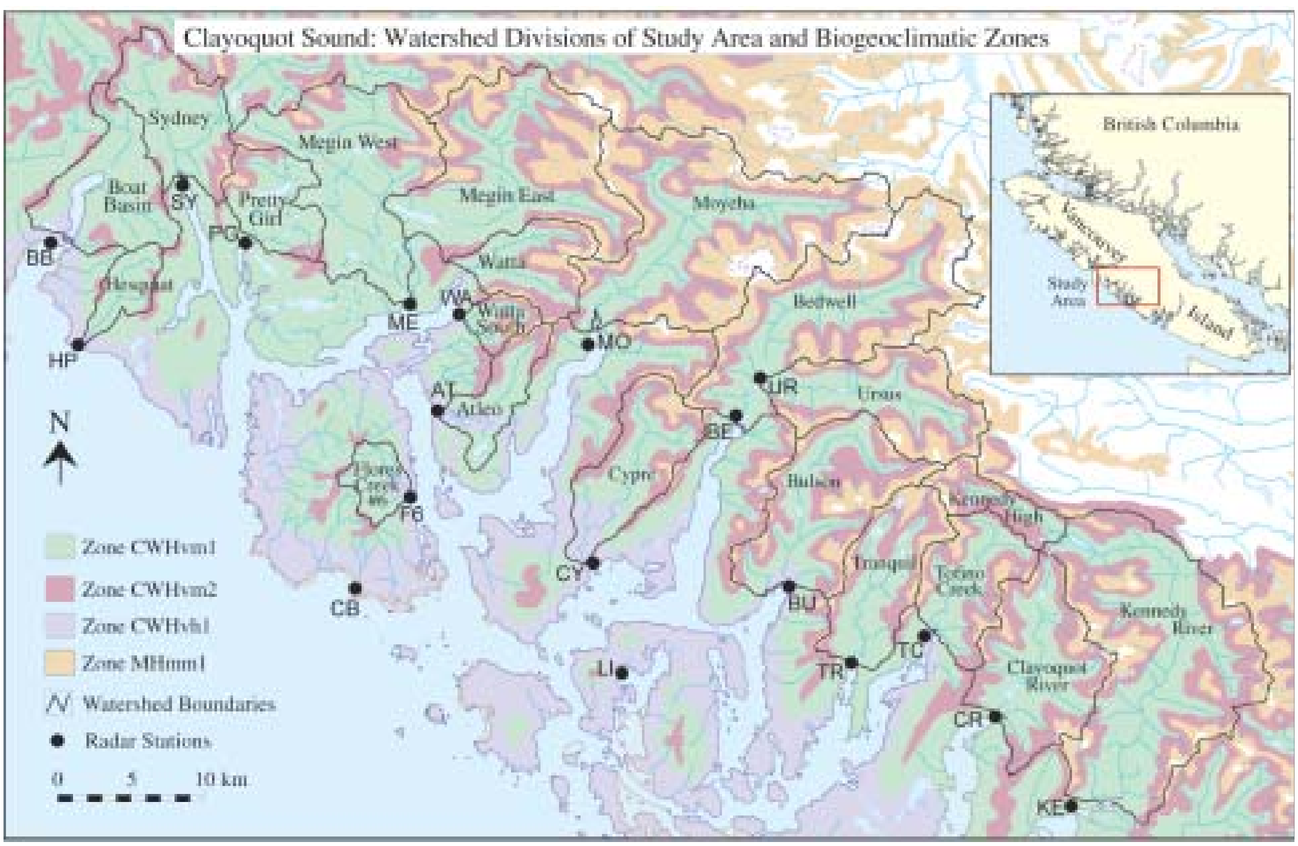

Figure 3-1. Clayoquot Sound: Watershed Divisions of Study Area and Biogeoclimatic Zones.

Radar Counts at the Junction of the Bedwell and Ursus Valleys

I stationed the radar unit near the junction of Ursus Creek and the Bedwell River from 9-12 May 1998. The radar unit was positioned, using a helicopter, on a boulder field next to the Bedwell River, 220 m upstream from the Bedwell-Ursus confluence (Figure 3-2). This site was selected to provide the maximum scanning field (approximately 180º horizontally) covering the expected flight paths of murrelets entering and leaving both valleys. Murrelets using the Ursus Valley were detected as they crossed the ridge to the southwest of the station, while those using the Bedwell Valley were detected above the trees from the northwest to the northeast (Figure 3-2).

Distances of flight paths from the radar station were measured to the nearest 10 m, using the unit's built-in range-finder, along a line from northwest to southeast (Figure 3-2, line A-D). This line was approximately at right angles to the Bedwell Valley and fell along the ridge-line where most of the Ursus birds were counted. After testing the unit at the 1.5-km-radius range to ensure no distant murrelets were being missed, it was run at the 1.0-km range. Since the screen is rectangular, this effectively yielded a scanning area of 1.0 x 1.4 km with the long axis pointing at 102º (i.e., nearly due east up the Ursus Valley).

Two radial lines at 52º and 72º were designated as the boundary zone between the two watersheds (Figure 3-2, lines B and C). Detections were allocated to the Bedwell if flight trajectories (incoming or outgoing) fell between lines A and B, and to the Ursus if between C and D

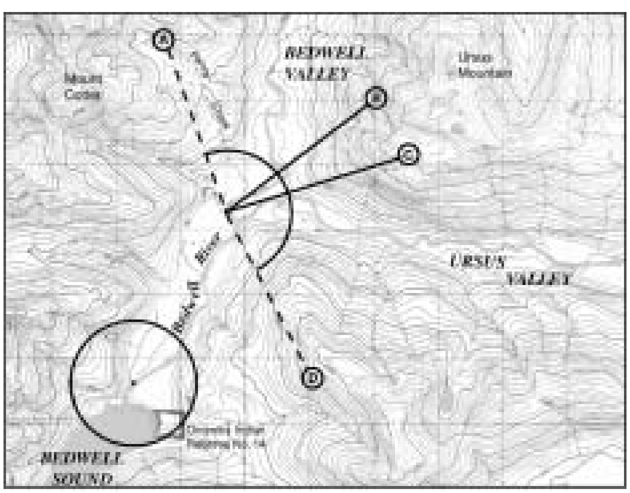

Figure 3-2. Location of the radar station at the junction of the Bedwell River and Ursus Creek. The semicircle shows the area in which Marbled Murrelets were detected. Those heading into or out of the area between lines A and B were designated as Bedwell birds, between C and D as Ursus birds, and between B and C as Indeterminate. The lower circle shows the area scanned by the standard radar surveys at the mouth of the Bedwell River.

(Figure 3-2). Flight paths that could have gone either way, between lines B and C, were allocated as Indeterminate. In addition, murrelets making obviously curved flights, designated as Circling, or those whose flight paths were not obvious, designated as Unknown, were omitted from analysis. Many birds flying along an east-west axis fell into this latter category.

Analysis of Habitat Associations

Areas of each biogeoclimatic subzone (Green and Klinka 1994), elevation category, age class polygons, and other habitat variables were measured for each watershed using overlays from three GIS digital databases: a 1:250,000 Biogeoclimatic Ecosystem Classification from Ministry of Forests (MOF); 1:250,000 Baseline Thematic Mapping from Ministry of Environment; and the 1:20,000 Clayoquot Sound Watershed atlas from MOF. The watersheds and biogeoclimatic subzones are shown in Figure 3-1. The age class polygons were too fragmented to show on this map. In Clayoquot Sound nearly all forests classified as mature (>140 years) were actually old-growth forests (>250 years), but the latter category was not available in the GIS databases. Distance from the watershed mouth to the nearest foraging aggregation (Distfeed) was estimated along flight paths over the ocean (see Burger 2001).

To correct for murrelets taking shortcuts across ridges into neighbouring watersheds, and to estimate the most appropriate catchment area for each radar station, adjustments were made to the catchment areas used for the Megin, Watta, Kennedy, Tofino Creek and Clayoquot River stations (details in Burger 2001). The Ursus and Bedwell valleys, with very different logging histories, were treated separately in the habitat analysis, based on the counts made at the Bedwell-Ursus junction described in this chapter. Data from Cow Bay (Flores Island) and Lemmen's Inlet (Meares Island) were not used in habitat analyses, because each station had only one radar survey and the watersheds were not clearly defined.

Statistical Analyses

Statistical analyses were done with SPSS 10.0. Pearson correlation coefficients were calculated to provide an overview of possible relationships between counts of murrelets per watershed and habitat variables measured within each watershed. Stepwise multiple regression analysis was used to investigate combinations of variables likely to explain murrelet counts, with the P value for inclusion set at 0.05 and for exclusion at 0.10. Adjusted R^2 values, which give a more realistic fit to models with more than one independent variable, were reported instead of the higher sample R^2 values (see SPSS 10.0 program).

Results

Factors Affecting Radar Counts in Clayoquot Sound

Birds and Bats Likely to be Confused with Marbled Murrelets

Confusion between murrelets and other flying birds or bats was a negligible source of error in Clayoquot Sound (see Burger 2001 for further details). Birds of similar size to murrelets were generally rare at the radar stations, relative to the numbers of murrelets counted (Table 3-2). Those that were more common, such as gulls, sea ducks and shorebirds, could readily be excluded on the basis of flight speeds (Burger 1997, 2001), flight patterns (e.g., meandering flight in gulls, swallows, swifts and bats), or because they remained over the water (loons and sea ducks) or along the shore (shorebirds). Band-tailed Pigeons (*Columba fasciata*), identified as potentially confusing with murrelets by Hamer et al. (1995) and Cooper et al. (2001), were rare (Table 3-2).

Common Mergansers (*Mergus merganser*) were the most likely birds to be confused with murrelets. They flew at similar speeds (Burger 2001), produced similar radar images and, like murrelets, crossed from the ocean into the river valleys. A few mergansers might have been inadvertently counted as murrelets, but most were excluded because they were seen or heard by the audio-visual observer at the radar station, or landed on the estuary instead of proceeding up the valley. Relative to murrelets, mergansers were uncommon at all stations (Table 3-2).

Comparison of the Two Radar Units Used in Clayoquot Sound

On 15 and 16 May 1998, we ran the two units simultaneously at Bedwell River mouth with the scanners about 10 m apart. Two operators watched the screens independently, and reported comparable results in two dawn and one dusk survey, especially for incoming murrelets (Table 3-3). Most of the variation was due to differences in flock size estimated by the operators. These comparisons were made during the training period, under my supervision, and as the operators gained experience their interpretations of flock size converged. Further testing was stopped when a Furuno dealer told us that the units risked damage if run simultaneously at similar heights for prolonged periods.

Appropriate Counts of Murrelets: Dawn or Dusk?

Counts of Marbled Murrelets at dusk averaged 33.6% (SD = 35.9%, N = 127) of the counts from the following dawn surveys, and dusk counts were significantly more variable than dawn counts (details in Burger 2001). Higher levels of inland activity at dawn than dusk were also reported in other radar studies (Burger 1997, Cooper et al. 2001), audio-visual surveys (Rodway et al. 1993, A. Burger unpubl. data) and observations at nests (Nelson and Hamer 1995). Dawn surveys were therefore used to estimate the total numbers of murrelets per watershed, but both dawn and dusk surveys were used to examine seasonal and annual variations, and to rank the watersheds.

Appropriate Counts of Murrelets: Incoming or Outgoing?

Counts of incoming murrelets at Clayoquot Sound were consistently higher than outgoing counts at dawn, but not at dusk (Burger 2001). Accordingly, I used incoming counts for all dawn surveys, and the maximum of incoming or outgoing for dusk surveys. The difference between detectability of incoming and outgoing murrelets at dawn and dusk is probably due to the effects of light intensity on the altitude and path of flight. Birds coming in from the sea in pre-dawn twilight flew well above the trees to avoid collisions with trees and were therefore readily detected by radar. By contrast, outgoing birds at dawn crossed the coast when there was stronger light and they could fly lower with less risk of collision with trees, but were more likely to be screened from the radar. The situation was reversed in the evening, making it more likely to detect the higher flying outgoing birds.

Variations in the Timing of Dawn Detections

Typically, incoming murrelets showed a strong, unimodal pre-sunrise peak (Burger 1997, 2001; Cooper et al. 2001), which is consistent with observations at nests where most incubation switches or chick-feeding occurred before sunrise (Nelson and Hamer 1995, Manley 1999). On a few mornings in this study there were one or two post-sunrise peaks of incoming birds, evidence that some murrelets were making one or more round-trips between feeding grounds and their nests, following the initial pre-sunrise entrance (Burger 2001). Surveys with a high proportion of post-sunrise counts were rare; there were no significant effects of weather or season on the percentage of incoming birds counted after sunrise (Burger 2001). Although multiple dawn visits were uncommon, their occurrence would seriously bias counts. To avoid this I restricted analyses to pre-sunrise counts. See Burger (2001) for further details on this topic.

Seasonal Trends

There was considerable variability in counts through the season (details in Burger 2001). Low dawn counts were common at the end of breeding after mid July and during incubation in May, and low dusk counts were common in May and early June. Data from the core portion of the breeding season (15 May through 16 July), when most stations were sampled twice per

Table 3-2. Mean values of the maximum daily counts of birds seen at the radar stations in 1996-1998 which might be confused with Marbled Murrelets on radar screens. Some rare species are omitted.

Station	Loons	Common Merganser	All other ducks	Bald Eagle	Merlin	All shore-birds	Mew Gull	Other gulls	Band-tailed Pigeon	Belted King-fisher	Common Night-hawk	North-western Crow	Common Raven
Atleo	1.2	13.6	0.0	2.0	0.0	0.0	15.4	1.4	1.2	0.0	0.4	7.0	1.2
Bedwell mouth	1.8	5.3	2.3	1.3	0.1	0.7	7.3	0.7	1.5	0.5	0.1	8.8	0.4
Bedwell/Ursus junction	0.0	8.5	0.0	0.5	0.0	0.5	4.0	0.0	0.5	0.0	0.0	0.0	0.0
Boat Basin	3.0	0.0	6.0	2.0	0.0	0.0	6.0	1.0	0.0	0.0	0.0	2.0	3.0
Bulson	1.9	10.2	4.0	1.5	0.1	10.4	14.8	0.8	0.2	0.6	0.0	11.8	0.2
Clayoquot River	1.0	3.0	0.0	1.6	0.0	2.0	1.0	0.4	1.6	0.0	0.0	0.2	0.6
Cypre	1.8	6.2	10.0	3.3	0.3	3.0	3.7	0.0	0.3	0.5	0.7	21.8	0.3
Flores #6	0.2	5.2	0.0	2.0	0.0	0.2	3.3	0.3	0.5	0.7	0.0	4.2	1.2
Hesquiat Point Creek	1.0	0.0	66.0	1.8	0.0	2.5	0.7	0.5	0.0	0.2	0.0	2.3	2.3
Kennedy River	1.2	3.8	0.0	1.0	0.0	0.3	1.2	0.0	0.0	0.0	0.0	0.2	1.8
Megin	4.3	3.0	0.0	1.7	0.0	0.3	5.3	0.7	0.0	0.7	0.0	3.7	0.7
Moyeha	2.3	4.8	0.0	2.1	0.1	0.1	6.3	0.0	0.1	0.0	0.1	4.4	2.3
Pretty Girl	0.3	2.7	0.0	1.9	0.1	0.1	10.7	0.0	0.0	0.3	0.0	4.1	1.4
Sydney (cabin)	1.3	2.3	0.0	2.0	0.0	0.3	9.8	0.0	0.0	0.5	0.0	3.8	0.8
Sydney (estuary)	0.3	2.3	0.0	2.8	0.0	0.0	2.3	0.0	0.0	0.0	0.0	4.3	1.0
Tofino Creek	0.3	5.7	0.0	0.7	0.0	0.0	1.0	0.0	2.7	0.0	0.0	4.3	0.0
Tranquil	0.5	11.3	0.2	0.7	0.0	0.7	0.2	0.3	0.0	0.3	0.8	8.5	0.5
Watta	0.9	3.9	0.4	1.7	0.0	0.0	2.1	0.6	0.1	0.1	0.0	4.6	0.4
Mean all stations	1.3	5.1	4.9	1.7	0.04	1.2	5.3	0.4	0.5	0.2	0.1	5.3	1.0
% occurrence/station	94	89	39	100	28	72	100	56	56	56	28	94	89

Table 3-3. Comparison between the F810D and F7111 radar units used in Clayoquot Sound, running simultaneously at Bedwell River mouth in May 1998.

Time	Date	Machine	Incoming detections 1 bird	Incoming detections 2 birds	Incoming detections >2 birds	Total birds incoming	Outgoing detections 1 bird	Outgoing detections 2 birds	Outgoing detections >2 birds	Total birds outgoing
Dawn	15-May	F810D	53	5	0	63	42	0	0	42
	15-May	F7111	60	3	0	66	40	0		40
Dawn	16-May	F810D	70	15	2	106	22	1	0	24
	16-May	F7111	83	6	0	95	46	1	0	48
Dusk	15-May	F810D	7	0	0	7	7	0	0	7
	15-May	F7111	7	0	0	7	7	0	0	7

season, showed no significant seasonal effects (Burger 2001) and were used in subsequent analyses.

Effects of Weather on Radar Counts

Pre-sunrise counts in the core part of the season were, on average, 1.4 times higher on cloudy or drizzly/foggy days combined than on clear days, but there was no difference between cloudy days with no precipitation and drizzly/foggy days (Burger 2001). Dusk counts were 2.8 times higher on cloudy than clear days, but data were insufficient to test the effects of precipitation, which was rare at dusk. The major effect of weather on radar counts seemed to be from cloudiness rather than from precipitation. Similar results were found by Cooper et al. (2001). The effects of weather were therefore considered when comparing counts made in different years (next section), but cloud and drizzle/fog categories were combined (hereafter called cloud/drizzle/fog).

Annual Variations in Counts

There was considerable variation among years for counts of murrelets at some stations, but I found no significant difference among years in mean pre-sunrise counts or mean dusk counts, controlling for the effects of weather (Burger 2001). These results suggest that there were similar numbers of murrelets entering the Clayoquot Sound watersheds in each year, but they appeared to shift somewhat from one watershed to another between years.

Murrelets Crossing Ridges to Adjacent Watersheds

Marbled Murrelets counted by radar at a watershed mouth sometimes crossed ridges into an adjacent watershed. Radar showed many murrelets taking shortcuts across coastal ridges about 200 m high to enter Pretty Girl and Bulson watersheds. Researchers doing audio-visual surveys in 1993, recorded murrelets crossing the 250-m-high ridge between the Watta and western Megin watersheds, 4 km up from the Watta mouth (S. Hughes, pers. comm.).

To investigate possible ridge-crossing, radar units were positioned at two roadside stations in the upper Kennedy Valley. Kennedy station 1 (49º16'20" N, 125º22'0" W; elevation 250 m) was 200 m NW of Highway 4 near the 500-m-high pass taken by the highway between the Kennedy and Sutton Creek drainages. Kennedy Station 2 (49º17'05" N, 125º24'20" W; elevation 350 m) was 4 km further up the Kennedy River and monitored a pass 600 m high into the Taylor drainage. At both stations a few murrelets flew on bearings that might have taken them into the adjacent drainage (maximum 20 and 14, respectively, in 2 surveys at each station between 21 and 23 June 1998), although some of these might have remained within the Kennedy drainage. Hills and trees obscured the radar view at both stations so that accurate counts could not be made.

Clearly one cannot assume that all the murrelets counted at a watershed mouth remain within that watershed, but the problems of using radar in wooded, hilly terrain with few or no roads made it very difficult to determine the

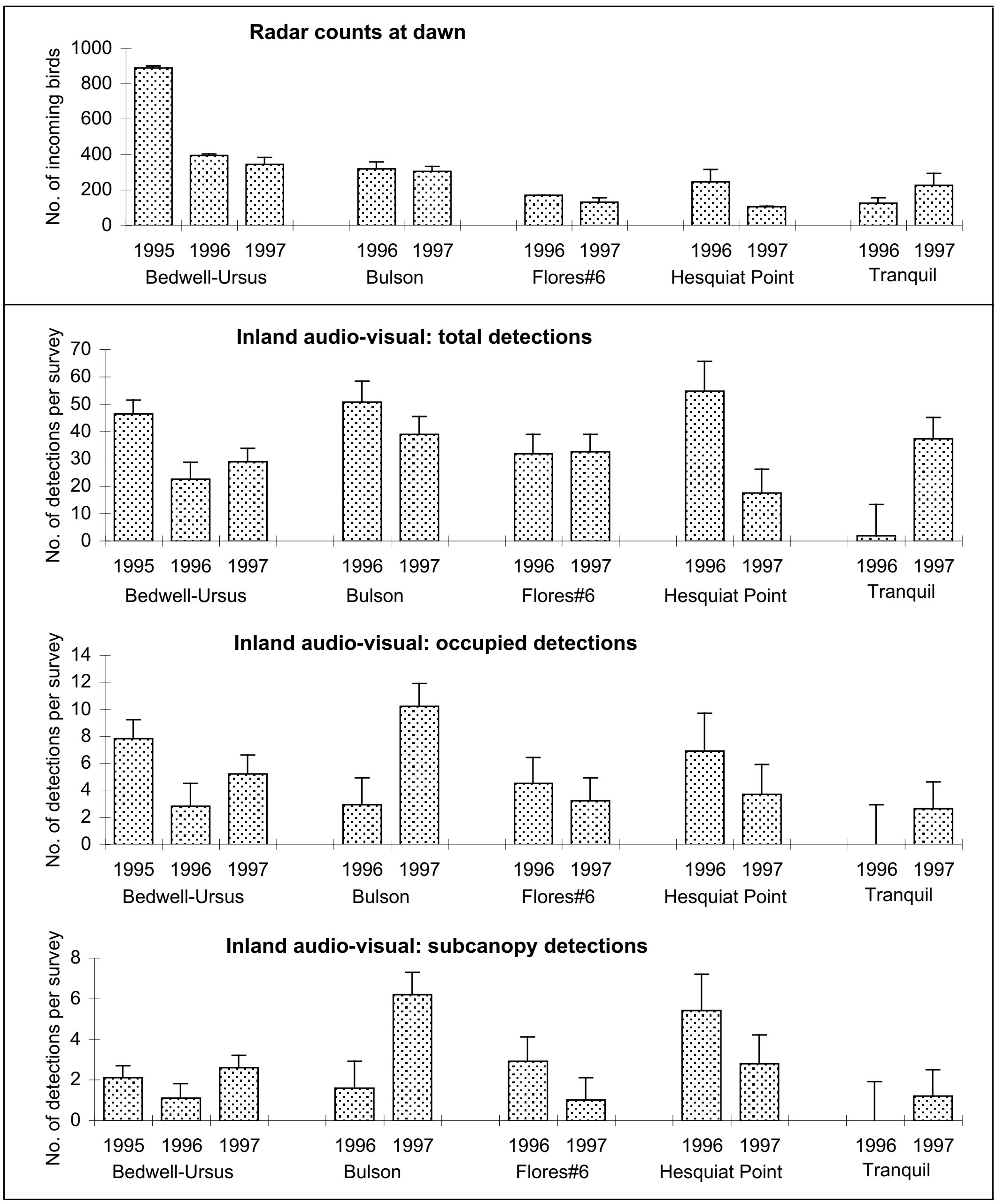

Figure 3-3. Annual variations in the mean (± SE) counts of incoming Marbled Murrelets at dawn radar surveys, and total occupied and subcanopy detections from inland audio-visual surveys at Clayoquot Sound watersheds sampled in more than one year.

Table 3-4. Numbers and percentages (in parentheses) of Marbled Murrelets going in and out of the Ursus and Bedwell valleys in June 1998, counted with radar at the junction of the two streams.The percentages excluded indeterminate birds.

		Incoming birds				Outgoing birds			
	Date	Bedwell	Ursus	Indeterminate	Total	Bedwell	Ursus	Indeterminate	Total
Dawn									
	10 Jun	10 (9.9)	91 (90.1)	17	118	28 (35.0)	52 (65.0)	8	88
	11 Jun	14 (20.6)	54 (79.4)	9	77	10 (21.7)	36 (78.3)	13	59
	12 Jun	14 (20.3)	55 (79.7)	4	73	28 (42.4)	38 (57.6)	7	73
Mean dawn		12.7 (16.9)	66.7 (83.1)	10.0	89.3	22.0 (33.1)	42.0 (66.9)	9.3	73.3
Dusk									
	10 Jun	6 (40.0)	9 (60.0)	0	15	1 (6.7)	14 (93.3)	0	15
	11 Jun	4 (28.6)	10 (71.4)	0	14	5 (20.8)	19 (79.2)	2	26
Mean dusk		5.0 (34.3)	9.5 (65.7)	0.0	14.5	3 (13.8)	16.5 (86.3)	1.0	20.5

precise numbers or proportions crossing to adjacent watersheds. Topographic maps were used to estimate likely flight paths between Clayoquot watersheds and some adjustments were made to the watershed areas matched with each radar station to account for ridge-crossing (details in Burger 2001).

Comparing Radar and Audio-visual Surveys at the Watershed Level

The relationships between radar counts and the mean audio-visual detections made at multiple inland stations in the same watersheds in Clayoquot Sound were examined by Rodway and Regehr (this volume; see also discussion below). I examined inter-annual variations in radar counts and detection frequencies from multi-station audio-visual surveys at five watersheds (Figure 3-3). The audio-visual data were adjusted for the effects of date and weather (Rodway and Regehr this volume). The annual changes in radar and audio-visual detections followed similar patterns at three watersheds (Bedwell-Ursus, Hesquiat Point and Tranquil), but not at two others (Bulson and Flores #6). At Bedwell-Ursus, the dramatic drop in incoming murrelets from 1995 to 1996 was matched by a similar drop in detections, particularly in the occupied detections which are likely to reflect near-nest activity. The subsequent increase in audio-visual detections at Bedwell-Ursus in 1997 was not matched by an increase in mean radar counts, although the maximum count in 1997 (457 birds) was higher than that of 1996 (410 birds). At Hesquiat Point, both radar counts and inland detections in 1997 dropped to about half of the 1996 values. The reverse trend was found at Tranquil Creek, but in 1996, audio-visual surveys in this watershed occurred at only 10 surveys at 5 inland stations very late in the season (13-27 July) so this comparison is rather meaningless. Radar counts at Bulson and Flores #6 were relatively unchanged between years, in contrast to large changes in detection frequencies at Bulson and lesser ones at Flores #6.

Radar Counts in Bedwell and Ursus Watersheds

Bedwell-Ursus Junction Compared with Bedwell Mouth

At the Bedwell-Ursus junction, I recorded a total of 491 murrelet detections in three dawn and two dusk surveys, of which 327 (67%) could be allocated as incoming or outgoing. The remaining birds were circling in the lower Ursus Valley or in the Bedwell Valley. During three dawn surveys, a mean of 89 incoming and 73 outgoing birds were detected (Table 3-4). These represent 21% and 45% of the mean incoming and outgoing murrelets, respectively, detected in the two previous mornings at the Bedwell River mouth (incoming counts at the river mouth on 8 and 9 June 1998 were 372 and 466 birds, respectively, and outgoing were 144 and 178, respectively). In two dusk surveys at the Bedwell-Ursus junction I counted a mean of 15 incoming and 21 outgoing murrelets (Table 3-4). This represents 53% of incoming and 37% of outgoing murrelets detected earlier at the river mouth (incoming counts at dusk at the river mouth on 7 and 8 June were 8 and 49 birds, respectively, and outgoing were 28 and 87, respectively). Evidently 47-69% of the murrelets passing the mouth were not detected at the junction station.

Flight Paths and Audio-visual Surveys at the Bedwell-Ursus Junction

The distances from the radar station at which murrelets crossed the NW-SE line are plotted on Figure 3-4. With the Indeterminate birds excluded, there was little overlap in the flight paths of Bedwell and Ursus birds, giving confidence that I was not misidentifying the valley of destination or origin. These data also indicate that the murrelets were not closely following the watercourses while commuting. Most murrelets entering the Ursus crossed the southeast ridge along a broad flight path about 700 m wide. Birds destined for Bedwell were scattered across much of the broad Bedwell Valley. Overall, 41-91% of the commuting birds were flying more than 200 m away from the watercourses at the Bedwell-Ursus junction.

Further evidence that the murrelets were not following the watercourses came from the standard audio-visual surveys. The audio-visual observer was positioned right at the junction of the two rivers on a wide gravel bar with an excellent view of the sky (<20% canopy closure). Murrelets following the watercourses would have been easily detected. Four dawn surveys (15 May and 10-12 June 1998) yielded no visual detections and a mean of 1.0 (range 0-2) audio detections per survey. Likewise, three dusk audio-visual surveys (9-11 June) yielded no visual and only one audio detection (on 11 June). Stream noise might have masked most calls >100 m away.

Murrelet Use of the Ursus and Bedwell Valleys

On average, 75% (range 65-93%) of all murrelets came in or out of the Ursus Valley and 25% in or out of the Bedwell Valley (Table 3-4). The Ursus consistently had higher counts than the Bedwell in all five surveys. Slightly higher proportions were recorded for the Ursus among incoming birds at dawn and outgoing birds at dusk. These correspond to periods of greatest darkness when the birds were likely to fly slightly higher above the trees, which apparently increased their detectability to radar along the Ursus flight path.

It was impossible to determine whether the birds using the Bedwell and Ursus were equally likely to be detected

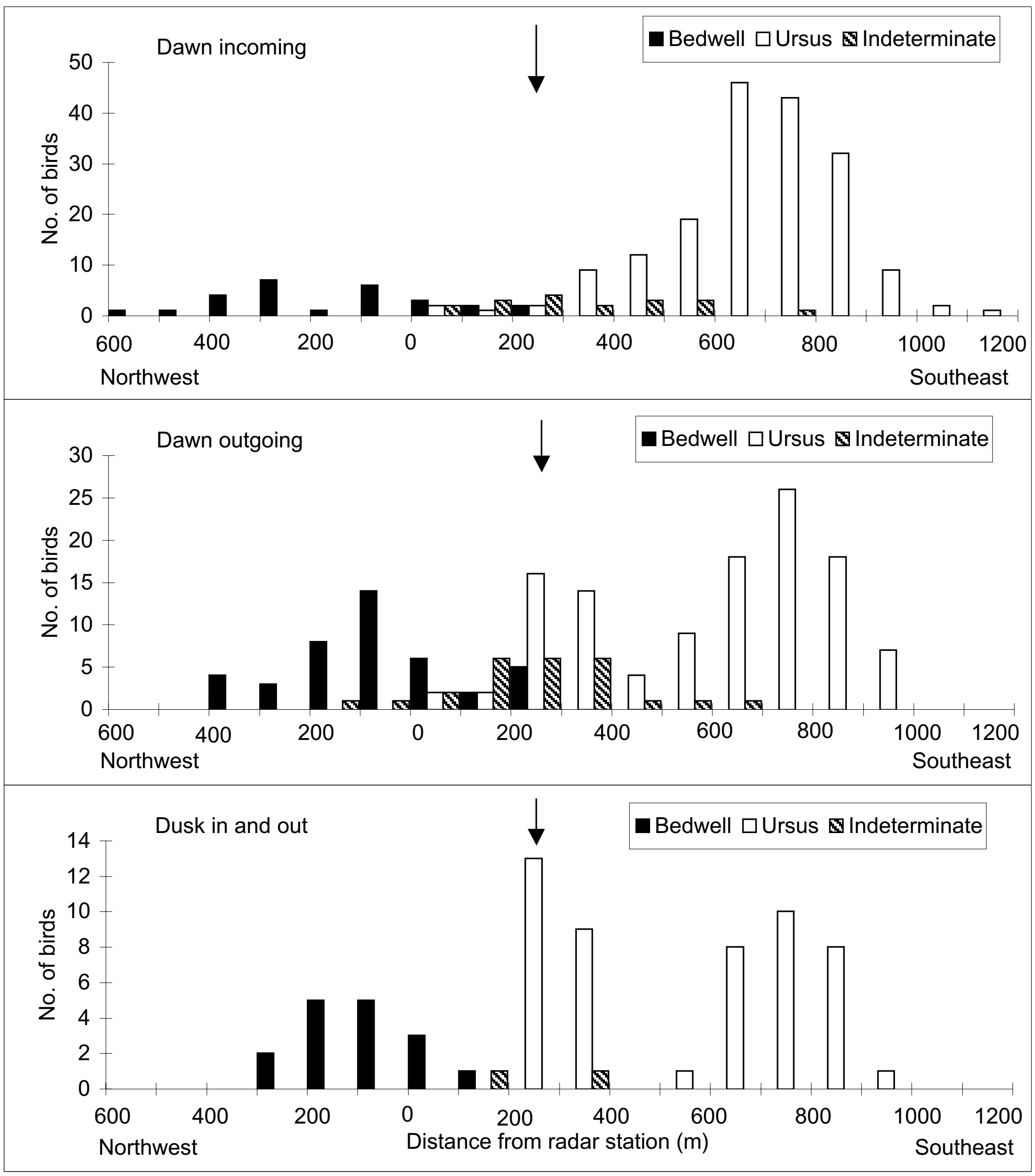

Figure 3-4. Distribution of incoming and outgoing Marbled Murrelets recorded along a NW to SE line at the Ursus-Bedwell junction radar station, 10-12 June 1998. Incoming and outgoing birds were plotted separately for dawn, but were too few to separate at dusk. The arrow indicates the location of Ursus Creek where it joins the Bedwell River.

Table 3-5. Summary of the annual mean (± SD) and maximum of counts of incoming Marbled Murrelets at dawn (pre-sunrise) and dusk at each station during the core period (15 May- 16 July) in 1996-1998.

Station	Measure	Dawn 1996	Dawn 1997	Dawn 1998	Overall dawn mean*	Dusk 1996	Dusk 1997	Dusk 1998	Overall dusk mean*
Atleo	Mean	64 ± 19	110 ± 38	-	87 ± 33	47 ± 21	65 ± 9	-	56 ± 13
	No. surveys (years)	3	3	0	(2)	3	3	0	(2)
	Maximum	85	150	-	118	62	76		69
Bedwell-Ursus	Mean	389 ± 24	332 ± 72	362 ± 189	361 ± 28	72 ± 22	162 ± 52	184 ± 288	139 ± 59
	No. surveys (years)	4	3	4	(3)	5	2	4	(3)
	Maximum	404	382	538	441	98	198	613	303
Boat Basin	Mean	-	192 ± 230	220 ± 123	206 ± 20	-	72 ± 18	93	83 ± 15
	No. surveys (years)	0	2	2	(2)	0	2	2	(2)
	Maximum	-	355	307	331	-	85	93	89
Bulson	Mean	308 ± 75	312 ± 65	360 ± 103	326 ± 29	87 ± 37	129 ± 58	71 ± 74	96 ± 30
	No. surveys (years)	5	3	6	(3)	4	3	5	(3)
	Maximum	403	374	459	412	124	189	160	158
Clayoquot River	Mean	-	521 ± 129	249 ± 78	385 ± 193	-	84 ± 31	20 ± 19	52 ± 45
	No. surveys (years)	0	3	4	(2)	0	3	4	(2)
	Maximum	-	659	329	494	-	103	47	75
Cow Bay	Mean	-	259	-	259	-	30	-	30
	No. surveys (years)	0	1	0	(1)	0	1	0	(1)
	Maximum	-	259	-	259	-	30	-	30
Cypre	Mean	34 ± 17	51 ± 26	-	42 ± 11	14 ± 11	47	-	47
	No. surveys (years)	5	2	0	(2)	5	2	0	(2)
	Maximum	57	69		63	31	48	-	40
Flores #6	Mean	146	109 ± 34	69 ± 16	108 ± 39	36 ± 17	25 ± 17	36 ± 11	32 ± 6
	No. surveys (years)	1	3	2	(3)	3	3	2	(3)
	Maximum	146	133	80	120	56	36	43	45
Hesquiat Point Cr.	Mean	215 ± 98	105 ± 3	-	160 ± 77	36	16	-	26
	No. surveys (years)	2	3	0	(2)	1	1	0	(2)
	Maximum	284	108	-	196	36	16	-	26
Kennedy	Mean	168 ± 61	449 ± 109	212 ± 26	276 ± 151	57 ± 20	116 ± 20	45 ± 8	73 ± 38
	No. surveys (years)	3	3	3	(3)	2	2	3	(3)
	Maximum	223	540	240	334	71	130	53	85
Lemmen's Inlet	Mean	-	83	-	83	-	21	-	21
	No. surveys (years)	0	1	0	(1)	0	1	0	(1)
	Maximum	-	83	-	83	-	21	-	21
Megin	Mean	432 ± 22	502 ± 34	310	415 ± 91	150 ± 36	119 ± 89	84	118 ± 33
	No. surveys (years)	3	2	1	(3)	3	3	1	(3)
	Maximum	455	526	310	430	178	219	84	160
Moyeha	Mean	261 ± 67	541 ± 148	614 ± 62	472 ± 186	225 ± 65	167 ± 144	85 ± 101	159 ± 70
	No. surveys (years)	5	4	3	(3)	3	4	3	(3)
	Maximum	366	755	666	596	296	314	200	270
Pretty Girl	Mean	-	262 ± 57	182 ± 24	222 ± 56	44	24 ± 6	26 ± 28	31 ± 11
	No. surveys (years)	0	4	3	(2)	1	3	2	(3)
	Maximum	-	309	210	260	44	29	45	39
Sydney (cabin)	Mean		166 ± 79	194 ± 31	180 ± 20	-	48 ± 23	40	44 ± 6
	No. surveys (years)	0	2	3	(2)	0	2	1	(2)
	Maximum		222	228	225	-	64	40	52
Tofino Creek	Mean	112 ± 6	133	390	262 ± 182	29 ± 7	43 ± 20	-	36 ± 10
	No. surveys (years)	2	1	1	(3)	2	2	0	(2)
	Maximum	116	133	390	213	34	57	-	46
Tranquil	Mean	121 ± 65	222 ± 120		172 ± 71	23 ± 16	72 ± 22	48	47 ± 25
	No. surveys (years)	5	3	0	(2)	4	4	1	(3)
	Maximum	188	347		268	40	102	48	63
Watta	Mean	852 ± 66	505 ± 29	528	628 ± 194	223 ± 71	129 ± 33	114	155 ± 59
	No. surveys (years)	2	3	1	(3)	2	3	1	(3)
	Maximum	899	524	528	650	273	158	114	182
Watta South	Mean		23	37 ± 19	30 ± 10	-	8	11 ± 7	9 ± 2
	No. surveys (years)	0	1	5	(2)	0	1	3	(2)
	Maximum		23	66	45	-	8	16	12

*Overall mean calculated using a single value per year, sample size in this column is number of years.
Surveys made a few days after the core period have been included for Boat Basin (1997) and Tofino Creek (1998) to increase sample size.

Table 3-6. Means of all counts, means of maximum counts, and percentage of total counts at 20 watersheds in Clayoquot Sound in 1996-1998. Spearman rank correlation coefficents among the counts are also given. The Bedwell and Ursus are treated separately here, based on an estimated 25%:75% split (see text).

	Dawn Surveys (Pre-sunrise count)				Dusk Surveys			
Watershed	Overall mean	%	Mean of maximum	%	Overall mean	%	Mean of maximum	%
Atleo	87	1.9	118	2.1	56	4.5	69	3.9
Bedwell	90	2.0	110	2.0	35	2.8	76	4.3
Boat Basin	206	4.5	331	6.0	83	6.7	89	5.0
Bulson	326	7.1	412	7.4	96	7.8	158	9.0
Clayoquot River	385	8.3	494	8.9	52	4.2	75	4.2
Cow Bay	259	5.6	259	4.7	30	2.4	30	1.7
Cypre	42	0.9	63	1.1	31	2.5	40	2.3
Flores #6	108	2.3	120	2.2	32	2.6	45	2.5
Hesquiat Point Creek	160	3.5	196	3.5	26	2.1	26	1.5
Kennedy	276	6.0	334	6.0	73	5.9	85	4.8
Lemmen’s Inlet	83	1.8	83	1.5	21	1.7	21	1.2
Megin	415	9.0	430	7.8	118	9.5	160	9.1
Moyeha	472	10.2	596	10.8	159	12.8	270	15.3
Pretty Girl	222	4.8	260	4.7	31	2.5	39	2.2
Sydney	180	3.9	225	4.1	44	3.6	52	2.9
Tofino Creek	212	4.6	213	3.8	36	2.9	46	2.6
Tranquil	172	3.7	268	4.8	47	3.8	63	3.6
Ursus	271	5.9	331	6.0	104	8.4	227	12.9
Watta	628	13.6	650	11.7	155	12.5	182	10.3
Watta South	30	0.7	45	0.8	9	0.7	12	0.7
Totals	4624	100	5536	100	1238	100	1765	100

Spearman rank correlation coefficients (all P<0.001)

	Dawn mean	Dawn maximum	Dusk mean
Dawn maximum	0.961		
Dusk mean	0.760	0.824	
Dusk maximum	0.720	0.773	0.971

and counted, but three bits of evidence suggest there was no bias favouring Ursus birds. First, radar surveillance at the Bedwell mouth in 1995-1998 showed that 95% of the murrelets flew along the eastern or central portions of the lower Bedwell Valley with equal opportunities to enter either valley. Very few flew along the western slope of the Bedwell, where they might not have been detected by the radar at the junction station. Second, the unobscured arcs where murrelets could be detected on the radar screen were approximately equal within the Bedwell and Ursus zones (74% and 65%, respectively). Third, by counting the number of images on the screen per detection, I was able to time the durations of each detection. Among incoming murrelets there was no difference between the mean durations for Bedwell (9.2 ± 2.1 [SD] s, range 6-15 s, $N = 19$) and Ursus (8.5 ± 3.3 s, 6-24 s, $N = 76$; two-tailed t-test, $t = 0.79$, df = 93, $P > 0.05$), indicating an equal chance of detecting murrelets entering either drainage. Murrelets leaving Bedwell were visible for significantly longer (12.0 ± 4.1 s, 6-21 s, $N = 24$) than those leaving Ursus (8.1 ± 3.3 s, 6-18 s, $N = 49$; t = 4.41, df = 71, $P < 0.001$), and perhaps flew slightly higher above the trees and hence were more likely to be detected. Overall, there was no evidence that the proportions of murrelets using Ursus Valley, relative to the Bedwell Valley, were overestimated.

Numbers of Marbled Murrelets in the Watersheds of Clayoquot Sound

Mean and maximum counts made at dawn and dusk are summarised in Table 3-5 and the proportions of the total Clayoquot count in each watershed in Table 3-6. In Table 3-6 the Bedwell-Ursus counts are split into separate estimates for Bedwell and Ursus based on the 25%:75% split derived from counts at the junction of these valleys. More than 4,600 Marbled Murrelets, and probably as many as 5,500 were using the watersheds sampled (Table 3-6).

Dawn and dusk counts produced similar rankings among the watersheds (Table 3-6; Spearman rank correlation, $r_s > 0.72$), and within dawn or dusk counts the ranking produced by mean and maximum counts were almost identical ($r_s \geq 0.96$). Any of these measures might therefore produce a reasonable assessment of the importance of each watershed for management purposes, although dawn counts give higher and less variable counts.

Table 3-7. Codes and descriptions of parameters used in comparing numbers of Marbled Murrelets and habitat parameters in watersheds in Clayoquot Sound.

Marbled Murrelet counts	
Dawnmean	Mean of the annual mean count of murrelets at dawn for 1996-1998
Dawnmax	Mean of the annual maximum count of murrelets at dawn for 1996-1998
Habitat attributes per watershed	
Alpine	Area of alpine meadows and scrub (ha)
Distfeed	Distance from the watershed mouth to the nearest foraging aggregation (km)
Imm	Area of immature forest <140 years old (ha)
Logged	Area of recently logged forest < 20 years old (ha)
Logimm	Combined area of logged and immature forest (ha)
Mature*	Area of mature forest >140 years old (ha)
Maturemm1*	Area of mature forest in the MHmm1 biogeoclimatic subzone (ha)
Maturevh1*	Area of mature forest in the CWHvh1 subzone (ha)
Maturevm1*	Area of mature forest in the CWHvm1 subzone (ha)
Maturevm2*	Area of mature forest in the CWHvm2 subzone (ha)
Mathigh*	Area of all mature forest above 600 m elevation (ha)
Matlow*	Area of all mature forest below 600 m elevation (ha)
Origforest	“Area of original forest (existing mature, logged and immature) (ha)
Totarea	Total area of the watershed (ha)

* In Clayoquot Sound most mature forest (>140 yr) was actually old-growth (>250 yr); see text.

Habitat Associations and the Effects of Clearcut Logging

Background

The goals of this section were to:

- examine relationships between radar counts and habitat parameters in order to determine landscape-level habitat preferences;
- produce equations predicting the numbers of Marbled Murrelets per hectare of suitable forest, applicable for management decisions within Clayoquot Sound; and
- predict likely effects of extensive clearcut logging on watershed populations.

Dependent variables in the analysis were the annual mean and mean maximum pre-sunrise dawn counts, and the independent habitat variables included areas of several habitat types, classified by tree age class and biogeoclimatic subzones (Table 3-7). Habitat data for each watershed are in Table 3-8. Further details of this analysis are in Burger (2001).

Correlations between Murrelet Counts and Habitat Variables

Murrelet counts (Dawnmean and Dawnmax) were significantly correlated with the total area of watersheds and several other habitat measures (Table 3-9). Many of the habitat variables showed significant correlations with total watershed area (Burger 2001). After controlling for total watershed area, the correlations between murrelet counts and area of original forest, alpine, high-elevation mature forest (Mathigh) and mid- to high-elevation biogeoclimatic subzones (Maturevm2 and Maturemm1) were no longer significant, whereas negative correlations with logged and immature areas became statistically significant, and positive correlations with total mature forest (Mature), mature forest below 600 m (Matlow) and the mature low-elevation CWHvm1 biogeoclimatic subzones (Maturevm1) remained significant. Matlow included both Maturevm1 and Maturevh1, but since the latter was rare or absent in most watersheds (Table 3-8), Matlow and Maturevm1 overlapped considerably.

Distances from the watershed mouths to the nearest known foraging area varied from 1 to 28 km, but had no significant effect on the number of murrelets entering watersheds (Table 3-9) and did not appear in regression models even when the effects of habitat had been statistically controlled in multiple regression models (Burger 2001). Suitable inland habitat throughout Clayoquot Sound was likely to be used regardless of commuting distance from marine foraging concentrations. There were no obvious relationships between watersheds and specific marine foraging areas and it seems clear that birds from many watersheds aggregate at the preferred feeding areas. Comparing watershed counts with the characteristics of marine foraging areas was thus impossible.

Predictive Models for Habitat Management of Marbled Murrelets

Models that reliably predict the number of murrelets in a watershed on the basis of readily available habitat measures are valuable for guiding management decisions and planning monitoring projects. Mean and maximum dawn counts (averaged over several years in this study) gave similar results, and both were used in predictive models because both measures have been used in other studies (Schroeder et al. 1999, Manley 2000). I tested

Table 3-8. Database of habitat features in 18 watersheds in Clayoquot Sound. See Table 3-7 for habitat codes. This analysis takes into account movements of murrelets between adjacent watersheds to match bird counts with appropriate watershed areas (Burger 2001).

Watershed	Alpine	Dist feed	Imm	Logged	Log imm	Mature	Mature mm1	Mature vh1	Mature vm1	Mature vm2	Mat high	Mat low	Orig forest	Tot area
Atleo	0	8	0	949	949	1762	96	255	900	511	607	1155	2711	2732
Bedwell (excluding Ursus)	2710	22	1603	456	2059	8577	2593	0	2942	2947	5540	2942	10540	13598
Boat Basin (Hesquiat)	0	8	0	379	379	5250	0	232	4342	675	675	4574	5628	5672
Bulson	705	18	0	167	167	7981	1064	197	3466	3247	4311	3662	8140	8856
Clayoquot + 0.5 upper Kennedy	983	22	0	60	60	8329	440	0	4663	3225	3665	4663	8388	9432
Cypre	125	7	0	2115	2115	3523	364	342	1427	1390	1754	1769	5638	5763
Flores Creek #6	0	2	0	0	0	1742	0	275	1389	78	78	1664	1742	1742
Hesq Point Creek	0	1	0	15	15	1752	0	55	1514	182	182	1570	1767	1767
Kennedy (excl. upper valley)	2094	20	646	2154	2800	13842	1555	0	6565	5700	7255	6565	16620	18769
Megin (West Megin only)	398	15	0	0	0	10321	502	0	8189	1630	2132	8189	10321	10745
Moyeha	4393	16	0	0	0	12935	2826	0	5365	4559	7385	5365	12750	17930
Pretty Girl	167	15	0	0	0	3362	72	0	2706	584	656	2706	3362	3540
Sydney	47	18	0	0	0	5517	126	0	3985	1406	1532	3985	5517	5591
Tofino Cr + 0.5 upper Kennedy	750	28	0	383	383	5232	490	2	2623	2117	2607	2624	5615	6454
Tranquil	439	22	0	1056	1056	4358	622	0	1977	1759	2381	1977	5414	5870
Ursus	919	24	44	0	44	6367	1251	0	3032	2082	3333	3032	6409	7348
Watta (includes East Megin)	2334	18	0	0	0	14951	2117	13	7857	4964	7081	7870	14951	17341
Watta South	0	16	0	0	0	1394	212	22	667	493	705	689	1394	1394

Table 3-9. Correlations and partial correlations (controlling for total watershed area) between radar counts of Marbled Murrelets (Dawnmean and Dawnmax) and habitat measures at 18 watersheds in Clayoquot Sound. See Table 3-7 for habitat codes.

	Uncontrolled Pearson correlation		Controlled for Total Area Partial correlation	
Habitat measure	Dawnmean	Dawnmax	Dawnmean	Dawnmax
Total watershed area	0.704**	0.694**	–	–
Distance to feeding aggregation	0.323	0.318	0.004	0.003
Forest age				
Immature (20-140 yr)	-0.196	-0.213	-0.757**	-0.767**
Logged (<20 yr)	-0.323	-0.298	-0.646**	-0.601*
Logimm (0-140 yr)	-0.344	-0.332	-0.862**	-0.828**
Mature (>140/250 yr)	0.822**	0.803**	0.845**	0.771**
Original forest	0.713**	0.696**	0.160	0.094
Elevation of mature habitat				
Alpine	0.560*	0.570*	-0.158	-0.103
Mathigh (>600 m)	0.677**	0.667**	-0.008	-0.002
Matlow (<600 m)	0.824**	0.796**	0.620**	0.566*
Biogeoclimatic zone				
Maturevh1 (exposed low)	-0.415	-0.386	-0.204	-0.162
Maturevm1 (<600 m)	0.850**	0.813**	0.674**	0.600*
Maturevm2 (600-900 m)	0.686**	0.685**	0.084	0.120
Maturemm1 (>900 m)	0.511*	0.504*	-0.271	-0.265

*P<0.05
**P<0.01

non-linear models, but they produced weaker regressions than the linear models shown below.

Multiple regression models were useful for showing the combined effects of important habitat measures and yielded the following equations (Burger 2001):

Dawnmean = 69.169 + 0.033Maturevm1 – 0.089Logimm + 0.049Maturevm2 (Adjusted $R^2 = 0.913$, $P < 0.001$);
Dawnmax = 110.914 + 0.031Maturevm1 – 0.100Loggimm + 0.060Maturevm2 (Adjusted $R^2 = 0.860$, $P < 0.001$).

These combined variables explained 91% and 86%, respectively, of the variability in Dawnmean and Dawnmax counts, although most of the variability (70% and 64%, respectively) was explained by Maturevm1 alone. These equations demonstrate the positive effects of low-elevation old-growth and negative effects of logged and immature areas on murrelet counts.

Several measures of old-growth area (Mature, Matlow, Maturevm1, Maturevm2) combined with areas of logged and immature forest (Logimm) produced multiple regressions with similar predictive power to the equations above (R^2 values 0.76-0.91). Such models are useful for showing the habitat variables apparently affecting counts of murrelets in Clayoquot Sound. They are, however, unlikely to be useful for predicting murrelet numbers in management situations, because they require knowledge of the age class, logging history and biogeoclimatic zones of the area under consideration.

Fortunately, a simpler model, using only the area of mature forest below 600 m (Matlow), explained a high proportion of the variability in dawn murrelet counts (high R^2 value) and provided a useful measure for predicting numbers of murrelets in areas being considered for logging or for preservation in Clayoquot Sound. Matlow could be readily estimated from GIS databases, aerial photographs or timber inventories. Linear regressions plotted through the origin seem likely to be the most useful predictors when small areas are being considered (by contrast, regressions that do not pass through the origin yield predictions of 50 or more murrelets when habitat area is zero). The resultant

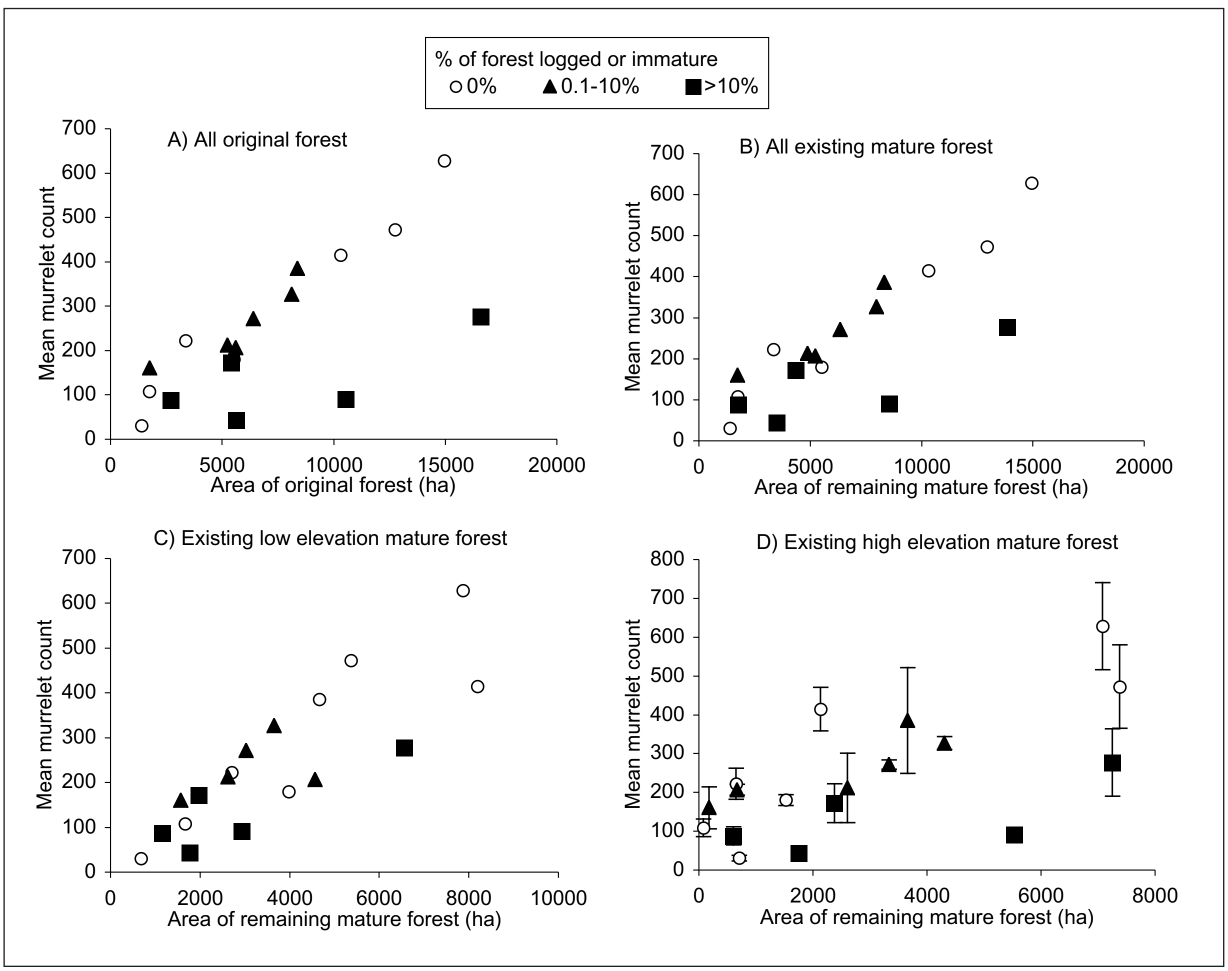

Figure 3-5. Relationships between mean counts of Marbled Murrelets (mean of mean annual counts) at 18 watersheds in Clayoquot Sound and various measures of forest area, including: area of original forest at all elevations, including forest logged or immature at the time of the study (A); area of mature forest remaining at the time of the study at all elevations (B); area of mature forest remaining at low elevations <600 m (C); and area of mature forest remaining at high elevations >600 m (D). Watersheds were labeled according to the proportion of original forest that was logged or immature (see legend). For clarity, error bars (± SE) are shown in only one graph.

equations were:

Dawnmean = 0.0653*Matlow (SE ± 0.005*Matlow; R^2 = 0.898, df = 17, P < 0.001);
Dawnmax = 0.0770*Matlow (SE ± 0.006*Matlow; R^2 = 0.892, df = 17, P < 0.001),

with Matlow measured in hectares (the R^2 values differ from those calculated from R values in Table 3-9 because of the effects of forcing the regressions through the origins).

Mature forest in the CWHvm1 subzone can be used instead of Matlow, giving almost identical results in Clayoquot Sound:

Dawnmean = 0.0651*Maturevm1 (SE ± 0.005*Maturevm1; R^2 = 0.910, df = 17, P < 0.001);
Dawnmax = 0.0764* Maturevm1 (SE ± 0.006* Maturevm1; R^2 = 0.895, df = 17, P < 0.001).

Total area of mature forest performed equally well (almost identical R^2 values):

Dawnmean = 0.0348*Mature (SE ± 0.003*Mature; R^2 = 0.892, df = 17, P < 0.001);
Dawnmax = 0.0410*Mature (SE ± 0.003*Mature; R^2 = 0.887, df = 17, P < 0.001).

However, as shown in the next section, the area of total mature forest was less able to compensate for the effects of logging than area of low-elevation mature forest. Overall, Matlow or Maturevm1 should be better predictors of murrelet numbers in situations where the effects of logging are important.

Effects of Clearcut Logging

The effects of past clearcut logging can be seen when mean dawn counts are plotted against forest areas (Figure 3-5). If the total area of original forest is considered, including those portions recently logged or immature, then the watersheds form a close linear pattern (Figure 3-5A), with the exception of three large watersheds (Cypre, Bedwell and Kennedy) which have lost large portions of the original old-growth (38%, 20% and 17%, respectively), and disproportionately large amounts of low-elevation old-growth below 600 m (51%, 35% and 29%, respectively). Two smaller watersheds, Atleo and Tranquil Creek, which have lost 35% and 20% of the original old-growth (45% and 35% of low-elevation forest, respectively) did not show the deviation from the linear trend, possibly because the logging there was more recent than in the other three logged watersheds and murrelets have not had time to adjust to the reduced areas. In all five watersheds, 78-99% of the logged and immature areas were below 600 m (average 92% in all watersheds in Clayoquot Sound). The deviations persisted when dawn counts were compared with total area of remaining mature forest at all elevations (Figure 3-5B), probably because the remaining habitat in the logged watersheds was high-elevation, less-suitable forest. The deviations disappeared when counts were plotted against remaining low-elevation old growth (Figure 3-5C). The dichotomous grouping evident in this plot (two separate linear groups), could not be explained by differences in the proportions of any of the habitat variables considered here (Mann-Whitney tests for all variables in Table 3-7, P > 0.19 in each case). Finally, area of remaining high-elevation mature forest (Mathigh), which was considered because several nests have been found above 600 m in Clayoquot Sound, was a poor predictor of murrelet counts (Figure 3-5D, Table 3-9).

Discussion

Factors Affecting Radar Counts and the Interpretation of These Counts

Radar counts of Marbled Murrelets have been done by several groups in Alaska, British Columbia, Washington, Oregon and California. They are increasingly being used for watershed-level censusing (Burger 1997, Cooper et al. 2001, this study), stand-level assessments (Hamer et al. 1995, Hamer Environmental 1998), landscape-level habitat associations (Schroeder et al. 1999, Manley 2000, Raphael et al. in press, this study), testing the audio-visual protocol (Cooper and Blaha 1998), and tracking seasonal trends in murrelets flying inland (L. Lougheed, pers. comm.; this study). Radar protocols have been developed by the Marbled Murrelet Technical Committee of the Pacific Seabird Group (Cooper and Hamer 2000) and in the Marbled Murrelet Resources Inventory Committee protocol for BC (RIC 2001). The Clayoquot Sound study reported here is one of the most comprehensive to date and has revealed some of the strengths and limitations of radar as a tool for watershed level inventory and habitat analysis.

Murrelet counts in Clayoquot Sound were affected by the following factors:

- time of day – counts at dawn were higher and less variable than dusk counts;
- flight direction – incoming counts were consistently higher at dawn, but both incoming and outgoing counts need to be considered at dusk;
- multiple visits at dawn – a few birds evidently came in more than once on some dawn surveys, requiring some correction, such as using only pre-sunrise counts;
- effects of weather – counts were sometimes, but not invariably, higher on cloudy, misty or drizzly mornings than on clear, bright mornings;

- seasonal effects – counts were affected by breeding chronology, but within the core period selected, 15 May to 16 July, dawn counts were reasonably consistent;
- annual effects – counts varied among years for many watersheds, but for the entire sample were not significantly different among years, suggesting that some murrelets (perhaps only prospecting birds?) shift from one watershed to another between seasons and that multi-year studies give more accurate data than a single year.

These effects are discussed in more detail by Burger (1997, 2001) and by Cooper et al. (2001). Similar analyses are needed in other areas to assess how widespread and significant these effects might be.

Radar counts include all murrelets entering watersheds, including breeders, failed breeders and prospecting non-breeders. The ratio between breeders and non-breeders is not known for Clayoquot Sound. Sealy (1975) found that 85% of a sample of dissected birds off Langara Island, BC were mature adults. Preliminary analyses of data from Desolation Sound indicate that 95% of captured murrelet females showed raised plasma vitellogenin levels (a precursor to egg production), but 63% of radio-tagged birds showed evidence of active breeding (repeated inland flights), which might be a low estimate due to the effects of capture and handling (F. Cooke, pers. comm.). Assuming that 70-85% of all incoming birds were breeders with an active nest, the number of nests (or nesting pairs) would be 35-43% of the total counts of murrelets made with radar. More refined estimates of the proportion of the population with an active nest will come from telemetry studies coupled with physiological measurements.

Despite daily, seasonal and annual variations in counts of murrelets, radar is likely the most accurate (closest to true value) and precise (least sampling variability) method for estimating watershed and regional populations. At-sea counts and audio-visual surveys are far more prone to error and misinterpretation. Much of the variability in the radar data is due to the variable behaviour of the birds themselves, in response to weather, stage of breeding, nest success and, probably, food availability at sea. Some variability is also likely due to observer accuracy and differences in detectability by radar at various stations. Some of the variability can be reduced through training observers, careful positioning of radar stations relative to flight paths, using multiple surveys over more than one year, considering only pre-sunrise counts at dawn, restricting counts to the mid May through mid July core period and accounting for the effects of weather.

Reliability of Inland Radar Counts

Comparison of radar counts at the Bedwell-Ursus junction with those made at the Bedwell mouth showed that 47-69% of the murrelets passing the mouth were not detected at the junction station. The area between the two stations (3.1 km linear distance) was almost entirely second-growth forest, newly logged clearcuts or scrubby slope forest in which few murrelets would nest. Consequently, nearly all the birds entering at the estuary should have passed the junction. Some might have been out of range of the radar up the slopes, but the majority probably passed within range but undetected. This shows that radar stations in inland forested areas, even in good open sites such as the one I used, provide less complete counts of incoming and outgoing murrelets than coastal stations. At inland sites the radar is usually surrounded by trees and hills, which obscure murrelets, especially those flying just above or below the trees. Stations on the shores of the ocean or lakes offer a larger unobscured field of view to the radar over the water and estuaries, and hence give more accurate counts.

Comparing Audio-visual Detections and Radar Counts

Audio-visual surveys made at the mouth of a watershed recorded less than a quarter of the murrelets detected by radar (Burger 1997), and there was no correlation between the number of audio-visual detections and the radar counts at the coastal Clayoquot stations (Burger et al. 1997). Therefore, audio-visual surveys made at watershed mouths could not substitute for radar counts.

There might, however, be significant relationships between radar counts and the mean audio-visual detections made at multiple inland stations in the same watersheds. Rodway and Regehr (this volume) found no significant correlations between mean radar counts and mean numbers of *total* detections in nine Clayoquot Sound watersheds, but if Cow Bay was excluded, significant correlations with radar counts were found for *occupied* detections ($r = 0.71$, $P = 0.050$) and detections of murrelets *within 50 m* ($r = 0.76$, $P = 0.029$). My analysis in this chapter showed that the annual variations in radar counts were not consistently tracked by the annual variations in average audio-visual detections from multiple inland stations.

These data, although sparse, confirm that there is no obvious relationship between the number of murrelets present and frequencies of total audio-visual detections (Paton 1995). Changes in audio-visual detections can result from changes in numbers of birds entering watersheds (reflected in the radar counts), as well as from changes in the spatial distribution, flight paths and behaviour of nesting and non-breeding birds at stands where audio-visual surveys are made (Rodway et al.

1993, Jodice and Collopy 2000). Audio-visual surveys might be useful indicators of murrelet activity in the forest stands adjacent to the survey stations, but they are not useful indicators of the numbers of murrelets using larger landscape units or specific drainages.

Flight Paths and Bias in Audio-visual Surveys

Rodway and Regehr (2000) found support for the hypothesis that murrelet activity was concentrated along stream channels and concluded that audio-visual surveys along streambeds therefore provided biased data on habitat preferences. Radar mapping of flight paths does not support this stream channel corridor hypothesis. At the Bedwell-Ursus junction, 41-91% of the incoming and outgoing murrelets flew more than 200 m from the rivers. Most murrelets entering the Ursus used a flight path about 700 m wide on the nearby slope. Birds destined for Bedwell were scattered across much of the broad Bedwell Valley. Audio-visual surveys at the junction station confirmed that murrelets were not flying low along the watercourses where they might not be detected by radar.

At 12 coastal stations in Clayoquot Sound where flight paths were mapped (Burger et al. 1997), incoming murrelets were flying above or within 100 m of the watercourses at six stations (Bedwell, Clayoquot River, Moyeha, Sydney estuary, Tofino Creek, Tranquil), but at six other stations (Atleo, Bulson, Cypre, Flores, Hesquiat, Megin) and at Carmanah (Burger 1997) most birds were not following watercourses. The location of the Kennedy and Watta stations precluded this test. It should not be automatically assumed that streamside audio-visual stations provide biased data, but I concur with Rodway and Regehr (2000) that stations with comparable opening sizes and visibility are desirable to compare habitats.

The radar data from the Bedwell-Ursus junction and from many coastal stations (Burger 1997, Burger et al. 1997) also confirm that hundreds of murrelets can pass undetected within 1 km of an audio-visual station, showing that data from standard audio-visual surveys should not be extrapolated uncritically to large tracts of adjacent forest. The habitat surrounding the Bedwell-Ursus station was predominantly second-growth forest, which explains the low frequencies of detections of non-commuting birds and absence of occupied detections.

Numbers of Murrelets in the Bedwell-Ursus Watersheds

Radar counts made at the junction of the Bedwell and Ursus valleys provide some insight into the numbers of murrelets using each valley. This is important because the Ursus Valley is a Special Management Area in Clayoquot Sound. The counts indicate that 75% and 25% of murrelets entering the Bedwell-Ursus system use the Ursus and Bedwell valleys, respectively. I have no way of knowing whether these proportions varied among years.

Assuming that 75% were using the Ursus Valley in each year, a mean of 271 murrelets used the Ursus Valley (range 249-291) in 1996-1998. If the higher 1995 counts were included (Burger 1997), then the annual mean in the Ursus would be 341 (range 249-554) murrelets. Although the Bedwell Valley (13,598 ha) is almost double the area of the Ursus (7,348 ha), the former has been extensively logged over many decades and has proportionately less old-growth forest remaining (Burger 2001).

Size and Importance of the Clayoquot Sound Population

More than 4,600 Marbled Murrelets, and probably as many as 5,500, were using the 20 watersheds sampled with radar (Table 3-6). These estimates, based on pre-sunrise incoming counts were likely to be underestimates, because some murrelets would not have been detected by the radar and because our assessment of flock size tended to underestimate flocks larger than two birds. These watersheds represent most of the suitable inland forested habitat surrounding Clayoquot Sound, but there were large tracts of apparently suitable forest along the slopes of the fjords and in smaller watersheds that were not sampled (Figure 3-1). Taking these factors into consideration, the total Clayoquot Sound population of Marbled Murrelets certainly exceeded 6,000 birds in 1996-1998, and probably fell within the range of 7,000-8,000 birds. These totals include both breeding birds and non-breeding birds that venture inland.

Previous estimates of the Clayoquot Sound population were made from counts at sea using boats. The maximum single count made at sea between 1992 and 1996 was 4,510 birds, using a grid sampling method that covered most of Clayoquot Sound and some of the adjacent open ocean (Kelson et al. 1995, Kelson and Mather 1999). Using the same method, Sealy and Carter (1984) had counted 6,549 birds in NW and SE Clayoquot Sound and off Long Beach in 1982, but densities have possibly declined since then. The decline has been attributed to loss of nesting habitat from logging (Kelson et al. 1995) and, possibly, changes in local marine ecosystem (Burger 2000). The grid method assumes all birds are counted up to 250 m on either side of the boat (Sealy and Carter 1984), but it is now known that many murrelets more than 100-150 m from a boat are missed (Becker et al. 1997), so that these marine counts underestimate total resident populations. Taking these missed birds into account, the radar and boat counts both suggest a population in excess of 6,000 murrelets and likely much higher.

The total provincial population of Marbled Murrelets is not known, but the most recent estimate suggests about 66,000 birds in 2001 (Burger 2002). About one-tenth of the province's murrelets appear to be using Clayoquot Sound during the breeding season, forming one of the largest breeding concentrations south of Alaska. At-sea surveys and radar counts around the British Columbia coast consistently show high numbers or densities of murrelets off the southwest coast of Vancouver Island, including Clayoquot Sound and adjacent coasts (Sealy and Carter 1984; Rodway et al. 1992; Burger 1995, 2002). Conservation of the essential attributes of the murrelet's nesting habitat and marine foraging areas in Clayoquot Sound should therefore be a provincial priority.

Landscape-level Habitat Associations

There has been considerable work on the habitat relationships of Marbled Murrelets at nest sites, nesting patches and at the level of forest stands. There has been less work at the landscape level, testing relationships between Marbled Murrelet densities and habitat characteristics per watershed. This is important for understanding whether stand-level habitat attributes can be applied at the landscape level, plotting the regional distribution of murrelets and their preferred habitats, predicting regional and provincial population sizes and estimating the effects of clearcut logging on watershed populations. In addition, there is a demand among foresters, land managers and Regional Endangered Species Biologists to have reasonable estimates of the numbers of murrelets per hectare likely to be nesting in areas being designated for cutblocks or Wildlife Habitat Areas.

Our radar inventory included 18 watersheds with varying biogeophysical features (Moore 1991, Chapman and Cheong 1995, Clayoquot Scientific Panel 1995). A major goal of the study was to determine which, if any, of the habitat features was a significant predictor of murrelet populations in the watersheds. Murrelet counts were positively correlated with the size of the watershed and, more specifically, with the available areas of mature (i.e., old-growth) forests. Three measures of mature forest gave virtually identical correlations with dawn counts: Maturevm1, Matlow and Mature. Not surprisingly, these three were also strongly intercorrelated and overlapping. Once the effects of mature forest were included, the residual variation in dawn counts was best explained by the negative effects of logging, specifically the combined areas of recently logged and immature forest (Logimm). The combined positive effects of old-growth availability and negative effects of logged and immature forest explained up to 91% of the variability in dawn counts. This high coefficient gives some confidence that these were causal relationships and not spurious correlations. The distribution of watersheds relative to marine foraging concentrations did not emerge as an important factor.

Linear regressions of dawn counts (Dawnmean and Dawnmax) against Matlow, plotted through the origins, provide a simple predictive equation for management purposes. Estimating the availability of existing old-growth forest below 600 m should be a relatively simple task, allowing some predictions to be made of the number of murrelets likely to be entering the area. These regressions allow, for the first time, landscape-level predictions of the effects on murrelets of removing or preserving tracts of old-growth forest. Equations for predicting murrelet numbers from total mature forest area were also produced, but this measure was less able to compensate for the effects of logging and consequently might be less useful.

Application of these regressions beyond Clayoquot Sound should be done with caution, because relationships between murrelets and habitat might differ elsewhere. Support for the ability to predict murrelet numbers from areas of old-growth forest comes from three similar radar studies. Manley (2000) found a strong positive correlation between murrelet numbers and area of mature forest below 600 m at 20 watersheds on northwest Vancouver Island, north of Clayoquot Sound. Along the central mainland coast of BC, murrelet counts were significantly correlated with areas of mature forest assessed to be "suitable" on the basis of forest age, canopy structure, presence of platform limbs and tree species composition (Schroeder et al. 1999). On the Olympic Peninsula, Washington, Raphael et al. (in press) found a significant positive correlation between murrelet counts and late-seral forest area below 1,067 m in nine watersheds over three years. More work is needed to establish general associations between murrelets and landscape-level habitat attributes. Radar counts combined with detailed GIS information are most likely to show such associations.

Finally, the Clayoquot study revealed disturbing effects of clearcut logging on murrelet numbers (see also Burger 2001). In the area sampled, more than 92% of the recently logged or immature forest was below 600 m. When low-elevation old-growth forest was removed, the murrelets did not pack into the remaining forest in higher densities. If they had done so, the counts would have remained constant relative to the areas of original mature forest. This did not happen: three of the five watersheds which were extensively logged showed greatly reduced counts (Figure 3-5A). These deviations disappeared when murrelet counts were compared with the remaining low-elevation mature forest, but not when compared with remaining mature forest at all elevations, or with high-elevation mature forest. Evidently, murrelets were responding to loss of low-elevation mature forest by leaving heavily impacted watersheds, rather than packing into the remaining habitat in greater densities. Similar results were found by Manley (2000), while Schroeder et al. (1999) found that murrelet counts in heavily logged watersheds did not show the same relationships with forest area as those in less disturbed watersheds.

These results have serious implications for the widespread application of the Identified Wildlife Management Strategy (IWMS), part of the BC Forest Practices Code. The existing 1999 IWMS guidelines for Marbled Murrelets call for 10-12% of the original suitable habitat to be maintained. In addition, there is strong pressure to place murrelet Wildlife Habitat Areas in non-contributing forest, which is often at higher elevations. Three separate radar studies indicate a linear relationship between murrelet counts and available old-growth forest (Manley 2000, Raphael et al. in press, this study), which suggests that murrelets do not pack into remaining old-growth habitat in higher densities.

There will almost certainly be a dramatic drop in the population of murrelets nesting in managed forests in BC over the next few decades if 10-12% or less of the original habitat is left as old-growth. Some larger strongholds will, of course, persist in fully protected areas such as Carmanah-Walbran Provincial Park and the inland portions of Pacific Rim National Park and Gwaii Hannas National Park Reserve, but the bulk of nesting habitat falls within coastal forests where timber extraction is the primary management objective. It seems prudent to increase the areas of protected old growth in order to maintain viable populations of Marbled Murrelets throughout coastal BC and avoid the expensive and desperate measures currently necessary to protect murrelets in California, Oregon and Washington.

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Inland Activity and Forest Structural Characteristics as Indicators of Marbled Murrelet Nesting Habitat in Clayoquot Sound

by Michael S. Rodway and Heidi M. Regehr

Abstract

Our objective was to identify important nesting habitats for Marbled Murrelets (*Brachyramphus marmoratus*) at landscape and stand scales within Clayoquot Sound. We determined whether murrelet activity was related to structural characteristics common to known nest sites to assess whether activity patterns provided similar indications of habitat importance as stand-level characteristics thought to be important for nesting. We then determined how murrelet activity and nest-related structural characteristics varied in relation to topographic features and habitat categories, and how murrelet activity and predator abundance varied in relation to forest edges and fragmentation by logging in 14 watersheds during the 1995-1997 breeding seasons. Inland detections of murrelets were highly variable at daily, seasonal and annual temporal scales, and at survey station, watershed and biogeoclimatic subzone variant spatial scales. Results indicate that activity data alone are not adequate for determining habitat use for nesting at small scales (10s-100s of ha) within watersheds. We found positive relationships between occupied detection numbers and forest structural characteristics, especially density of trees with platforms, density of large trees and mean diameter at breast height (DBH) of all trees, indicating a general association between activity thought to be associated with nesting and structural characteristics known to be important to nesting murrelets. This suggests that comparisons of structural characteristics may be a more useful method for differentiating and prioritizing breeding habitats for Marbled Murrelets at small scales within watersheds than audio-visual surveys measuring relative activity levels. Highest activity levels occurred in Bulson, Flores #6, Hesquiat Point, Sydney and Ursus valleys, and lowest levels in Cypre and Flores Cow Bay. Many forest structural characteristics, including mean DBH, epiphyte cover, density of large trees, density of trees with potential nesting platforms and total numbers of platforms, were positively associated with proximity to major streams channels, suggesting that these areas would provide high-quality nesting habitat for murrelets. Highest numbers of detections also were recorded along stream channels in valley bottoms. Some of this concentrated activity likely was due to murrelets using stream channels as flight corridors, and some likely was associated with nesting. Higher frequencies of potential predators, specifically Northwestern Crows (*Corvus caurinus*) and Bald Eagles (*Haliaeetus leucocephalus*), may reduce the quality of riparian zones. We found differences in murrelet activity and vegetation characteristics among biogeoclimatic subzone variants, but they did not clearly indicate differences in the quality of potential nesting habitat. Lower density of trees with nesting platforms, low detection numbers and increased predator abundance at ocean edges also indicated that perimeter coastal forest is lower-quality nesting habitat. All detection measures increased with distance from the sea and were highest at elevations of 50-500 m. Total numbers of platforms were highest at intermediate distances from the sea, and density of trees with platforms was highest at intermediate elevations below 800 m. We found clear differences in the quality of potential nesting habitat at a site series scale. Richer, more productive site series better provided the forest structural characteristics thought to be important to nesting murrelets compared to poorer site series. Positive associations between site productivity and forest structure used for nesting by murrelets confirm that economic interests of the forest industry and conservation needs of Marbled Murrelets overlap. Lower activity levels and higher predator frequencies indicated that areas fragmented by logging provide poorer nesting habitat than unfragmented forest. Increased predator abundance at edges and in stands fragmented by logging is a major concern for murrelet conservation. In summary, our results indicated that the most important nesting habitats for Marbled Murrelets in Clayoquot Sound are highly productive, unfragmented, multi-aged, old-growth stands located away from ocean and harvest edges in valley-bottom and slope areas below 800 m elevation. These results, in conjunction with information from other studies, will contribute to setting priorities for establishment of no-harvest reserves within Clayoquot Sound watersheds.

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Introduction

Clayoquot Sound contains a majority of the remaining unlogged watersheds on the west coast of Vancouver Island and a substantial proportion of the intact watersheds on the west coast of Canada (Moore 1991). The area has received regional and international attention because of its wilderness, aboriginal and economic values. The Clayoquot Scientific Panel (1995) developed recommendations for sustainable ecosystem management of the area. Marbled Murrelets (*Brachyramphus marmoratus*) were identified as a priority species for management because of their threatened status, their dependence on old-growth forest habitat for nesting and the importance of Clayoquot Sound to provincial and North American populations (Sealy and Carter 1984, Rodway 1990, Rodway et al. 1992, Burger 1995, Kelson et al. 1995).

Known nest sites in the Pacific Northwest indicate the importance to nesting murrelets of structural characteristics unique to old-growth forest, including a multi-layered canopy and large-diameter conifers with potential nesting platforms created by extensive epiphyte development, mistletoe blooms and unusual limb deformations (Hamer and Nelson 1995). High predation rates at known nests by corvids (ravens, crows and jays), and increases in corvid populations in fragmented and edge habitats, result in higher reproductive success at nests further from edges, suggesting that tracts of intact old-growth forest may be particularly important to productivity (Nelson and Hamer 1995, Manley 1999).

Our objective was to identify important habitats for nesting murrelets at landscape and stand scales within Clayoquot Sound. Identification of essential habitats is vital to subregional planning for the protection of Marbled Murrelets and the designation of no-harvest reserves within watersheds (Clayoquot Scientific Panel 1995). This is a difficult task because Marbled Murrelet nests are hard to find and prioritization of nesting habitat based on direct comparisons of nesting density and productivity is impractical at present (Rodway and Regehr 1999). We thus attempted to identify important nesting habitats by using three indirect measures that may be related to actual habitat use by murrelets: forest structural characteristics thought to be important for nesting; murrelet activity over forested habitat; and occurrence of potential murrelet predators.

Comparing forest structural characteristics among habitats likely provides a reliable indication of differences in the availability of these characteristics, although there are biases in observer estimates of the numbers of potential nesting platforms in different habitats (Manley 1999, Rodway and Regehr 1999).

In contrast, measures of inland activity levels are subject to a number of known biases and are more difficult to interpret. The unit of measurement in inland surveys is a detection, defined as *the sighting or hearing of one or more murrelets acting in a similar manner* (Paton 1995). Detections measure relative activity levels that cannot be translated into numbers of birds and have an unknown relationship to the occurrence and density of nests. Numbers of detections at particular survey stations are highly variable at daily, seasonal and inter-annual scales (Rodway et al. 1993a, Burger 1995, Naslund and O'Donnell 1995, O'Donnell et al. 1995, Jodice and Collopy 2000, but see Ralph 1995), and their measurement is subject to significant sources of bias due to station placement, visibility and observer (Rodway et al. 1993a, O'Donnell 1995, Singer et al. 1995, Rodway and Regehr 2000). Placement of survey stations in forest openings or along stream channels to maximize visibility and the chances of seeing murrelets introduces biases into habitat comparisons due to the size of the opening. Stations along stream channels in valley-bottom habitats generally have larger openings, and thus greater chances of seeing murrelets, than those placed in the forest. Greater numbers of detections also may be recorded at streambed stations because murrelets sometimes use stream channels as flight corridors when travelling to other areas (Rodway and Regehr 2000). Murrelets often fly over large areas covering many square kilometres, and detections of flying birds may not reflect local habitat use (Rodway et al. 1993a).

Biases in the measurement of activity levels can be reduced, and more reliable relationships between activity levels and forest habitat can be obtained, through appropriate survey design and data analysis. Certain behaviours, including flying within and below the forest canopy, landing in trees and circling above the canopy, are thought to be most indicative of nesting (Ralph et al. 1994, Paton 1995), and their occurrence has been used to distinguish "occupied" and "unoccupied" stands (e.g., Kuletz et al. 1995, Hamer 1995). As circling can occur over wide radii, a subset of these "occupied" behaviours, including only "subcanopy" detections may be more precise indicators of local habitat use. High and inconsistent temporal variability in activity levels among stations (Burger et al. 1997) means that repeated surveys are required to determine relative activity levels and whether "occupied" or "subcanopy" behaviours occur at specific sites (Ralph et al. 1994). Repeating surveys on different dates during the main nesting season and during different weather conditions, and including the effects of survey date and weather in statistical analyses, helps control for known seasonal and weather-related variation in murrelet activity (Rodway et al. 1993b). Including the effect of opening size in statistical analyses can control biases due to differences in opening size at survey stations. When considering all auditory and visual detections, and because murrelets can be heard at considerable distances, especially at elevated, open sites, more pertinent measures of local habitat use are obtained by limiting consideration to detections occurring within smaller radii of survey stations (Rodway et al. 1993b).

Because little is known about the murrelet's habitat associations in Clayoquot Sound, we chose to explore a variety of potential habitat relationships rather than develop specific hypotheses for testing. First, we determined whether variation in murrelet activity corresponded to variation in forest structural characteristics to assess whether activity patterns provided similar indications of habitat importance as stand-level structural characteristics thought to be important for nesting. Several previous studies in other areas have demonstrated relationships between occupied detections and forest structural characteristics common to known nest sites (Rodway et al. 1993b, Hamer 1995, Kuletz et al. 1995, Manley 1999). Secondly, we determined how murrelet activity and stand-level structural characteristics important for nesting varied in relation to topographic features at a landscape scale and to biogeoclimatic ecosystem categories at landscape (subzone variant) and stand (site series) scales. Inter-annual variation in activity was measured to determine the consistency of habitat relationships. Because of the uncertainty surrounding the interpretation of detection data, we used our results to assess whether and at what scale detection data can provide information about the location of nesting habitat. We included total detections in all analyses to help with this assessment, even though they were unlikely to be useful for stand-scale comparisons. Finally, because predation may reduce productivity near forest edges and in fragmented forests, we compared murrelet activity and predator abundance between edge and interior forest, and between areas of intact forest and areas fragmented by logging.

Methods

Murrelet Surveys

Inland surveys were conducted between 15 May and 19 July 1997 at 177 stations in the Tranquil, Bulson, Ursus, Pretty Girl, Sydney, Hesquiat Point, Flores #6, Flores Cow Bay, Atleo, Cypre and Bawden watersheds (Figures 4-1 to 4-7). Data from 21 stations surveyed in 1996 at three additional watersheds on Flores Island (Flores #9, Hootla Kootla and Flores North) were used for watershed comparisons on Flores. Surveys conducted at some of the same stations in the Ursus Valley in 1995 (Burger et al. 1995) and in six watersheds in 1996 (Beasley et al. 1997) were used to determine inter-annual trends. Surveys were replicated within three date blocks, 15 May-3 June, 8-25 June and 2-19 July, spanning the core of the nesting season, to control for variation in activity levels by date. Each station was thus surveyed three times during the season, except when torrential rains, flooding and risks to safety of observers prevented surveys. Observers worked in teams of two and paired survey stations were placed 500 m apart unless that distance was impractical or unsafe for observers to travel in pre-dawn darkness.

Murrelet surveys were conducted from 1 h before to 1 h after sunrise or until 15 min after the last detection, following standardized methods for intensive inland surveys (Ralph et al. 1994, RIC 1997). All observers had previous experience conducting Marbled Murrelet surveys and successfully completed training in RIC protocol for inland surveys and for measuring vegetation characteristics. Closest distance from the observer for each detection was estimated, from which detections were categorized by distance: 0-50 m; 51-150 m; 151-500 m; or >500 m. Occupied detections included visual detections of birds flying below or within the forest canopy and birds circling above the canopy, and auditory detections of birds calling at least three successive times from a stationary location (although stationary calling birds were very rarely recorded in this study). Behaviour was coded as circling if we saw flying birds make at least half a full circle (i.e., turn 180º or more from their initial direction). Subcanopy detections included all occupied detections except those of birds circling above the canopy.

Survey stations were described: elevation was estimated using landscape features referenced to 1:20000-scale topographic maps and air photos; distance from major drainage channels and shortest, direct distance to the sea were measured on 1:20,000 topographic maps; and location was classed as ocean edge, if within 200 m of the shore, and as valley bottom on stream, valley bottom in forest, lower slope, or upper slope, following macro-site positions described in Luttmerding et al. (1990) and Green and Klinka (1994). Level of creek noise that may interfere with audio detections was coded: none (0); low (1); medium (2); or high (3).

Opening size at survey stations was defined as the area over which murrelets flying just above the canopy could be detected, and was calculated from estimates of the length and width of the opening, or in some cases, more complex dimensions if the opening shape was irregular. Length and width of openings were estimated up to a maximum of 100 m in either dimension (i.e., opening size had an upper limit of 10,000 m^2). The 100-m maximum provided an adequate range to index relative opening size, was considered the practical limit of an

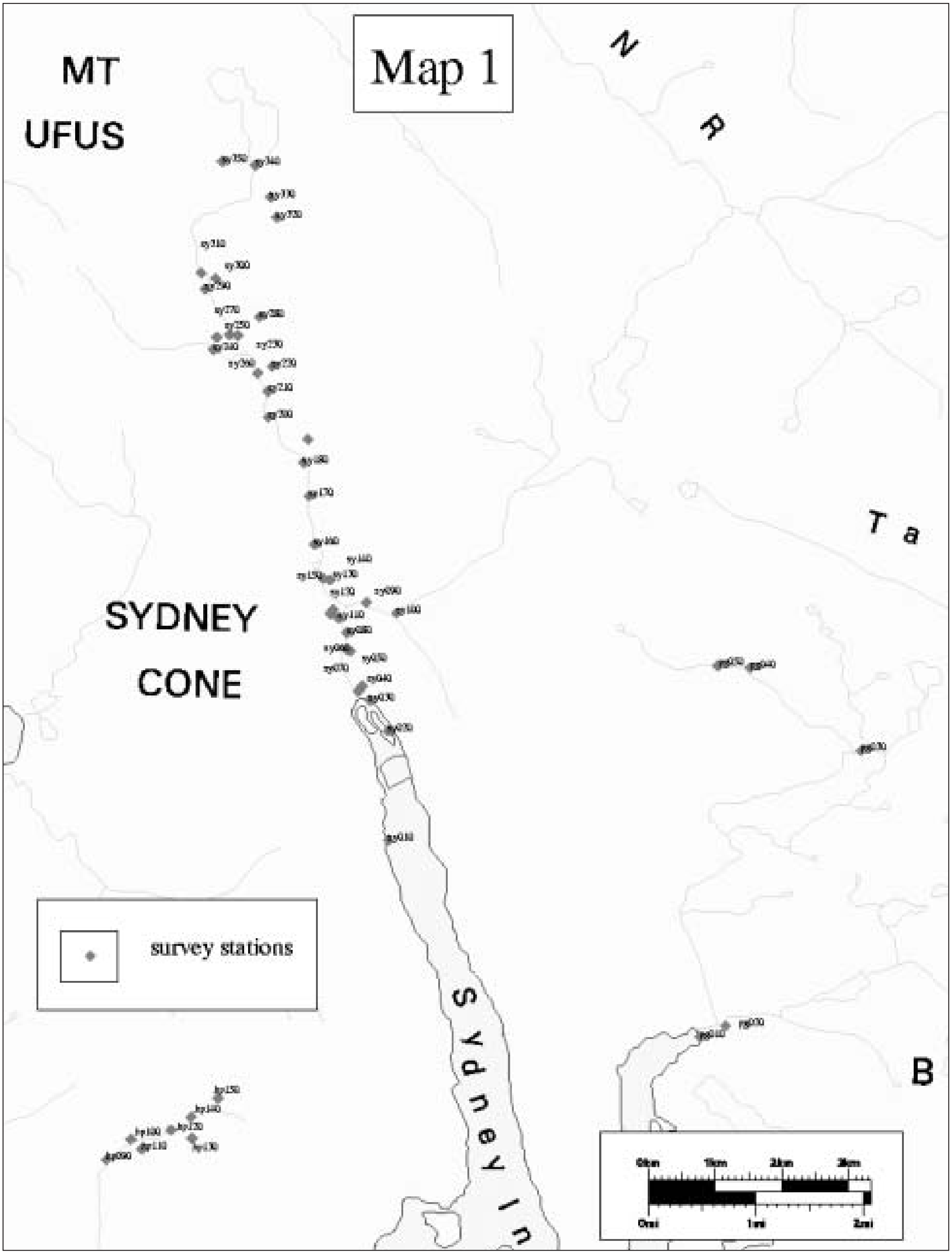

Figure 4-1. Locations of Marbled Murrelet inland survey stations in Sydney and Pretty Girl watersheds in Clayoquot Sound, 1996-1997.

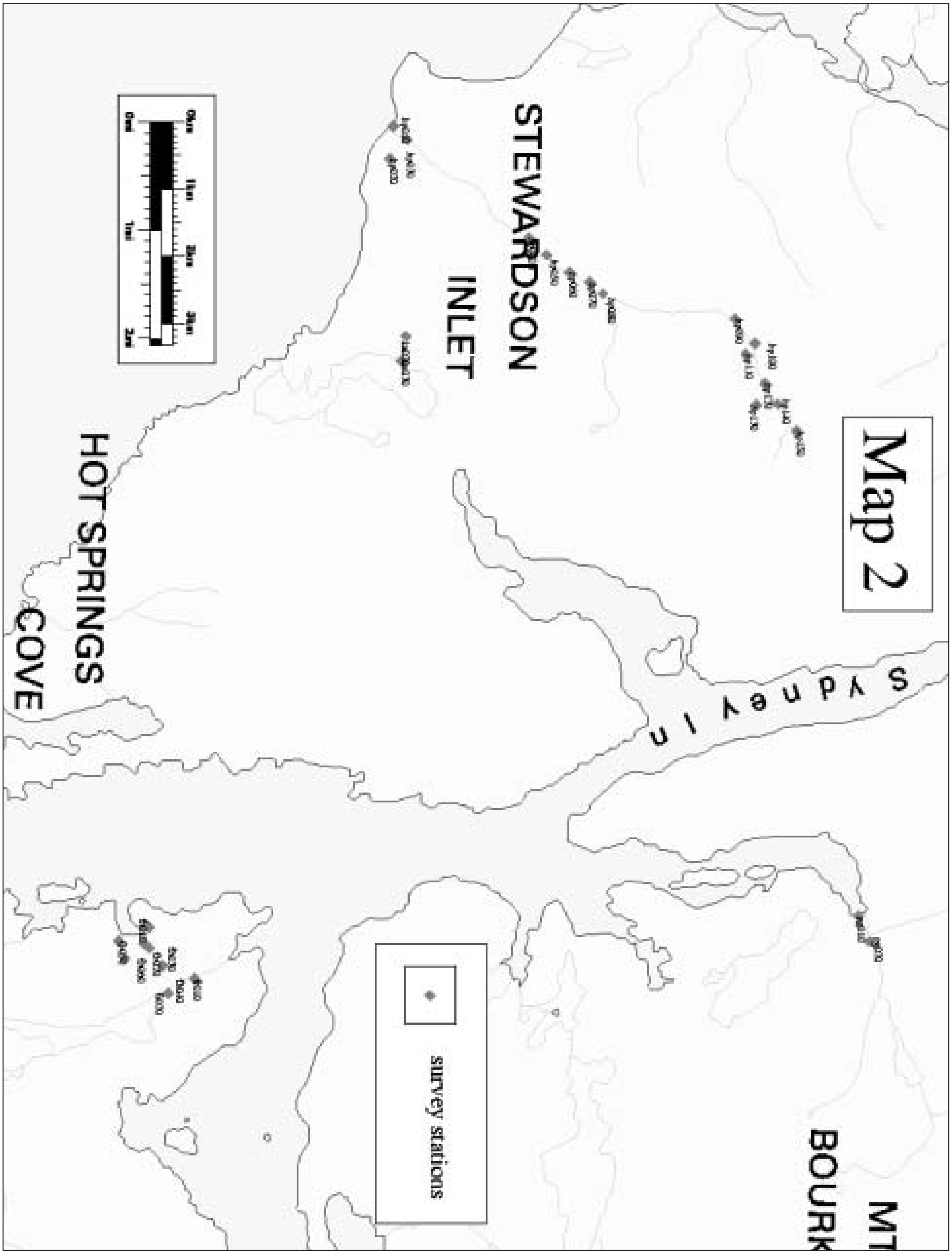

Figure 4-2. Locations of Marbled Murrelet inland survey stations in Hesquiat Point, Kanim Lake, Flores Hootla Kootla, and Flores Riley Creek watersheds in Clayoquot Sound, 1996-1997.

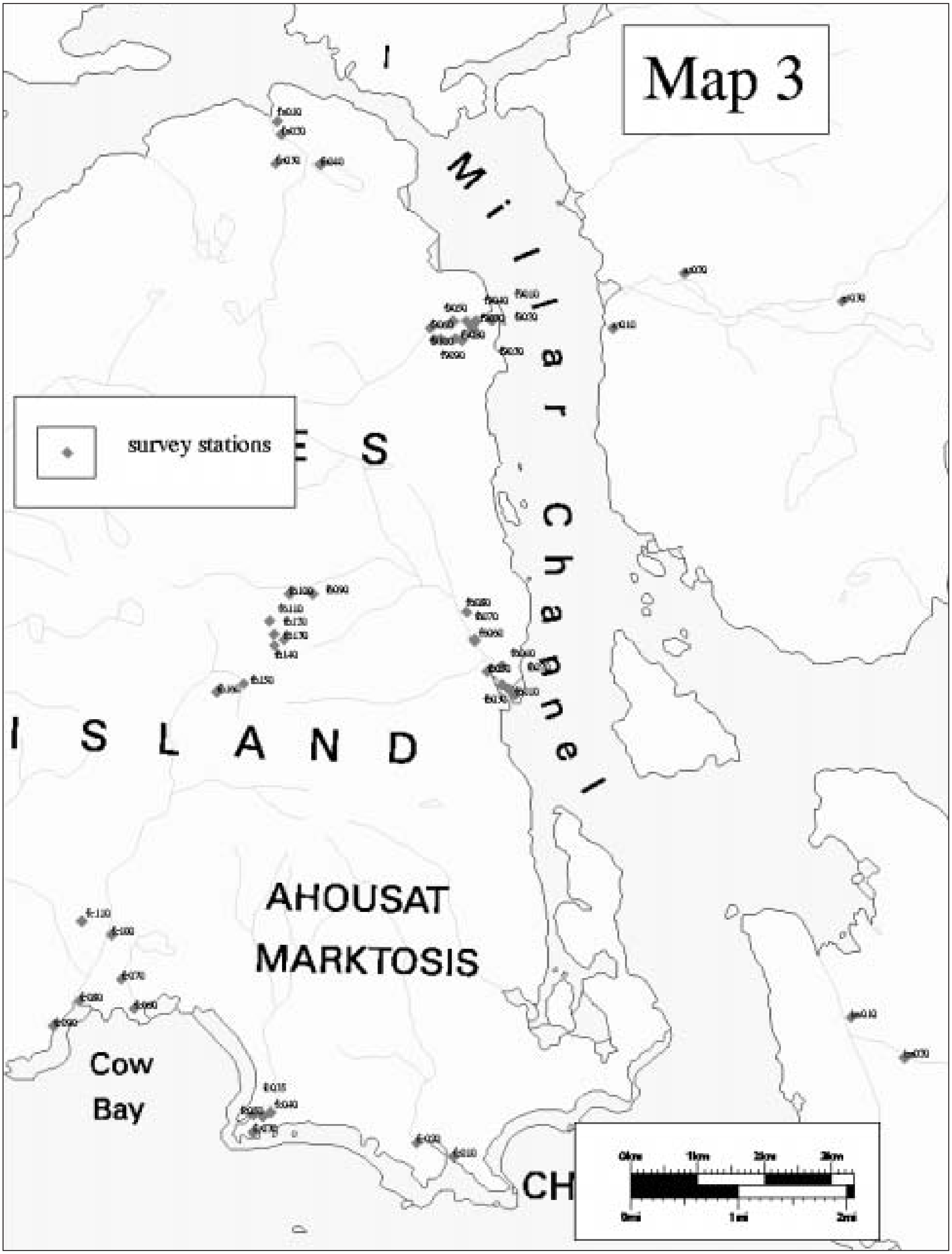

Figure 4-3. Locations of Marbled Murrelet inland survey stations in Flores #6, Flores #9, Flores Cow Bay, Atleo, and Bawden watersheds in Clayoquot Sound, 1996-1997.

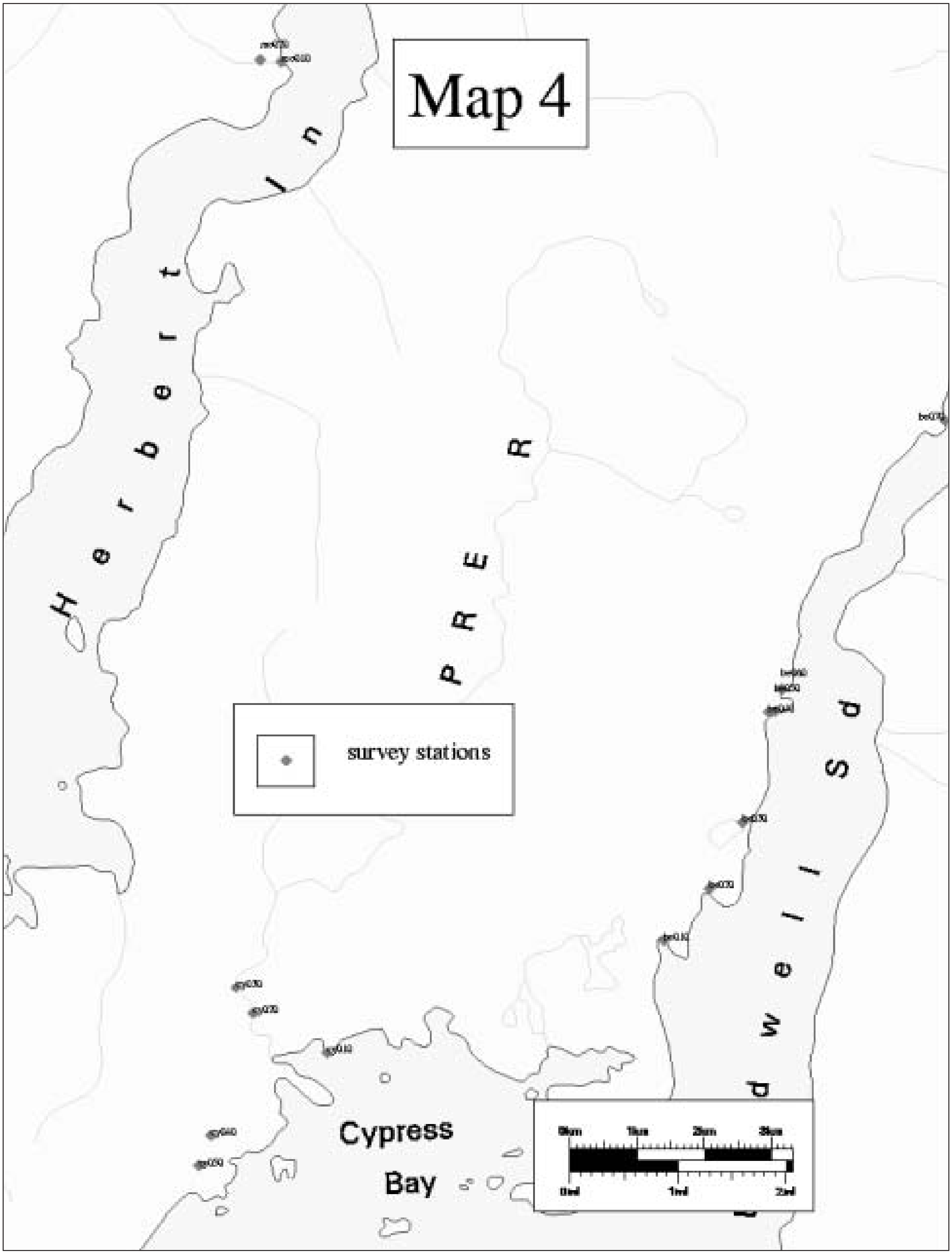

Figure 4-4. Locations of Marbled Murrelet inland survey stations in Cypre watershed and west Bedwell Sound in Clayoquot Sound, 1996-1997.

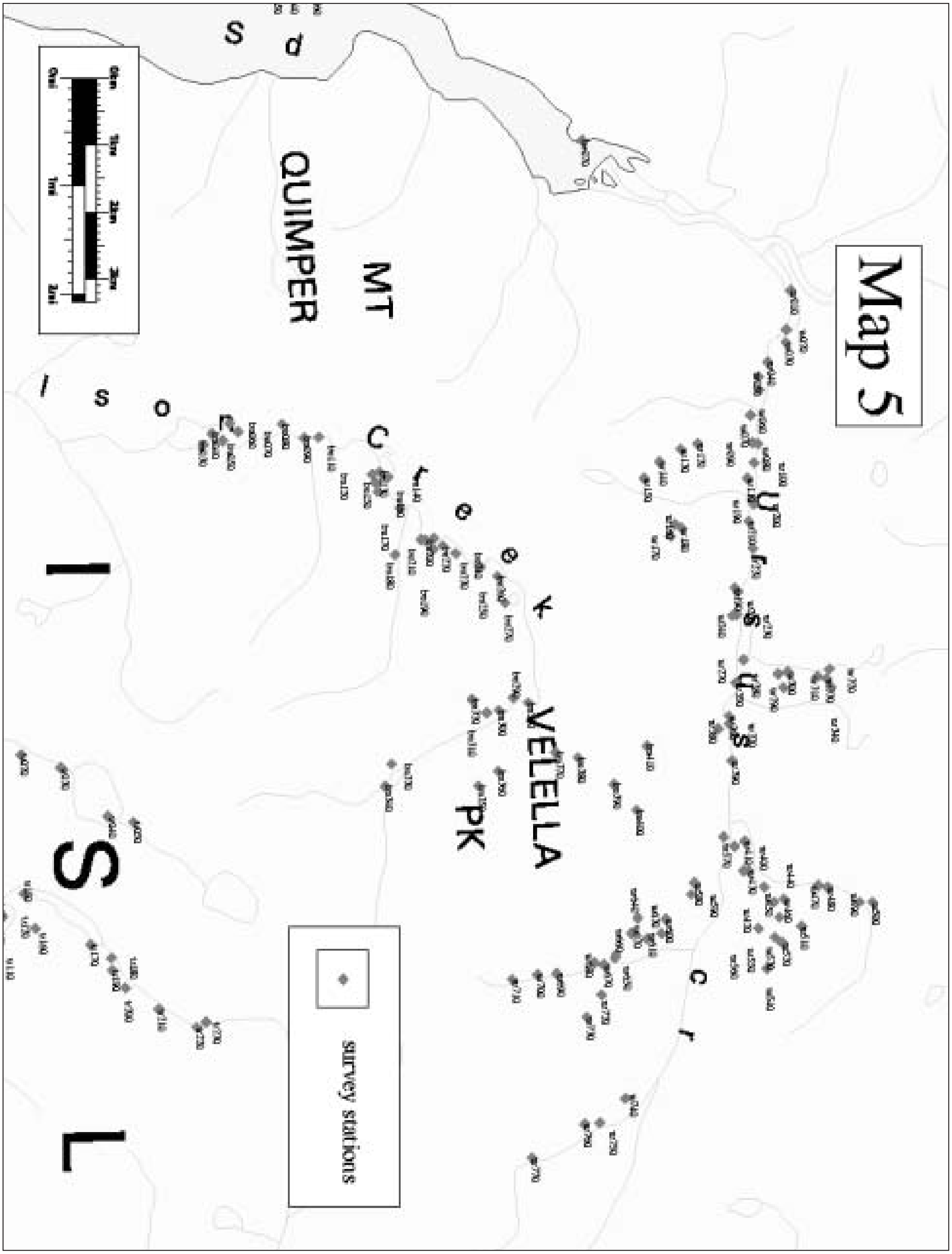

Figure 4-5. Locations of Marbled Murrelet inland survey stations in Ursus and Bulson watersheds in Clayoquot Sound, 1995-1997.

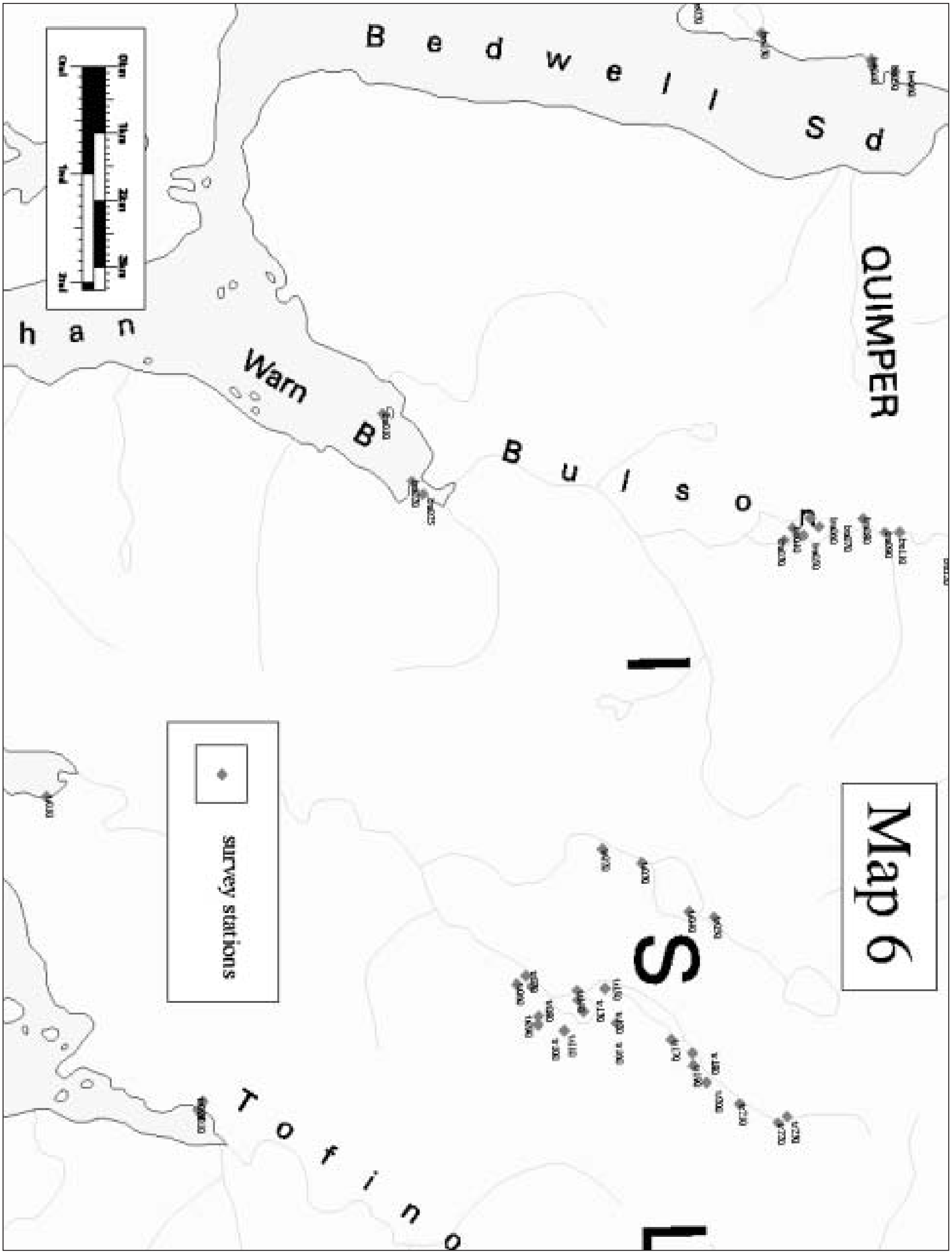

Figure 4-6. Locations of Marbled Murrelet inland survey stations in Bulson and Tranquil watersheds in Clayoquot Sound, 1996-1997.

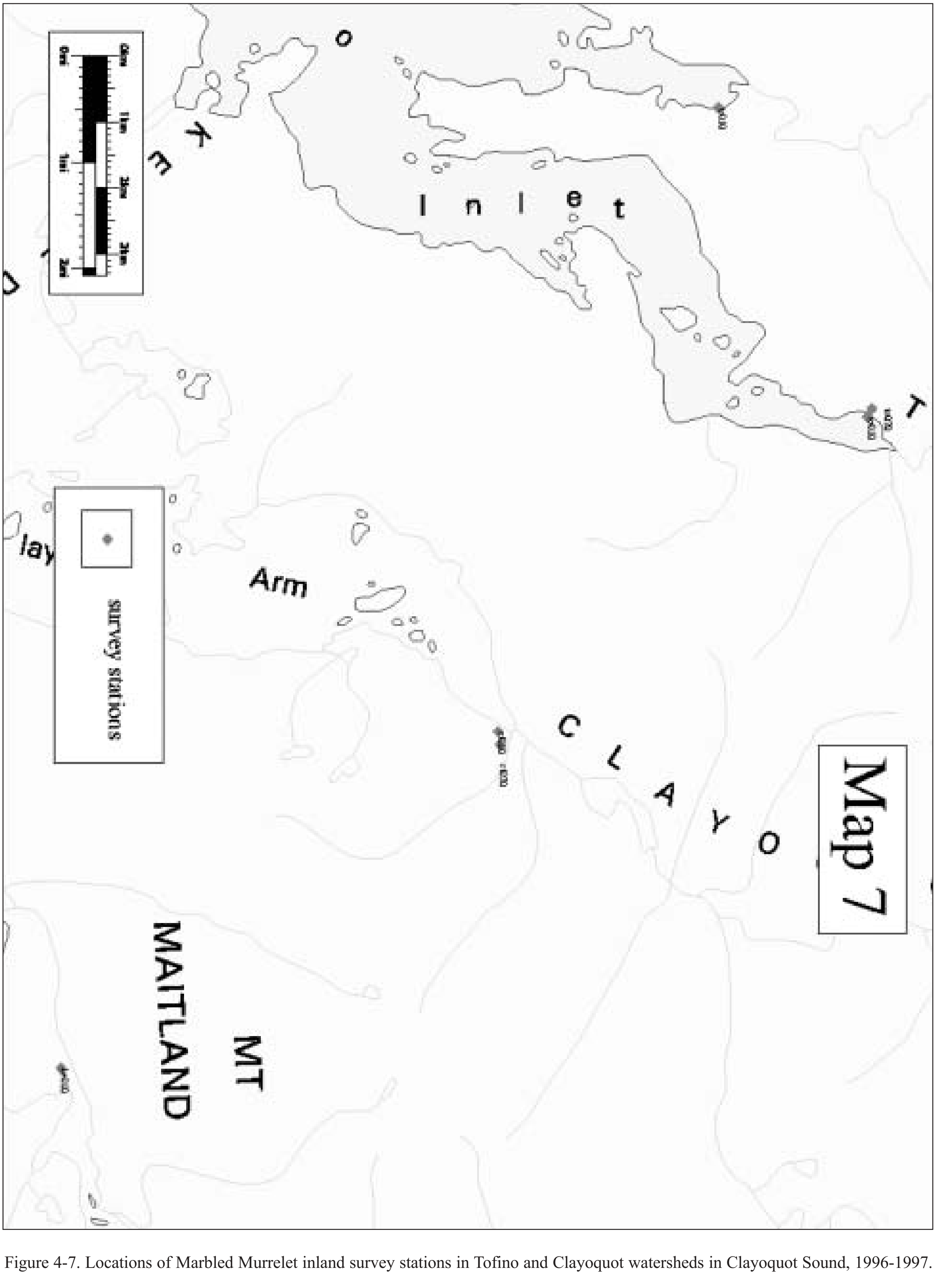

Figure 4-7. Locations of Marbled Murrelet inland survey stations in Tofino and Clayoquot watersheds in Clayoquot Sound, 1996-1997.

observer's visual scanning area (although birds could be tracked for greater distances), and avoided exaggerated estimates along long stretches of stream channel or where visibility was unimpaired to the horizon.

Percent cloud cover was estimated at the beginning and end of each survey period. The average of those two estimates was used to divide weather into two categories: fog or ≥80% cloud cover (cloudy); and <80% cloud cover (clear).

Vegetation Plots

Vegetation characteristics were measured in 30x30-m plots located adjacent to each survey station following standardized methodology (RIC 1997). Because survey stations were generally along creek openings or in windfall or deadfall openings in the forest, the closest corner of vegetation plots was located 10 m beyond the edge of intact forest from the survey station. This method provided representative and unbiased samples of forest habitat in the vicinity of each survey station.

We recorded characteristics of each live tree with a diameter at breast height (DBH) >10 cm that had >50% of its basal area within plot boundaries: 1) species; 2) DBH measured to the nearest 0.1 cm with a DBH tape; 3) stratum reached, classed as emergent, main canopy or subcanopy; 4) height estimated to the nearest m; 5) number of potential nest platforms, defined as a limb >18 cm in diameter, including moss, located >15 m above the forest floor; 6) epiphyte cover on limbs, coded as none (0), trace (1), 1-33% (2), 34-66% (3), 67-100% (4); and 7) mistletoe (*Arceuthobium campylopodum*) infestation, coded as none (0), light (1) or heavy (2) for the bottom, middle and upper thirds of the tree, giving a maximum score of 6 (Hawksworth 1977). Dead trees and snags were also measured if they were >10 m in height.

Site description and vegetation composition sections of Ecosystem Field Forms (Luttmerding et al. 1990) were completed for each plot. Using biogeoclimatic ecosystem classification (Pojar et al. 1987), we categorized each area into one of three biogeoclimatic subzone variants (Southern Very Wet Hypermaritime Coastal Western Hemlock –[CWHvh1], Submontane Very Wet Maritime Coastal Western Hemlock –[CWHvm1], or Montane Very Wet Maritime Coastal Western Hemlock [CWHvm2]), based on the mapped distribution of those variants (Anon. 1993). Each site was then assigned to a site series within the appropriate subzone variant based on slope position and percent, moisture and nutrient regimes (determined by digging small soil pits), and on percent composition of indicator species in tree, shrub, herb and moss strata (Green and Klinka 1994). Total percent cover was estimated for each stratum.

Potential Predators

Incidental records were kept during morning surveys of the occurrence of potential avian and mammalian predators of Marbled Murrelets. Known predators at murrelet nests include Steller's Jays (*Cyanocitta stelleri*) and Common Ravens (*Corvus corax*; Nelson and Hamer 1995). We also recorded Northwestern Crows (*Corvus caurinus*) and Red Squirrels (*Tamiasciurus hudsonicus*), which were considered possible nest predators, and Bald Eagles (*Haliaeetus leucocephalus*), which are potential predators on adults and could affect habitat choices made by nesting murrelets.

Statistical Analyses

We analysed relationships among both continuous and categorical variables using a General Linear Model procedure (GLM in SPSS 8.0). Interactions were not included in models if they were not significant ($P > 0.05$). Variables used in analyses are listed in Table 4-1. Residuals from linear models were inspected to insure that assumptions of normality and homoscedasticity were satisfied. Detection data were natural-log (count + 1) transformed to satisfy these assumptions. We did not have to transform percent data for canopy closure because all values fell within the middle of the range (Sokal and Rohlf 1981).

We used four measures of murrelet activity levels as dependant variables: numbers of total detections; detections within 50 m radii of survey stations; occupied detections; and subcanopy detections per survey. Numbers of detections within 50 m were not available for 1995 and 1996 surveys and thus only total, occupied and subcanopy detections were compared among years.

Date, cloud cover and opening size were included in all analyses of detection data to control for known variation due to those factors. Creek noise was included as an explanatory variable for total detections for the same reasons (but see Results). Location was included in hierarchical models testing for differences among watersheds because unequal distribution of survey stations among locations (e.g., on upper slopes or valley bottom) within watersheds could bias comparison of detection rates among watersheds. We were unable to control for possible variation due to observer bias (O'Donnell 1995) because each observer generally conducted all surveys at a unique set of stations that they had established and were familiar with. Because pairs of observers often surveyed all stations within particular watersheds, it was not possible to separate possible observer biases from differences among watersheds or other associated variables. However, we think that variation among observers was unlikely to bias our results because all observers had completed RIC training and most had multi-year experience conducting surveys.

Table 4-1. Variables used in analyses relating habitat characteristics to Marbled Murrelet activity in Clayoquot Sound, British Columbia in 1995-1997. Abbreviations used in tables are given in parentheses.

Variable	Definition and units of measurement
Total detections (TODETLOG)	Total number of audio and visual detections recorded during intensive morning surveys (natural log transformed).
Detections 0-50 (R50LOG)	Number of audio and visual detections within 50 m of the survey station (natural log transformed).
Occupied detections (OCCUPLOG)	Number of occupied, visual detections, including subcanopy and circling detections (natural log transformed).
Subcanopy detections (SUBCLOG)	Number of subcanopy, visual detections (natural log transformed).
Epiphyte >10 (EPI)	Mean code for epiphyte development on the limbs of all trees >10 cm DBH in vegetation plot
Epiphyte >80 (EPILG)	Mean code for epiphyte development on the limbs of trees >80 cm DBH in vegetation plot.
Mistletoe (MTOE)	Mean code for extent of mistletoe infestation in all trees >10 cm DBH in vegetation plot.
No. of platforms (TOTPLTF)	Total number of potential nest platforms (#/900 m^2 plot).
Trees with platforms (TWPLTF)	Number of trees with at least one platform (#/900 m^2 plot).
Canopy closure (CANCL)	Tree canopy closure in 900 m^2 vegetation plots (%).
Mean DBH >10 (DBH)	Mean DBH of all trees >10 cm DBH (cm).
SD DBH >10 (DBHSD)	Standard deviation of DBH of all trees >10 cm DBH (cm).
Mean DBH >80 (DBHLG)	Mean DBH of trees >80 cm DBH (cm).
SD DBH >80 (DBHLGSD)	Standard deviation of DBH of trees >80 cm DBH (cm).
Mean height (HGTMN)	Mean height of all trees >10 cm DBH (m).
SD height (HGTSD)	Standard deviation of height of all trees >10 cm DBH (m).
Density >10 (TREE#)	Density of all trees >10 cm DBH (#/900 m^2 plot).
Density Ss >10 (SS)	Density of Sitka Spruce >10 cm DBH (#/900 m^2 plot).
Density Hw >10 (HW)	Density of Western Hemlock >10 cm DBH (#/900 m^2 plot).
Density Hm >10 (HM)	Density of Mountain Hemlock >10 cm DBH (#/900 m^2 plot).
Density Ba >10 (BA)	Density of Amabilis Fir >10 cm DBH (#/900 m^2 plot).
Density Cw >10 (CW)	Density of Western Redcedar >10 cm DBH (#/900 m^2 plot).
Density Yc >10 (YC)	Density of Yellow-cedar >10 cm DBH (#/900 m^2 plot).
Density >80 (TREE#LG)	Density of all trees >80 cm DBH (#/900 m^2 plot).
Density Ss >80 (SSLG)	Density of Sitka Spruce >80 cm DBH (#/900 m^2 plot).
Density Hw >80 (HWLG)	Density of Western Hemlock >80 cm DBH (#/900 m^2 plot).
Density Hm >80 (HMLG)	Density of Mountain Hemlock >80 cm DBH (#/900 m^2 plot).
Density Ba >80 (BALG)	Density of Amabilis Fir >80 cm DBH (#/900 m^2 plot).
Density Cw >80 (CWLG)	Density of Western Redcedar >80 cm DBH (#/900 m^2 plot).
Density Yc >80 (YCLG)	Density of Yellow-cedar >80 cm DBH (#/900 m^2 plot).
Density snags >10 (SNAG)	Density of all snags >10 cm DBH (#/900 m^2 plot).
Density snags >80 (SNAGLG)	Density of snags >80 cm DBH (#/900 m^2 plot).

We used hierarchical, Type I sum of squares (Hays 1988, Freund and Littell 1991) to determine the effects of habitat variables on detection rates after variation due to these other factors had been removed. Hierarchical analysis tests the effect of each variable after the effects of previous variables have been considered. Thus, the analysis reveals whether the habitat variables we are most interested in are related to numbers of murrelet detections after differences between stations due to other factors such as weather and date have been considered.

To analyse relationships between detection numbers and the suite of habitat characteristics measured in vegetation plots, we first determined the correlations between detection rates (natural log transformed) and each forest structural characteristic. Those forest structural characteristics significantly correlated with detection rates were then entered into a hierarchical linear model in order of the strength of their relationships to determine which variables contributed significantly to variation in numbers of detections after the effects of weather, date and opening size had been controlled. To control for possible high correlations among habitat variables (multicollinearity), pairwise Pearson correlation coefficients were calculated for all continuous variables. If $r > 0.80$ for a pair of variables, then only the variable with the strongest correlation to numbers of detections was entered in regression models.

Forest structural characteristics were compared among locations in the valley (ocean edge, valley bottom, lower slope, upper slope), subzone variants and site series within each subzone variant using one-way ANOVAs. Site series sampled with less than 3 plots were excluded from analyses comparing site series within each variant. Relationships between forest structural characteristics and topographic features were tested using hierarchical GLMs, in the same manner as detection data were analysed, entering variables in the following order: distance from the stream; elevation; distance from the sea.

We used pairwise post-hoc comparisons of adjusted means, with Bonferroni corrections for the numbers of comparisons (Hays 1988: 410), to test differences among levels of categorical variables that were shown in the overall linear model to be significantly related to the

Table 4-2. Comparisons of numbers of total, within 0-50 m, occupied, and subcanopy Marbled Murrelet detections among weather and date categories at survey stations in Clayoquot Sound, 1997. Adjusted least square means from hierarchical ANOVA are reported for date categories after differences due to weather have been considered. Mean values followed by different letters indicate significant differences between pairwise comparisons at the 0.05 level. Detection data were natural-log transformed for analyses.

	Total	0-50 m	Occupied	Subcanopy					
	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Weather									
Clear	183	19.2a	2.1	6.0a	1.1	2.4a	0.5	1.5	0.3
Cloudy	185	30.0b	2.1	10.3b	1.1	4.1b	0.5	1.9	0.3
Date									
15 May-3 June	129	13.3a	2.3	3.9a	1.2	1.3a	0.6	0.9a	0.4
8-25 June	111	23.3a	4.5	8.7b	1.3	3.3b	0.6	1.8ab	0.4
2-19 July	128	37.1b	2.3	12.0c	1.2	5.3c	0.6	2.5b	0.4

dependant variable under question. Normal post-hoc tests given in SPSS could not be used because they compare unadjusted means, rather than the adjusted means that we were interested in. We used Tukey post hoc comparisons for one-way ANOVAs where adjusted means were not a concern.

We used chi-square tests to compare frequencies of occurrence of potential predators among edge and forest stations, and in fragmented and unfragmented forest stands. We did not consider numbers of a particular predator species that were recorded, but simply coded the species as occurring during a survey if one or more were observed during the 2-h survey period. Thus, frequencies compared in chi-square tests were the number of surveys during which the predator species in question was either observed or not observed.

Tolerance for Type I error was set at $P < 0.05$ for all tests. Least squares means for each variable, adjusted for terms that precede it in hierarchical models, are reported ± 1 SE in all tables and text. Raw, unadjusted data are plotted in all figures.

Results

Nuisance Variables Affecting Marbled Murrelet Activity Measures: Weather, Date, Opening Size and Creek Noise

Hierarchical analyses showed that detection numbers were significantly affected by weather, survey date and opening size. Numbers of total detections, detections within 50 m and occupied detections were higher in cloudy than in clear weather (Ps < 0.01; Table 4-2). All detection measures differed significantly among date categories, increasing as the season progressed (Ps < 0.001; Table 4-2). Total detections and detections within 50 m increased with increasing opening size (Ps < 0.01). However, exploratory analysis showed that opening size had the greatest effect on detection rates at elevations between 20 and 60 m in the valley bottom. Within those elevations, opening size significantly affected within 50 m ($r^2 = 0.07$, $P = 0.021$), occupied ($r^2 = 0.15$, $P < 0.001$) and subcanopy ($r^2 = 0.18$, $P < 0.001$) detections. Creek noise was also considered as a nuisance variable because it was hypothesised that increased levels of creek noise would decrease total numbers of detections because of auditory limitations. However, creek noise did not have a significant effect on total detections after variance due to weather, date and opening size was removed ($P = 0.30$). Interestingly, creek noise was significantly related to within 50 m, occupied and subcanopy detections, but trends were the reverse of predictions, increasing with increasing creek noise. We concluded that the effect of creek noise was an artifact, representing placement on and off the stream more than the level of creek noise per se, and it was thus dropped as a variable for subsequent analyses.

Relationships Between Marbled Murrelet Activity and Forest Structural Characteristics

Correlations between Marbled Murrelet detection rates (natural log transformed) and forest structural characteristics are presented in Table 4-3. Those forest structural characteristics significantly correlated with detection rates were entered into a hierarchical linear model in order of the strength of their relationships. To control for potentially high correlations between variables in linear models (multicollinearity) we examined the correlations between all pairs of habitat variables. Only one pair of variables, density of mountain hemlock (*Tsuga mertensiana*) and density of yellow-cedar (*Chamaecyparis nootkatensis*) had a correlation higher than 0.80. We thus excluded density of mountain hemlock from linear models because density of yellow-cedar was more highly correlated to numbers of detections than density of mountain hemlock.

Hierarchical models indicated that density of trees with platforms, of large trees and of large amabilis fir (*Abies amabilis*) were the main predictors of detection numbers after the effects of weather, date and opening size were controlled. Density of trees with platforms was positively related to total ($r^2 = 0.01$, $P = 0.025$), within

Table 4-3. Correlation matrix for numbers of Marbled Murrelet detections (natural-log transformed) recorded at survey stations and habitat variables measured in adjacent 30x30-m vegetation plots in Clayoquot Sound, 1997. See Table 4-1 for full variable names and definitions.

	TODETLOG	R50LOG	OCCUPLOG	SUBCLOG
TODETLOG	1.000	.648**	.561**	.398**
R50LOG	.648**	1.000	.843**	.689**
OCCUPLOG	.561**	.843**	1.000	.826**
SUBCLOG	.398**	.689**	.826**	1.000
BA	.037	.227**	.176**	.219**
BALG	.063	.243**	.213**	.238**
CANCL	-.056	.051	.128*	.200**
CW	.119*	-.067	-.067	-.088
CWLG	.032	.063	.043	.044
DBH	-.045	.185**	.195**	.193**
DBHSD	-.049	.168**	.184**	.158**
DBHLG	.106	.103	.049	-.016
DBHLGSD	.079	-.006	.021	-.054
EPI	-.046	.215**	.211**	.240**
EPILG	-.053	.167**	.167**	.188**
HGTMN	-.056	.071	.072	.159*
HGTSD	-.050	.115*	.131*	.219**
HM	.129*	-.106	-.110*	-.208**
HMLG	-.091	-.107*	-.116*	-.092
HW	-.005	-.085	-.108*	-.025
HWLG	-.009	.081	.110*	.128*
MTOE	.016	-.004	-.060	-.029
SNAG	.111*	-.007	-.046	-.062
SNAGLG	.050	.174**	.139*	.158**
SS	-.208**	-.110*	-.055	-.019
SSLG	-.130*	-.005	.051	.069
TOTPLTF	.092	.211**	.199**	.236**
TWPLTF	.083	.223**	.208**	.211**
TREE#	.170**	.053	-.026	-.059
TREE#LG	.008	.258**	.248**	.274**
YC	.170**	-.032	-.088	-.222**
YCLG	.022	-.047	-.094	-.156**

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

50 m ($r^2 = 0.04$, $P < 0.001$), occupied ($r^2 = 0.05$, $P < 0.001$) and subcanopy ($r^2 = 0.04$, $P < 0.001$) detections. Density of large trees was positively related to within 50 m ($r^2 = 0.03$, $P < 0.001$), occupied ($r^2 = 0.03$, $P < 0.001$) and subcanopy ($r^2 = 0.04$, $P < 0.001$) detections. Density of large amabilis fir also was positively related to within 50 m ($r^2 = 0.02$, $P = 0.005$), occupied ($r^2 = 0.01$, $P = 0.034$) and subcanopy ($r^2 = 0.01$, $P = 0.033$) detections. In addition, total detections were positively related to numbers of yellow-cedar ($r^2 = 0.03$, $P = 0.001$) and density of all trees ($r^2 = 0.01$, $P = 0.017$), and were negatively related to mean epiphyte cover ($r^2 = 0.01$, $P = 0.035$), numbers of large mountain hemlock ($r^2 = 0.02$, $P = 0.007$) and density of Sitka spruce (*Picea sitchensis*; $r^2 = 0.03$, $P < 0.001$). Detections within 50 m were negatively related to numbers of yellow-cedar ($r^2 = 0.01$, $P = 0.019$) and large mountain hemlock ($r^2 = 0.02$, $P = 0.012$), and were positively related to the standard deviation of mean tree height ($r^2 = 0.02$, $P = 0.008$). Occupied detections were negatively related to large mountain hemlock ($r^2 = 0.01$, $P = 0.023$) and to all western hemlock (*Tsuga heterophylla*; $r^2 = 0.01$, $P = 0.038$). Subcanopy detections were positively related to numbers of large snags ($r^2 = 0.01$, $P = 0.041$).

Density of trees with platforms, density of large trees and mean DBH of all trees were the main predictors of, and positively related to, occupied and subcanopy detections if combined data for stations surveyed in both 1996 and 1997 were considered (Ps < 0.05). Subcanopy detections also were positively related to mean tree height. Total detections were positively related to density of yellow-cedar and mean tree height at stations surveyed in both years (Ps < 0.05).

Forest Structural Characteristics and Murrelet Activity in Relation to Topographic Features

Distance from Major Stream Channels, Elevation and Distance from the Sea

Mean DBH of all trees, epiphyte cover on all trees and on large trees, density of large trees, canopy closure, total platforms and density of trees with platforms significantly declined with increasing distance from the stream (Figure 4-8). Mean DBH of all trees and of large trees, epiphyte cover on all trees, and mistletoe declined with increasing elevation (Figure 4-9). Density of trees with platforms also was negatively related to elevation, but the trend was better described with a quadratic equation, with highest density of trees with platforms occurring at intermediate elevations. Density of all trees in the plot was positively related to elevation and data were best fit with a quadratic model. Intermediate elevations had highest numbers of trees per plot (Figure 4-9). Canopy closure was negatively related to distance from the sea (Figure 4-10). Mean epiphyte cover showed an overall negative relationship to distance from the sea, but greatest epiphyte cover was recorded at intermediate distances from the sea, and the relationship was best fit with a quadratic model. Total platforms showed an overall positive trend with distance from the sea, but again the relationship was better described with a quadratic term, showing that numbers of platforms were highest at intermediate distances. Density of large trees significantly increased with greater distance from the sea, but the trend appeared to be driven by a few large outliers. When unadjusted means were plotted, no trend was evident (Figure 4-10).

Total, within 50 m, occupied and subcanopy detections were not significantly related to distance from major stream channels (Ps > 0.1) after effects of weather, date, opening size and station placement on or off stream channels had been removed. High numbers of occupied and subcanopy detections occurred along stream channels (see below), and once differences due to station placement on and off stream channels were accounted for, no trends with increasing distance from streams were apparent. All detection measures varied

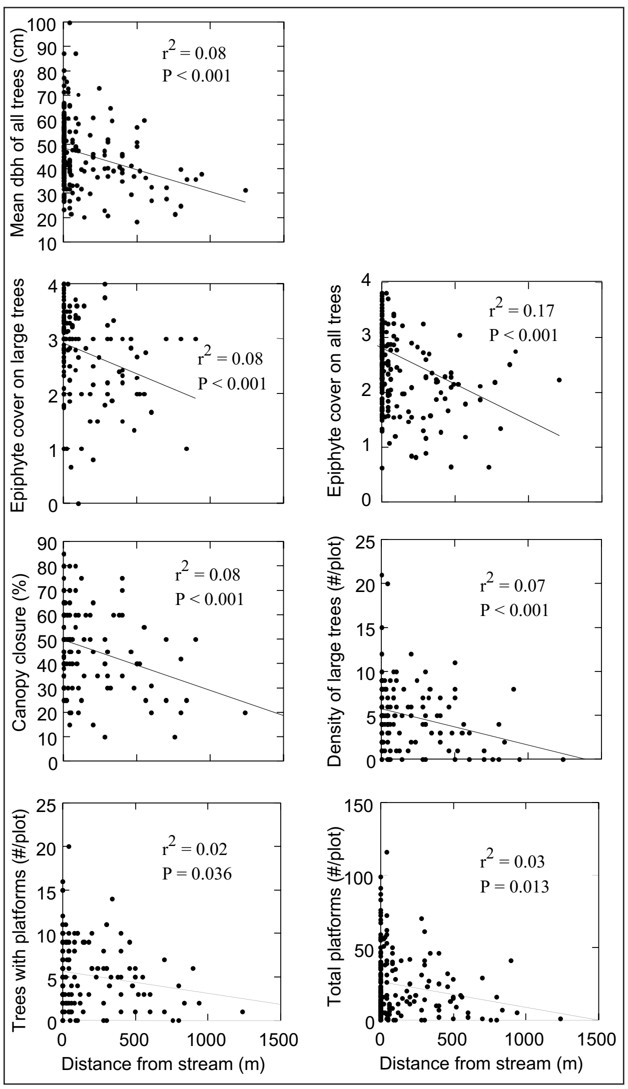

Figure 4-8. Significant relationships between forest structural characteristics measured in 30x30 m vegetation plots and distance from major streams in Clayoquot Sound, 1995-97.

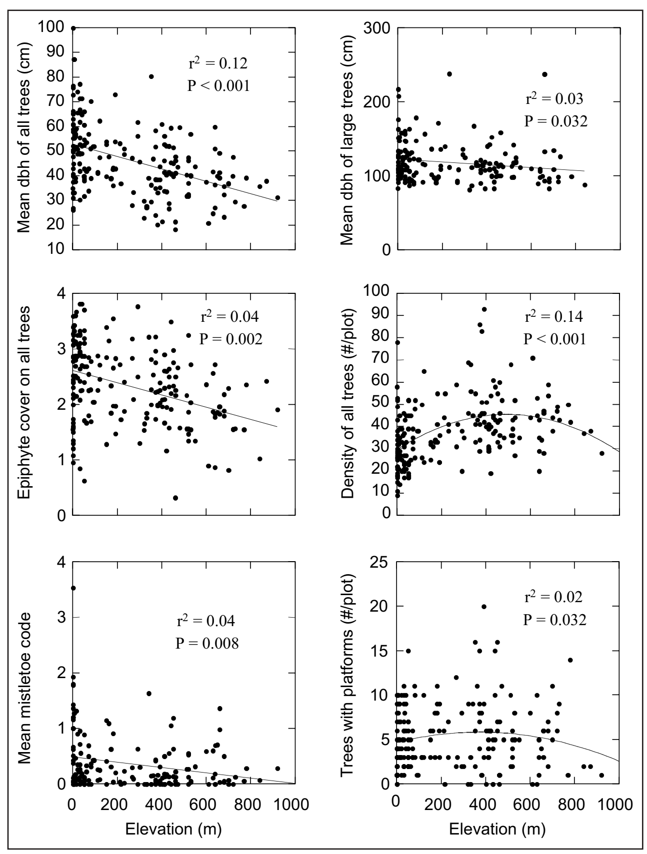

Figure 4-9. Significant relationships between forest structural characteristics measured in 30x30 m vegetation plots and elevation in Clayoquot Sound, 1995-97.

Table 4-4. Comparison of forest structural characteristics measured in 30x30-m vegetation plots among location categories (ocean edge, valley bottom, lower slope, upper slope) in Clayoquot Sound, 1995-97. Mean values followed by different letters indicate significant differences between pairwise comparisons at the 0.05 level. See Table 4-1 for full variable names and definitions.

	Ocean edge	Valley bottom	Lower slope	Upper slope								
	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE
DBH	20	50.9a	4.3	112	49.6a	1.2	43	41.5b	2.1	23	37.9b	1.8
DBHLG	18	124.7	8.1	109	117.9	2.4	37	118.5	3.6	18	110.6	8.2
EPI	20	2.1a	0.2	112	2.7b	0.1	43	2.0a	0.1	23	1.8a	0.1
EPILG	19	2.7ab	0.2	109	3.0a	0.1	37	2.4b	0.1	18	2.6b	0.2
TREE#	20	33.6ad	3.9	112	34.6a	1.1	43	44.3bc	2.6	23	43.2bd	2.1
TREE#LG	20	4.8ab	0.5	112	5.8a	0.3	43	4.9ab	0.6	23	3.4b	0.6
MTOE	15	1.0a	0.2	100	0.3b	0.0	35	0.3b	0.1	21	0.3b	0.1
TOTPLTF	20	12.7	3.5	112	26.3	2.1	43	23.0	3.5	23	20.7	3.7
TWPLTF	20	3.0a	0.6	112	5.5b	0.3	43	5.6b	0.6	23	5.2ab	0.7
CANCL	18	54.9a	3.6	109	50.9a	1.5	37	40.7b	2.6	21	40.1b	15.3

significantly with elevation, in a manner best fit with quadratic models (Figure 4-11). Detection rates increased from 0 to 50 m, were high at middle elevations, and declined at elevations higher than about 500-600 m. Total, within 50, occupied and subcanopy detections varied positively with distance from the sea, after weather, date, opening size and station placement had been considered (Figure 4-12).

Location in the Valley

We found significant differences among location categories (ocean edge, valley bottom on stream, valley bottom in forest, lower slope, upper slope) for mean DBH ($r^2 = 0.11$, $P < 0.001$), epiphyte cover on all trees ($r^2 = 0.25$, $P < 0.001$), epiphyte cover on large trees ($r^2 = 0.14$, $P < 0.001$), density of all trees ($r^2 = 0.10$, $P < 0.001$), density of large trees ($r^2 = 0.05$, $P = 0.013$), mistletoe ($r^2 = 0.17$, $P < 0.001$), canopy closure ($r^2 = 0.10$, $P < 0.001$) and density of trees with platforms ($r^2 = 0.04$, $P = 0.040$). Mean DBH of large trees and total number of platforms per plot did not vary significantly with location (Ps > 0.05).

Mean DBH was greater at the ocean edge and in the valley bottom than on lower and upper slopes (Table 4-4). Mean epiphyte cover of all trees and of large trees was greater in the valley bottom than on upper and lower slopes. Epiphyte cover of all trees was also greater in the valley bottom than at the ocean edge. Density of live trees was significantly lower in the valley bottom than on lower and upper slopes, and significantly lower at the ocean edge than on lower slopes. Density of trees >80 cm DBH was greater in the valley bottom than on

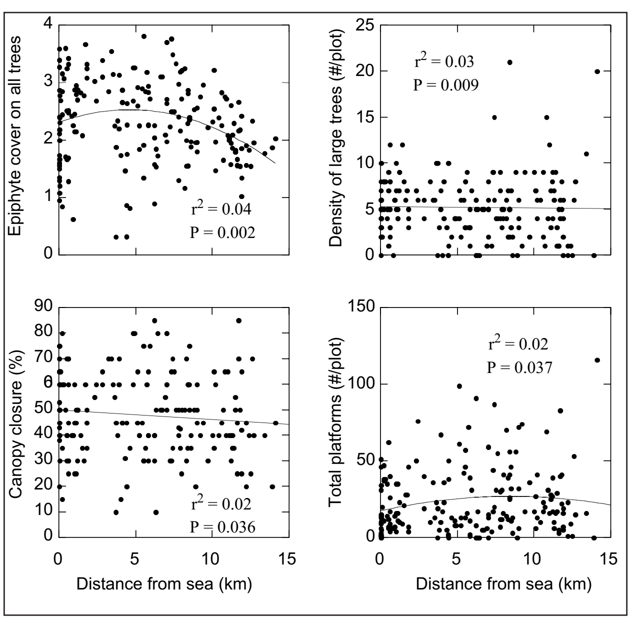

Figure 4-10. Significant relationships between forest structural characteristics measured in 30x30 m vegetation plots and distance from the sea in Clayoquot Sound, 1995-97.

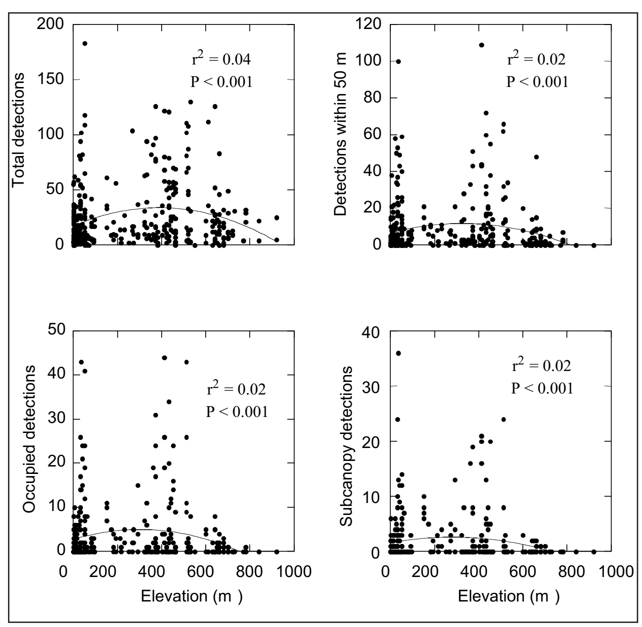

Figure 4-11. Relationships between numbers of Marbled Murrelet detections per survey and elevation in Clayoquot Sound, 1997.

Table 4-5. Comparisons of numbers of total, within 0-50 m, occupied, and subcanopy Marbled Murrelet detections among locations, subzone variants, and logging categories at survey stations in Clayoquot Sound, 1997. Adjusted least square means from hierarchical ANCOVA are reported after differences due to weather, date, opening size and, for subzone variant, station placement have been considered. Mean values followed by different letters indicate significant differences between pairwise comparisons at the 0.05 level. Detection data were natural-log transformed for analyses.

	Total	0-50 m	Occupied	Subcanopy					
	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Location									
Ocean edge	29	14.3	5.3	3.2a	2.9	0.0a	1.3	0.1a	0.8
Valley bottom									
On stream	188	23.1	1.9	11.1b	1.0	5.0b	0.5	2.9b	0.3
Off stream	34	22.4	4.5	5.1a	2.4	1.9a	1.1	1.1a	0.7
Lower slope	61	34.1	3.3	6.6a	1.8	2.4a	0.8	0.5a	0.5
Upper slope	56	24.7	3.5	4.1a	1.9	1.2a	0.9	0.2a	0.5
Variant									
vh1	73	10.2a	3.1	2.6a	1.7	0.6a	0.8	0.5	0.5
vm1	225	26.3b	2.3	8.4b	1.2	3.1b	0.6	1.7	0.4
vm2	68	28.4b	3.2	8.2b	1.7	3.0ab	0.8	1.1	0.5
Logging									
Unfragmented	326	26.0a	1.4	8.8a	0.8	3.6a	0.4	1.8a	0.2
Fragmented	42	13.0b	4.3	3.4b	2.3	0.7b	1.1	0.6b	0.7

the upper slope. Vegetation plots near the ocean edge had higher mean values for mistletoe than plots on the valley bottom and on upper and lower slopes. Canopy closure was significantly higher on the valley bottom and at the ocean edge than on lower and upper slopes. Density of trees with potential nesting platforms was greater in valley bottom and lower slope than at ocean edge plots (Table 4-4).

Numbers of detections within 50 m ($r^2 = 0.07$, $P < 0.001$), occupied detections ($r^2 = 0.11$, $P < 0.001$) and subcanopy detections ($r^2 = 0.15$, $P < 0.001$) varied significantly across locations (i.e., ocean edge, valley bottom on stream, valley bottom in forest, lower slope, upper slope) after effects of weather, date and opening size had been considered. Differences within location were due to significantly higher detection rates recorded at on-stream survey stations than at all other locations (Table 4-5).

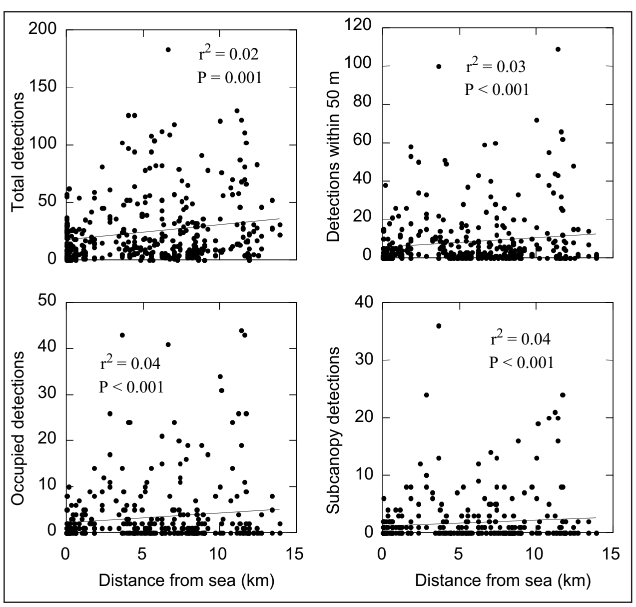

Figure 4-12. Relationships between numbers of Marbled Murrelet detections per survey and distance from the sea in Clayoquot Sound, 1997.

Known nest predators, Common Ravens and Steller's Jays, were recorded during 28%, 13% and 9% of survey at stations located at ocean edge, on stream channels and in forest, respectively ($X_2^2 = 7.33$, $P = 0.026$). They were significantly more frequent at ocean edge than at forest stations ($X_1^2 = 7.51$, $P = 0.006$). Frequencies at stream channel and forest stations were not significantly different ($X_1^2 = 1.28$, $P = 0.257$). Differences in frequency of occurrence among locations did not reach significance when each species was considered separately (Steller's Jays: $X_2^2 = 4.91$, $P = 0.086$; Common Ravens: $X_2^2 = 5.43$, $P = 0.066$; Table 4-6).

Occurrence of Northwestern Crows ($X_2^2 = 107.04$, $P < 0.001$) and Bald Eagles ($X_2^2 = 45.95$, $P < 0.001$) also differed among locations (Table 4-6). Crows were reported during a greater proportion of surveys at the ocean edge than in the forest ($X_1^2 = 90.95$, $P < 0.001$) and on the stream channel than in the forest ($X_1^2 = 6.67$, $P = 0.010$). Similarly, Bald Eagles were reported during a greater proportion of surveys at the ocean edge than in the forest ($X_1^2 = 51.73$, $P < 0.001$) and on the stream than in the forest ($X_1^2 = 11.84$, $P < 0.001$). No significant relationship between the occurrence of

Table 4-6. Comparison of percentage of surveys during which potential Marbled Murrelet predators were recorded at ocean edge, on stream channel and forest station locations, and in partially logged and unlogged areas in Clayoquot Sound in 1997.

	Number of surveys	Steller's Jay	Common Raven	Northwestern Crow	Bald Eagle	Red Squirrel
Location						
Ocean edge	29	21	14	66	48	17
Stream channel	188	11	5	9	14	12
Forest	150	7	3	2	3	13
Logging						
Fragmented	42	26	2	29	14	2
Unfragmented	326	8	6	8	12	14

Table 4-7. Comparisons of numbers of total, within 0-50 m, occupied, and subcanopy Marbled Murrelet detections among watersheds at survey stations in Clayoquot Sound, 1997. Adjusted least square means from hierarchical ANCOVA are reported after differences due to weather, date, opening size and location have been considered. Mean values followed by different letters indicate significant differences between pairwise comparisons among watersheds at the 0.05 level. Detection data were natural-log transformed for analyses. Only watersheds sampled more than 5 times were included in statistical comparisons.

Total	0-50 m	Occupied	Subcanopy						
Watershed	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Bawden	6	24.4ad	10.3	9.2acd	5.6	2.6ab	2.6	0.8a	1.6
Bulson	59	32.3a	3.4	12.3ad	1.8	5.1b	0.9	2.9a	0.5
Cypre	9	0.1b	8.4	0.6bc	4.6	0.3ab	2.1	0.2a	1.3
Flores #6	26	32.8a	5.0	9.2d	2.7	2.9b	1.3	0.8a	0.8
Flores Cow Bay	26	8.4bc	5.0	0.8b	2.7	0.6a	1.3	0.4a	0.8
Hesquiat Point	15	16.2ac	6.8	6.2acd	3.7	3.1ab	1.7	2.1a	1.1
Pretty Girl	7	16.4ac	9.7	8.1abcd	5.3	1.0ab	2.5	0.5a	1.5
Sydney	57	15.5cd	3.5	8.3acd	1.9	2.8ab	0.9	1.8a	0.5
Tranquil	44	31.9a	3.9	7.3acd	2.1	2.1ab	1.0	0.6a	0.6
Ursus	94	31.7a	2.7	7.3c	1.4	3.3ab	0.7	1.3a	0.4

squirrels and station placement was found ($X_2^2 = 0.71$, $P = 0.702$).

Watershed

Watersheds sampled with less than 6 surveys in 1997 were excluded from analyses comparing watersheds. Total ($r^2 = 0.18$, $P < 0.001$), within 50 m ($r^2 = 0.15$, $P < 0.001$), occupied ($r^2 = 0.09$, $P < 0.001$) and subcanopy ($r^2 = 0.07$, $P = 0.001$) detections varied significantly among watersheds after variance due to date, weather, opening size and location had been removed. Bulson Creek had highest and Cypre had lowest adjusted means for all measures of detection rates (Table 4-7). Pairwise comparisons among watersheds showed that total detections did not differ among Bulson, Flores #6, Tranquil and Ursus, and these watersheds had significantly higher numbers of total detections than Cypre, Flores Cow Bay and Sydney. Total detections also were higher at Bawden than Cypre and Flores Cow Bay, and at Hesquiat Point, Pretty Girl and Sydney than Cypre. Numbers of detections within 50 m were higher in Bulson and Flores #6 than in Cypre, Flores Cow Bay and Ursus, and in Bawden, Hesquiat Point, Sydney and Tranquil than Flores Cow Bay. For occupied detections, Bulson and Flores #6 had higher numbers than Flores Cow Bay. Although the overall test showed significant variation in subcanopy detections among watersheds, pairwise comparisons among individual watersheds were not significant (Table 4-7).

We used the combined data from 1996 and 1997 to compare activity levels among Flores Island watersheds because mostly different watersheds were surveyed there in 1996 and 1997. Comparisons across years were likely unbiased because no significance differences in total ($r^2 = 0.05$, $P = 0.171$), occupied ($r^2 = 0.01$, $P = 0.500$) and subcanopy ($r^2 = 0.08$, $P = 0.101$) detections were found between years at stations surveyed in both 1996 and 1997 on Flores #6, after effects of weather and date had been considered. Significant differences were found among Flores watersheds for total ($r^2 = 0.26$, $P < 0.001$), occupied ($r^2 = 0.29$, $P < 0.001$) and subcanopy ($r^2 = 0.21$, $P < 0.001$) detections, after differences due to weather, date, year and location were controlled. Flores #6 had higher occupied detections than Flores #9, Hootla Kootla and Cow Bay and higher subcanopy detections than Flores #9 (Table 4-8). Cow Bay had lower total detections than Flores #6, Flores #9, Hootla Kootla and Flores North. Although detections on Riley Creek were not significantly different from other

Table 4-8. Comparison of total, occupied and subcanopy Marbled Murrelet detections among watersheds on Flores Island in Clayoquot Sound in 1996 and 1997. Adjusted least square means from hierarchical ANOVA are reported for watersheds after differences due to weather, date, year and location have been considered. Mean values followed by different letters indicate significant differences between pairwise comparisons at the 0.05 level.

	Total	Occupied	Subcanopy				
	N	Mean	SE	Mean	SE	Mean	SE
Flores #6	51	30.3a	2.5	3.0a	0.5	1.5a	0.3
Flores #9	15	27.0a	4.8	0.5b	1.1	0.2b	0.6
Flores Cow Bay	26	4.6b	3.5	0.4b	0.8	0.4ab	0.5
Flores Hootla Kootla	7	16.5a	6.6	0.0b	1.4	0.0ab	0.9
Flores North	4	20.2a	8.6	0.8ab	1.9	0.0ab	1.1
Flores Riley Creek	2	15.0ab	12.1	2.5ab	2.6	1.0ab	1.6

Table 4-9. Comparison of forest structural characteristics measured in 30x30-m vegetation plots among biogeoclimatic subzone variants (Green and Klinka 1994) in Clayoquot Sound, 1995-97. Mean values followed by different letters indicate significant differences between pairwise comparisons at the 0.05 level. See Table 4-1 for full variable names and definitions.

	CWHvh1	CWHvm1	CWHvm2						
	N	Mean	SE	N	Mean	SE	N	Mean	SE
DBH	39	53.5a	2.4	131	46.4b	1.2	28	37.8c	1.8
DBHLG	37	126.5a	4.5	122	116.9ab	2.2	23	109.8b	6.5
EPI	39	2.2a	0.1	131	2.5a	0.1	28	1.8b	0.1
EPILG	38	2.7ab	0.1	122	2.9a	0.1	23	2.4b	0.2
TREE#	39	29.9a	2.1	131	39.0b	1.2	28	42.2b	2.0
TREE#LG	39	5.4a	0.4	131	5.5a	0.3	28	3.5b	0.6
MTOE	38	0.6a	0.1	107	0.3b	0.0	26	0.3b	0.1
TOTPLTF	39	19.6	2.8	131	25.5	2.1	28	19.9	3.2
TWPLTF	39	4.8	0.5	131	5.4	0.3	28	4.9	0.7
CANCL	39	45.9ab	2.7	120	50.7a	1.5	26	39.1b	12.7

watersheds, occupied and subcanopy detections at Riley Creek were high, and small sample size probably prevented differences from reaching significance (Table 4-8).

Forest Structural Characteristics and Murrelet Activity in Relation to Habitat Categories

Biogeoclimatic Subzone Variants

Significant differences among subzone variants CWHvh1, CWHvm1 and CWHvm2 were found for mean DBH ($r^2 = 0.10$, $P < 0.001$), DBH of large trees ($r^2 = 0.03$, $P = 0.042$), epiphyte cover on all trees ($r^2 = 0.11$, $P < 0.001$), epiphyte cover on large trees ($r^2 = 0.06$, $P = 0.003$), density of all trees ($r^2 = 0.08$, $P < 0.001$), density of large trees ($r^2 = 0.04$, $P = 0.012$), mistletoe ($r^2 = 0.08$, $P = 0.001$) and canopy closure ($r^2 = 0.06$, $P = 0.003$). Total platforms per plot and density of trees with platforms did not vary significantly among variants (Ps > 0.05).

Vegetation plots in vm1 had greater DBH of all trees, greater epiphyte cover on all and on large trees, greater numbers of large trees and greater canopy closure than those in vm2 (Table 4-9). Vh1 vegetation plots had greater DBH of all trees, fewer total trees and more mistletoe than vm1 and vm2, and greater DBH of large trees, greater epiphyte cover of all trees and greater numbers of large trees than vm2.

All measures of detection rates differed significantly among subzone variants ($P_s < 0.001$) and vm1 had higher detection rates for within 50 m, occupied and subcanopy detections than vm2 ($P_s < 0.05$), after differences due to weather, date and opening size had been considered. However, we were concerned that differences in detection rates between vm1 and vm2 might be due to the fact that most survey stations in variant vm1 were placed on stream channels (64%, $n = 225$) while most stations in vm2 were placed in the forest (91%, $n = 68$). Our analysis of detection rates in relation to valley location had shown that greater numbers of detections occurred at valley-bottom, stream channel stations than at all other locations. Because subzone variant vm1 in Clayoquot Sound includes most of the valley-bottom habitat away from stream channels, as well as slope habitat up to about 600 m elevation (Green and Klinka 1994), we wanted to know whether detection rates differed between vm1 and vm2 habitat beyond the difference already found between stream channel stations in the valley bottom and all other locations. We thus removed the effect of being on or off stream channels by including station placement in hierarchical models to test differences among subzone variants.

Table 4-10. Comparison of forest structural characteristics measured in 30x30-m vegetation plots among site series within variant CWHvh1 (Green and Klinka 1994) in Clayoquot Sound, 1995-97. Mean values followed by different letters indicate significant differences between pairwise comparisons among site series at the 0.05 level. Site series sampled with <3 vegetation plots were excluded from statistical comparisons. See Table 4-1 for full variable names and definitions.

	Site Series													
	01 (N = 8)		03 (N = 3)		05 (N = 4)		06 (N = 3)		07 (N = 6)		08 (N = 4)		11 (N = 8)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
DBH	49.8	2.9	36.6	5.3	53.1	5.9	49.6	5.7	54.5	6.2	52.7	7.1	59.4	6.3
DBHLG	131.3	11.0	100.5	8.0	132.2	7.1	113.0	11.1	123.6	6.3	111.3	8.0	138.2	10.9
EPI	1.8ad	0.2	1.0ab	0.3	2.5cd	0.3	2.7cd	0.2	2.2cd	0.2	2.9c	0.2	2.4cd	0.2
EPILG	2.0ad	0.3	1.3ab	0.4	3.0cd	0.0	3.6c	0.2	3.0c	0.2	3.1cd	0.1	2.8cd	0.2
TREE#	30.0a	4.8	58.7b	9.8	30.0a	4.6	33.0ab	6.0	25.3a	3.6	22.0a	8.5	27.1a	1.3
TREE#LG	4.4	0.3	4.3	1.2	5.5	1.3	6.0	1.2	6.3	0.5	4.8	1.1	6.4	1.4
MTOE	0.8	0.2	0.1	0.1	0.6	0.2	0.5	0.2	1.0	0.3	0.2	0.2	0.6	0.2
TOTPLTF	11.4	2.9	8.7	3.9	19.3	6.6	41.3	19.1	23.2	9.6	27.5	8.3	18.0	5.4
TWPLTF	2.5a	0.3	5.3ab	2.6	6.3ab	1.9	9.7b	3.2	3.8ab	1.3	5.5ab	0.3	5.4ab	1.0
CANCL	34.8a	3.5	25.0a	7.6	62.5b	9.5	60.0ab	0.0	45.5ab	6.7	55.0ab	8.4	42.5ab	5.2

Total ($r^2 = 0.07$, $P < 0.001$), within 50 m ($r^2 = 0.03$, $P = 0.001$) and occupied ($r^2 = 0.01$, $P = 0.039$) detections differed significantly among variants after effects of date, weather, opening size and placement were removed. Vm1 and vm2 had higher detection rates than vh1; no difference was found between detection rates in vm1 and vm2 habitat (Table 4-5). Although differences between variants in subcanopy detections did not attain significance ($P = 0.086$), a similar pattern in means was observed, in which vh1 stations had fewer subcanopy detections than vm1 and vm2 (Table 4-5). The same pattern emerged if, instead of statistically removing the effect of greater station placement on stream channels in vm1 variant, we considered only survey stations placed in the forest for all variants. In this case only total detections varied significantly by variant ($r^2 = 0.08$, $P = 0.001$), with vh1 again having lower total detections than vm1 and vm2, and with no significant differences between vm1 and vm2 habitat.

Data from Flores #6 watershed suggested a different trend. Flores #6 was the only area with adequate samples distributed in both vh1 ($N = 25$ surveys) and vm1 ($N = 22$ surveys) subzones in the same watershed. Data from 1996 and 1997 indicated similar numbers of occupied detections in vh1 (3.7 ± 1.1 [SE]) and vm1 (3.2 ± 0.5) subzones, and higher numbers of subcanopy detections in vh1 (2.8 ± 0.8) than vm1 (1.1 ± 0.2).

Site Series

Site series was analysed separately for each subzone variant. Within subzone variant CWHvh1, sample sizes were >2 for site series 01, 03, 05, 06, 07, 08 and 11. Epiphyte cover on all ($r^2 = 0.54$, $P = 0.001$) and on large trees ($r^2 = 0.60$, $P < 0.001$), tree density ($r^2 = 0.49$, $P = 0.002$), density of trees with platforms ($r^2 = 0.34$, $P = 0.047$) and canopy closure ($r^2 = 0.43$, $P = 0.008$) varied significantly among those site series. Site series 01 and 03 had least epiphyte development on all trees and large trees (Table 4-10). Site series 01 had less epiphyte development on all trees than site series 08, and less on large trees than site series 06 and 07. Site series 03 had less epiphyte development on all and on large trees than site series 05, 06, 07, 08 and 11. Tree density was greater in site series 03 than all other site series except 06. Site series 06 had a higher density of trees with platforms than 01, and site series 05 had higher canopy closure than 01 and 03.

Within subzone variant CWHvm1, sample sizes were >2 for site series 01, 03, 05, 06, 07 and 09. Mean DBH of all trees ($r^2 = 0.33$, $P < 0.001$), epiphyte cover of all trees ($r^2 = 0.30$, $P < 0.001$) and of large trees ($r^2 = 0.33$, $P < 0.001$), density of live trees ($r^2 = 0.34$, $P < 0.001$) and of large trees ($r^2 = 0.16$, $P = 0.006$), total number of platforms ($r^2 = 0.15$, $P = 0.003$) and canopy closure ($r^2 = 0.12$, $P = 0.018$) varied significantly among those site series. Site series 03 had lowest mean DBH of all site series, significantly lower than site series 01, 05, 06, 07 and 09, and site series 09 had higher mean DBH than all other site series (Table 4-11). Site series 09 had higher epiphyte development on all trees than all other site series, and higher epiphyte development on large trees than site series 03 and 06. Site series 03 and 06 had poorest epiphyte development on all trees and on large trees. Site series 03 had higher density of live trees than all other site series except 06, and lower density of large trees than all site series except 01. Site series 03 also had lower canopy closure than site series 09 and 01. Site series 07 and 09 had lower density of all trees than 03 and 06; site series 03 had lower density of large trees than 05, 06, 07 and 09. Site series 09 had higher

Table 4-11. Comparison of forest structural characteristics measured in 30x30-m vegetation plots among site series within variant CWHvm1 (Green and Klinka 1994) in Clayoquot Sound, 1995-97. Mean values followed by different letters indicate significant differences between pairwise comparisons among site series at the 0.05 level. Site series sampled with <3 vegetation plots were excluded from statistical comparisons. See Table 4-1 for full variable names and definitions.

	Site Series											
	01 (N = 15)		03 (N = 8)		05 (N = 19)		06 (N = 29)		07 (N = 27)		09 (N = 19)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
DBH	47.3a	2.8	29.0b	3.5	49.0a	2.3	41.9a	1.8	47.8a	2.1	59.5c	3.2
DBHLG	115.6	5.9	88.5	3.4	115.4	3.7	120.4	4.6	116.3	5.9	125.3	6.1
EPI	2.6ab	0.2	2.0a	0.2	2.7b	0.1	2.2a	0.1	2.6ab	0.1	3.2c	0.1
EPILG	3.0bcd	0.2	1.8a	0.5	3.3d	0.1	2.6ac	0.1	3.0d	0.1	3.4bd	0.1
TREE#	37.1ad	3.1	59.1bc	7.6	36.6ad	2.2	46.3cd	2.4	33.4a	1.9	28.1a	2.2
TREE#LG	5.0ab	0.3	1.1a	0.5	6.6b	1.0	5.7b	0.8	6.1b	0.7	6.5b	0.6
MTOE	0.6	0.2	0.2	0.1	0.3	0.1	0.4	0.2	0.3	0.1	0.2	0.1
TOTPLTF	30.1ab	5.7	7.0a	3.0	28.2ab	6.4	24.1ab	4.6	17.1a	3.1	41.5b	5.6
TWPLTF	5.9	0.7	3.3	1.3	5.6	1.0	6.2	0.9	4.4	0.7	5.9	0.7
CANCL	60.0a	4.0	34.3b	6.4	50.0ab	3.4	49.9ab	2.8	51.1ab	2.6	53.8a	4.0

Table 4-12. Comparison of forest structural characteristics measured in 30x30-m vegetation plots among site series within variant CWHvm2 (Green and Klinka 1994) in Clayoquot Sound, 1995-97. Mean values followed by different letters indicate significant differences between pairwise comparisons among site series at the 0.05 level. Site series sampled with <3 vegetation plots were excluded from statistical comparisons. See Table 4-1 for full variable names and definitions.

	Site Series					
	01 (N = 7)		06 (N = 4)		09 (N = 7)	
	Mean	SE	Mean	SE	Mean	SE
DBH	37.5	2.9	38.3	5.7	33.6	1.4
DBHLG	106.8	5.4	100.4	4.5	94.0	2.8
EPI	1.7	0.2	2.0	0.1	1.8	0.2
EPILG	2.8	0.1	2.7	0.2	2.0	0.5
TREE#	40.9	3.4	41.5	6.7	42.6	2.7
TREE#LG	4.6ab	1.2	6.5a	1.9	1.7b	0.5
MTOE	0.3	0.1	0.2	0.1	0.1	0.0
TOTPLTF	24.6	6.1	23.3	5.1	15.6	6.2
TWPLTF	6.3	1.3	5.3	1.3	4.4	1.8
CANCL	42.4	5.9	43.8	2.4	33.6	5.6

numbers of total platforms than site series 03 and 07 (Table 4-11).

Within subzone variant CWHvm2, sample sizes were >2 for site series 01, 06 and 09. Number of large trees per plot was the only forest structural characteristic that varied significantly among site series in vm2 (r^2 = 0.37, P = 0.033). Site series 06 had more large trees per plot than site series 09 (Table 4-12).

Within CWHvh1, site series was significantly related to total (r^2 = 0.27, P = 0.009), within 50 m (r^2 = 0.31, P = 0.018) and occupied (r^2 = 0.27, P = 0.040) detections, but not to subcanopy detections (r^2 = 0.23, P = 0.117), after the effects of weather, date, opening size and placement had been removed. Post-hoc, pairwise comparisons were significant for total detections only: higher total detections were recorded in site series 01 (15.9 ± 3.3) and 11 (19.4 ± 3.4) than in 08 (3.7 ± 3.5).

Within CWHvm1, site series was significantly related to total detections only (r^2 = 0.07, P = 0.037). Post-hoc, paired comparisons among individual site series were not significant. No significant differences among site series were detected within vm2 (P > 0.05). We combined site series into larger categories based on productivity units (Green and Klinka 1994), but in no cases were we able to distinguish site series groups beyond what individual comparisons had already shown.

Logging

Logging was significantly related to total (r^2 = 0.03, P = 0.001), within 50 m (r^2 = 0.03, P = 0.001), occupied (r^2 = 0.02, P = 0.010) and subcanopy (r^2 = 0.01, P = 0.039) detections after variance due to date, weather and opening size was removed. Unfragmented forest had significantly higher detection rates than fragmented forest for all measures of detections (Table 4-5).

Table 4-13. Comparison of total, occupied and subcanopy Marbled Murrelet detections among weather, date and year categories in the Ursus watershed, Clayoquot Sound 1995-1997. Adjusted least square means from hierarchical ANOVA are reported for date categories after differences due to weather have been considered, and for year categories after differences due to weather and date have been considered. Mean values followed by different letters indicate significant differences between pairwise comparisons at the 0.05 level.

		Total		Occupied		Subcanopy	
	N	Mean	SE	Mean	SE	Mean	SE
Weather							
Clear	58	18.3a	2.1	2.0a	0.5	0.8a	0.2
Cloudy	56	48.1b	6.5	8.7b	1.7	3.2b	0.7
Date							
15 May-3 June	31	14.7a	6.2	1.7a	1.7	0.9a	0.7
4-27 June	29	36.4b	6.5	6.9b	1.7	2.2b	0.7
28 June-20 July	54	42.1b	4.7	6.5b	1.2	2.5b	0.5
Year							
1995	42	46.4a	5.0	7.8a	1.4	2.1a	0.6
1996	30	22.6b	6.1	2.8b	1.7	1.1b	0.7
1997	42	28.9b	5.0	5.2ab	1.4	2.6a	0.6

Steller's Jays (X_1^2 = 13.65, P < 0.001) and Northwestern Crows (X_1^2 = 16.17, P < 0.001) were reported during a greater percentage of surveys in fragmented than unfragmented forest (Table 4-6). Occurrence of Common Ravens (X_1^2 = 0.75, P = 0.387) and Bald Eagles (X_1^2 = 0.14, P = 0.71) did not differ between fragmented and unfragmented areas. Squirrels were reported during a greater proportion of surveys in areas that were unlogged than in partially logged areas (X_1^2 = 4.44, P = 0.035).

Inter-annual Trends in Detection Rates

At all stations surveyed in both 1996 and 1997, there were significantly more occupied detections in 1997 (5.1 ± 0.6 [SE]) than in 1996 (2.2 ± 0.8; r^2 = 0.02, P = 0.022), after differences due to weather and date had been considered. Numbers of total and subcanopy detections did not differ significantly between years (Ps > 0.2). There were inconsistent inter-annual trends in numbers of total detections among locations, watersheds and subzone variants, producing significant interactions for year*location (r^2 = 0.04, P = 0.003), year*watershed (r^2 = 0.06, P = 0.004) and year*variant (r^2 = 0.03, P = 0.007). Numbers of total detections were higher in 1997 than in 1996 at ocean edge (24.2 ± 6.2 vs. 14.0 ± 6.9) and lower slope stations (43.5 ± 5.4 vs. 32.0 ± 7.3), while numbers were higher in 1996 than in 1997 at valley-bottom stations on streams (29.0 ± 3.6 vs. 26.7 ± 2.8). Among watersheds, numbers of total detections were higher in 1996 than in 1997 at Bulson (50.8 ± 7.6 vs. 39.0 ± 6.5), Hesquiat Point (54.8 ± 10.9 vs. 17.5 ± 8.6) and Sydney (25.8 ± 6.2 vs. 14.2 ± 5.4), but higher in 1997 than 1996 at Tranquil (37.3 ± 7.8 vs. 1.9 ± 11.3) and Ursus (30.8 ± 4.2 vs. 20.1 ± 5.0).

Stations surveyed in Ursus in 1995, 1996 and 1997 permitted an inter-year comparison across three years. Only stations surveyed in all three years were included in analyses. We found significant differences among years for total (r^2 = 0.10, P < 0.001), occupied (r^2 = 0.10, P < 0.001) and subcanopy (r^2 = 0.07, P < 0.001) detections, after effects of weather and date had been considered (Table 4-13). Higher total detections were recorded in 1995 than in 1996 and 1997, higher occupied detections were recorded in 1995 than in 1996, and higher subcanopy detections were recorded in 1995 and 1997 than in 1996. Year*date interaction also was significant for total (r^2 = 0.10, P < 0.001), occupied (r^2 = 0.06, P = 0.001) and subcanopy detections (r^2 = 0.09, P < 0.001). Higher numbers of detections were recorded in July than June in 1996 and 1997, and in June than July in 1995 (Table 4-14). Total (r^2 = 0.16, P < 0.001), occupied (r^2 = 0.21, P < 0.001) and subcanopy (r^2 = 0.25, P < 0.001) detections differed among survey stations. The year*station interaction was significant for occupied (r^2 = 0.19, P = 0.015) and subcanopy (r^2 = 0.23, P = 0.009) detections.

Discussion

The objective of this study was to identify important nesting habitats for Marbled Murrelets at landscape and stand scales within Clayoquot Sound. We could not approach this objective directly by finding nests, but had to rely on indirect measures that have uncertain relationships to actual habitat use by nesting murrelets. We determined whether murrelet activity was related to structural characteristics common to known nest sites to assess whether activity patterns provided similar indications of habitat importance as stand-level characteristics thought to be important for nesting. We then determined how murrelet activity and nest-related structural characteristics varied in relation to topographic features and habitat categories, and how murrelet activity and predator abundance varied in relation to forest edges and fragmentation by logging. Because

Table 4-14. Interaction between year and date categories for numbers of total, occupied and subcanopy Marbled Murrelet detections in the Ursus watershed in Clayoquot Sound, 1995-1997. Adjusted least square means from hierarchical ANCOVA are reported after differences due to weather, date, year, opening size, location and watershed have been considered.

			Total		Occupied		Subcanopy	
Date	Year	N	Mean	SE	Mean	SE	Mean	SE
15 May-3 June	1995	15	18.4	7.1	1.7	2.0	1.0	0.9
	1997	16	7.1	6.7	0.7	1.9	0.5	0.8
4-27 June	1995	7	116.4	10.1	25.0	2.9	6.0	1.3
	1996	8	10.0	9.4	0.6	2.7	0.3	1.2
	1997	14	20.5	7.2	3.6	2.1	2.2	0.9
28 June-20 July	1995	20	44.1	6.0	6.4	1.7	1.7	0.7
	1996	22	27.0	5.8	3.1	1.7	1.5	0.7
	1997	12	64.4	7.8	12.6	2.3	5.8	1.0

of the uncertainty surrounding the interpretation of detection data, we first use our results to assess whether and at what scale detection data may provide information about the location of nesting habitat. Integrating these results provides some guidance in identifying important nesting habitats and establishing no-harvest reserves within Clayoquot Sound watersheds.

How Should We Interpret Murrelet Activity Patterns for the Purpose of Locating Important Nesting Habitat?

In this section we interpret our detection data in an attempt to determine how best to use such data for identifying and prioritizing potential murrelet nesting habitat in Clayoquot Sound. Our conclusions are inherently speculative because they are not based on data from areas with known nesting densities. However, we think that useful conclusions are possible through consideration of the variability of our detection data and the limitations in our ability to reveal differences among habitat characteristics at different spatial scales.

Numbers of detections were affected by weather, date and opening size, and these differences had to be accounted for before relationships between detection rates and habitat variables could reliably be determined. Activity generally increased from May to July and was greater in cloudy than clear weather, as found in previous studies (Rodway et al. 1993a, Naslund and O'Donnell 1995, O'Donnell et al. 1995, Beasley et al. 1997). Opening size was related to total detections and detections within 50 m, but not to numbers of occupied or subcanopy detections when all stations were considered. It was an important predictor of numbers of within 50 m, occupied and subcanopy detections at stations in valley bottoms between elevations of 20-60 m. Contrary to our expectations, creek noise did not reduce numbers of total detections, probably because numbers of detections were highest on stream channels.

After statistically controlling for variability due to weather, date and opening size, all detection measures were still highly variable at daily, seasonal and annual temporal scales, as well as at survey station, watershed and subzone variant spatial scales. Inter-annual trends were not consistent, stations with highest activity levels in one year had relatively low activity levels in other years, and apparent differences among stations with one year of data were less clear with multi-year data. Such contrary trends in detection numbers at stations located close to each other in similar habitat are likely more related to changes in murrelet flight or vocalization behaviour than changes in nesting activity in the immediate vicinity. Murrelet behaviour measured at a single survey station (e.g., circling) often occurs over larger spatial scales (e.g., square kilometres) than habitat differences we are interested in for management (Rodway et al. 1993b). Also, murrelets are typically silent and secretive in the vicinity of their nests (Nelson and Hamer 1995), peak numbers of silently flying birds entering the forest occur earlier in the morning than most detections recorded during standard surveys (Burger 1997), and some proportion of detections, especially later in the nesting season, are likely of non-breeding birds (Gaston and Jones 1998). Thus, it is not certain that inland surveys are measuring activity associated solely with nesting. These factors make it difficult and likely inappropriate to determine small-scale differences in habitat use based on differences in activity levels. We were unable to detect differences in activity levels at small scales among site series or site series groups within subzone variants. Similarly, Rodway et al. (1993b) were unable to distinguish differences in detection numbers among site associations in low-elevation forest in the Queen Charlotte Islands.

Most other studies of murrelet activity also have reported high variability in detection numbers (Rodway et al. 1993a, Burger et al. 1997, Jodice and Collopy 2000, Smith and Harke 2001). Ralph (1995) found little evidence of inter-annual variation in mean monthly total detections at each of three sites in northern California, but daily variability in detection numbers was high and monthly sample sizes were low, resulting in low power to detect inter-annual differences. Also, Ralph (1995) did not test whether trends across years and sites were consistent.

We included total detections in all analyses, although we assumed from the outset that total detections were little related to habitat use at smaller, stand-level scales. Total detections sometimes showed contrary trends to other detection measures, especially for stand-level forest structural characteristics; e.g., they were positively related, while detections within 50 m were negatively related to density of yellow-cedar (see Table 4-3). These contrary trends for total detections probably occurred because murrelets can be heard at considerable distances, especially over water at the ocean edge or at open, elevated locations (Rodway et al. 1993b). Numbers of total detections were high at upper slope stations where yellow-cedar was common because surveyors could hear distant calling birds. Numbers of detections were low at those locations when only detections within 50 m of the survey station were considered. This confirms that total detections are not a good measure of local activity and emphasizes the importance of considering only the other detection measures when relating activity to local forest structural characteristics.

After controlling for differences due to weather, date and opening size, we did find consistent relationships between within 50 m, occupied and subcanopy detection numbers and forest structural characteristics known to be important to nest-site selection in Marbled Murrelets (Hamer and Nelson 1995, Manley 1999). Total numbers of platforms, epiphyte cover and DBH were significantly correlated with detection numbers when considered independently (see Table 4-3). Detection numbers also were independently related to the standard deviations of tree height and DBH, indicating higher activity in multi-aged stands with more variable tree sizes. Density of trees with platforms and density of large trees were the main predictors of within 50 m, occupied and subcanopy detections in multivariate models.

Significant relationships between detection numbers and stand characteristics important for nesting found in this and other studies (Rodway et al. 1993b, Hamer 1995, Kuletz et al. 1995, Manley 1999), suggest that murrelet activity patterns are related to actual habitat use for nesting. However, it is important to point out that these relationships between detections and stand-scale characteristics are determined from consideration of all sample stations in Clayoquot Sound. They therefore reflect a broad-scale pattern and do not imply that we can detect differences in activity patterns at smaller spatial scales. Also, relationships were weak, with forest stand characteristics explaining no more than 10% of the variation in numbers of occupied or subcanopy detections. This suggests that comparisons of structural characteristics may be a more useful method for differentiating and prioritizing breeding habitats for Marbled Murrelets at small scales of 10s to 100s of hectares within watersheds than inland surveys measuring relative activity levels. Like radar counts (Hamer et al. 1995; Burger 1997, 2001; Cooper et al. 2001), activity levels may more appropriately be compared at a landscape scale, or at small, isolated forest fragments, such as occur in the southern portion of the murrelet's range (Miller and Ralph 1995).

At a landscape scale, total detections showed the same significant trends as within 50 m, occupied and subcanopy detections in relation to elevation, distance from the sea, subzone variant and logging, and similar trends as other detection measures among watersheds. Other studies also have found that total detections reveal the same trends as other detection measures in relation to landscape-scale characteristics such as elevation (Rodway et al. 1993b, Manley 1999) and distance from the sea (Hamer 1995, Burger et al. 2000). In this study, location was the only landscape-scale variable for which trends differed for total and other detection measures. Numbers of within 50 m, occupied and subcanopy detections, but not total detections, were significantly higher along stream channels than at all other locations. A possible explanation for this discrepancy is that numbers of visual detections are higher along stream channels than in adjacent forest, while numbers of auditory-only detections are similar (Rodway and Regehr 2000). Because visual detections were a minority of total detections, the proportional difference in total detections between streambed and forest locations would be small.

The general concordance between detection measures in relation to landscape variables suggests that all four detection measures used in this study may provide useful information about the location of murrelet nesting habitat at a landscape scale. More consistent inter-annual trends among locations, watersheds and variants for within 50 m, occupied and subcanopy detections than for total detections suggest that total detections are a less reliable indicator of habitat use than other detection measures, assuming that murrelets are selecting similar habitat and areas for nesting in each year. However, Bahn and Newsom (1999) found contrary inter-annual trends in numbers of occupied detections within different regions of the Ursus watershed, and radar counts of numbers of murrelets entering different watersheds also showed contrary inter-annual trends, suggesting some movement among watersheds, perhaps by non-breeders (Burger this volume). In some cases, comparing total detections may reveal trends that are not apparent with other detection measures. For example, differences among watersheds indicated by total detections were less apparent using occupied detections and were not significant using subcanopy detections, probably because of the greater range in total than other detection numbers.

In conclusion, our results indicate that murrelet activity patterns may be useful indicators for locating important nesting habitat at a landscape scale but not at smaller, stand-level scales. Comparisons of forest structural characteristics are likely more useful for differentiating and prioritizing breeding habitats at smaller scales. Although detection numbers were significantly related to a number of landscape-scale variables, most relationships were weak, explaining little of the variation in detection numbers. This is not surprising, considering the high variability in numbers of detections at even a single station, and means that the predictive power of these relationships is low. For this reason, and because we do not understand the relationship between activity levels and habitat use, we recommend against making conclusions about the location of important murrelet nesting habitat at a landscape scale based solely on relative activity levels.

Location of Important Nesting Habitat for Marbled Murrelets in Clayoquot Sound

Many forest structural characteristics associated with known nest sites, including mean DBH, epiphyte cover, density of large trees, density of trees with potential nesting platforms and total numbers of platforms, were negatively related to distance from major stream channels. Mean DBH, epiphyte cover and density of large trees were higher in valley bottoms than on slopes, but density of trees with potential nesting platforms and total numbers of platforms did not differ between valley-bottom and slope habitats. If murrelets are selecting nest sites at a stand scale based primarily on the density of potential nesting platforms (Manley 1999), then our vegetation data suggest that valley-bottom and slope habitats would not differ in the quality of habitat they offer for nesting murrelets, but that lower areas closer to stream channels would be preferred. However, the lack of differences found between valley-bottom and slope locations for total numbers of platforms may partially be due to a bias in estimating numbers of platforms in large trees in the valley bottom (Manley 1999, Rodway and Regehr 1999). There are many more platforms in large spruce than are estimated by observers on the ground, and it is likely that more platforms occur in valley-bottom locations with large Sitka spruce than in other areas. Within subzone variant CWHvm1, our results did show greatest numbers of platforms in site series 09 (High Bench Floodplain Sitka Spruce / salmonberry *Rubus spectabalis*).

Highest numbers of detections were recorded along stream channels in valley-bottom habitat, further suggesting that these areas would provide high quality nesting habitat for Marbled Murrelets. However, we recommend caution in interpreting these results. Numbers of within 50 m, occupied and subcanopy detections at valley-bottom stations off stream channels did not differ from those on lower and upper slopes and on the ocean edge. Also, distance from major stream channels did not affect detection levels, after differences due to station placement on or off stream channels were considered. Thus, there was no evidence that activity levels were higher in valley-bottom habitat generally, only that activity was highest along stream channels. In contrast, Rodway et al. (1993b) found highest activity, as well as greatest abundance of platform-bearing trees, at valley-bottom and low-elevation stations in the Queen Charlotte Islands. In that study, stations were not located on stream channels. Hamer (1995) also reported higher probability of occupied detections occurring at valley-bottom and lower slope than at higher slope sites.

A number of nest sites have been found in proximity to stream channels in old-growth, valley-bottom habitat (Hamer and Nelson 1995), and some activity along stream channels in Clayoquot Sound likely was associated with nesting. However, some of the concentrated activity along streams likely was due to murrelets using stream channels as flight corridors (Manley 1999, Rodway and Regehr 2000). Murrelets do not seem to show a preference for stream habitat when selecting nest sites in Oregon (S. Nelson, pers. comm.). Nest sites summarized by Hamer and Nelson (1995) were located an average of 123 m from stream channels or other openings (n = 68). It is possible that higher frequencies of potential predators, specifically crows and eagles, along stream edges may reduce the quality of riparian zones, and increase the attractiveness of sites away from edges for nesting murrelets (Burger et al. 2000). Otherwise, forest habitat near stream channels appears to offer high quality habitat for nesting murrelets in Clayoquot Sound.

Lower density of trees with nesting platforms, low detection numbers and increased predator abundance at ocean edges indicated that perimeter coastal forest is low-quality nesting habitat. Burger et al. (2000) reached similar conclusions. Hamer (1995) speculated that increased numbers of predators or perhaps exposure to coastal storms may account for the lack of occupied detections at nine sites that appeared to have excellent murrelet nesting habitat located within 0.8 km of salt water in western Washington. In Clayoquot Sound, several relationships suggested that better quality habitat is located away from the sea and at intermediate elevations, although most of these relationships were relatively weak. All detection measures increased with distance away from the sea and were highest at elevations between 50 and 500 m. Total numbers of platforms were highest at intermediate distances from the sea, and density of trees with platforms was highest at intermediate elevations below 800 m. Lower density of trees with platforms at the ocean edge was probably not due to differences in tree sizes because mean DBH of trees was similar at ocean edge and valley-bottom locations, and was higher at ocean edge than inland on lower and upper slopes. Poorer epiphyte development at ocean edge than valley-bottom locations may have contributed to the lower density of trees with platforms found at the ocean edge (Rodway et al. 1993b, Burger et al. 2000).

Higher detection numbers at lower elevations has been a common finding in murrelet studies throughout the murrelet's range (Rodway et al. 1993b, Hamer 1995, Kuletz et al. 1995, Miller and Ralph 1995). Manley (1999) found the reverse trend in an area on the Sunshine Coast in southern British Columbia, where most low-elevation forest had been harvested. However, activity still was higher at lower elevations when only the more intact, high-elevation forest was considered (Manley 1999). In contrast, a preference for higher elevation was found when comparing habitat use at known nest sites to habitat availability in a similar area where most low-elevation forest also had been removed (Huettmann and Cooke 2001). The study by Huettmann and Cooke is the first to analyze habitat preferences at what can be considered a random sample of nest sites located using telemetry. Some caution is thus warranted in accepting the common trend of higher activity at lower elevations as indicating a nest-selection preference for low-elevation sites.

At a watershed scale, results from 1996 (Beasley et al. 1997) and 1997 were similar, identifying Bulson, Flores #6, Hesquiat Point, Sydney and Ursus as having highest rates of occupied and subcanopy detections. Lowest activity levels were found in Cypre and Flores Cow Bay. Detection levels were high at the few stations sampled at Riley Creek in 1996, and that area may warrant further sampling, perhaps with radar. Although we assume that statistical differences in detection rates represent real differences among watersheds after controlling for sampling biases due to weather, date, opening size and location of survey stations, the difficulties of adequately controlling for differences in the distribution and intensity of sampling effort among watersheds should be kept in mind when interpreting these results. More representative and balanced distribution of survey stations within watersheds would increase our confidence in those comparisons. Careful consideration needs to be given to flight paths of murrelets and how differences in flight behaviour could affect comparisons among watersheds (Burger 1997). Broad valleys, such as the lower Sydney, offer multiple channels and a wide area over which murrelets can fly up and downstream, making it less likely that they will be detected from specific survey stations placed in the valley bottom. More birds will likely be detected from a valley-bottom survey station if the same number of birds enter a narrow watershed that constrains their flight path. Survey stations distributed across broad valleys, in conjunction with radar stations at estuaries, could be used to map flight corridors and compensate for potential differences in how murrelets concentrate their flight paths in broad and narrow watersheds.

There was some agreement in our ranking of watersheds using detection data and the ranking resulting from radar counts of incoming murrelets (Burger this volume). Among the eight watersheds investigated by both radar and inland surveys, Bulson ranked highest and Cypre ranked lowest by both measures. Comparing the eight watersheds, we found significant correlations with radar counts for within 50 m ($r = 0.76$, $P = 0.029$) and occupied ($r = 0.71$, $P = 0.050$) detections. These correlations suggest some relationship between these detection measures and actual numbers of murrelets using a watershed. However, when we corrected for the different sizes of watersheds, and compared mean numbers of audio-visual detections with the mean number of murrelets detected by radar per 100 ha of watershed area, these correlations disappeared ($r < 0.33$, $P > 0.5$, for all audio-visual measures; area data from Burger this volume). This suggests that occupied and within 50 m audio-visual detections are providing some measure of the overall level of activity in a watershed (i.e., total numbers of birds entering a watershed), but are little related to habitat use at a scale of 10s to 100s of hectares within watersheds. Mean numbers of total detections were not significantly related to radar counts and appear to have little relation to total numbers of birds present (Burger this volume).

Differences among subzone variants did not clearly indicate differences in the quality of potential nesting habitat they provide. Mean DBH, epiphyte cover and density of large trees were greater in CWHvm1 than CWHvm2, but density of trees with platforms and total numbers of platforms did not differ among variants. Activity levels were higher in vm1 than vm2. However, this was entirely due to the high detection numbers recorded along stream channels. There were no differences in activity levels between vm1 and vm2 at forest stations. This result was somewhat surprising to us because variant vm2 generally occurs above 600 m elevation in Clayoquot Sound (Green and Klinka 1994) and numbers of detections declined with elevation above about 500-600 m altitude (see Figure 4-11). Greater sampling in variant vm1 on valley bottoms away from stream channels and on slopes, as well as larger samples in vm2 may be required to reveal differences between these variants. Detection numbers were lower in CWHvh1 than in vm1 and vm2, but based on structural characteristics, we would predict that vh1 would provide attractive nesting habitat for Marbled Murrelets. Variant vh1 had greater DBH of large trees, greater epiphyte cover of all trees and greater numbers of large trees than vm2, and vh1 also had greater DBH of all trees, fewer total trees and more mistletoe than both vm1 and vm2. Why differences in these structural characteristics did not translate into differences in the number of platforms and the density of trees with platforms is not clear, but may be related to the same factors discussed above for valley-bottom vs. slope habitats, and for ocean edge areas. Analyses by Bahn and Newsom (this volume Ch. 6) also indicated that stands of smaller trees at higher elevations, more typical of variant vm2, and stands of larger trees at lower elevations, more typical of variants vh1 and vm1, generate similar densities of trees with platforms.

Contrary results at Flores #6 watershed, where subcanopy detections were higher in vh1 than vm1 habitat, indicate that some areas in subzone vh1 do have high activity levels and may be attractive to nesting murrelets. Draining on the more sheltered east side of Flores Island, Flores #6 may not be as exposed to the ocean as a lot of other vh1 forest. Survey stations in vh1 at Flores #6 were also further inland on average than at other areas (e.g., Flores Cow Bay), supporting the idea that only the perimeter coastal strip in vh1 habitat is unattractive to nesting murrelets. Topography may also have played a role in differences in detection rates, because the narrow valley of Flores #6 many have had a funnelling effect on murrelet flight behaviour, whereas the flat topography at Flores Cow Bay would not confine murrelet flight paths. Overall, our results suggest that some areas in each of vh1, vm1 and vm2 variants likely provide good-quality nesting habitat for murrelets and that subzone variant is not a particularly useful landscape-scale classification for distinguishing important nesting areas, a conclusion also reached by Manley (1999).

We found clear differences in the quality of potential nesting habitat at a site series scale. Richer, more productive site series, such as site series 06 (Western Redcedar – Sitka Spruce / foamflower) in variant vh1, and 09 (High Bench Floodplain Sitka Spruce / salmonberry) in vm1, better provided the forest structural characteristics thought to be important to nesting murrelets than poorer site series. However, using site series differences to identify potential reserve areas is problematical because of the variability in site series at small scales, inaccurate mapping on Terrestrial Ecosystem maps and the fact that site series classifications indicate potential and not necessarily actual stand structure (Bahn and Newsom this volume Ch. 6). More general groupings of site series into productivity classes may be more useful. Positive associations between site productivity and forest structure used for nesting by murrelets confirm that economic interests of the forest industry and conservation needs of Marbled Murrelets overlap.

Lower activity levels and higher predator frequencies indicated that areas fragmented by logging provide poorer nesting habitat than unfragmented forest. Increased predator abundance at edges and in stands fragmented by logging is a major concern for murrelet conservation. Reductions in murrelet reproductive success associated with elevated predator levels at forest edges or in forest fragments need to be considered in the planning of no-harvest reserves within watersheds (Nelson and Hamer 1995, Manley 1999).

In summary, our results imply that the most important nesting habitats for Marbled Murrelets in Clayoquot Sound are highly productive, unfragmented, multi-aged, old-growth stands located away from ocean and harvest edges in valley-bottom and slope areas below 800 m elevation. These results, in conjunction with information from radar surveys (Burger 2001, this volume), habitat suitability mapping (Bahn and Newsom this volume Ch. 6), tree climbing (Conroy this volume) and telemetry (Huettmann and Cooke 2001), will contribute to setting priorities for the establishment of no-harvest reserves within Clayoquot Sound watersheds (Chatwin this volume). Information on actual nesting densities, breeding success and recruitment in different habitats is needed to verify whether differences in relative activity levels and forest structural characteristics reflect the relative importance of different habitats used for nesting by Marbled Murrelets (Rodway and Regehr 1999, Conroy this volume).

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Heidi Regehr evaluates a Sitka spruce floodplain stand on the Sydney River. (photo by Trudy Chatwin)

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Can Marbled Murrelet Use of Nesting Habitat be Predicted from Mapped Forest Characteristics?

by Volker Bahn and Deanna Newsom

Abstract

We tested whether the use of nesting habitat by Marbled Murrelets (*Brachyramphus marmoratus*) could be predicted from mapped information. Our goal was to evaluate the feasibility of modelling habitat suitability on a large scale in preparation for building a sophisticated model, and to determine whether such a habitat suitability model could make basic predictions on murrelet nesting activity. In this study we did not build an elaborate habitat suitability model, but rather tested the predictions from a simple, preliminary model, based on a single mapped forest characteristic. Of the forest and terrain characteristics available on resource maps, tree height was the most useful variable to predict suitability of murrelet habitat in an analysis of data from 118 vegetation plots collected previously in the study area. We compared audio-visual detections of murrelets at 11 pairs of stands, selected using Vegetation Resource Inventory maps, with each pair having one stand with trees ON AVERAGE >35 m tall (TALL) and one with trees <26 m tall (SHORT). Our prediction was that the TALL stands would show more activity associated with breeding by murrelets than the SHORT stands. Each pair of stands had a similar elevation, distance to ocean, slope position and aspect. We performed standardized audio-visual surveys at paired stands on the same morning to avoid biases caused by weather and season. We observed significantly higher numbers of occupied detections and subcanopy detections (both thought to be related to nearby breeding) in the TALL stands than in SHORT stands. Thus, we were able to show that Marbled Murrelet breeding activity can be predicted based on a mapped forest characteristic, a result that set the stage for the more sophisticated habitat model.

Introduction

Loss of nesting habitat is a major threat to populations of the Marbled Murrelet (*Brachyramphus marmoratus*; Ralph et al. 1995a). Protection of this habitat necessitates knowledge about the murrelet's habitat requirements, and the development of models that can accurately predict habitat suitability across landscapes based on characteristics of forest stands. Habitat requirements, which are the basis of a habitat suitability model, have been researched with various methods, including audio-visual surveys (e.g., Rodway et al. 1993a,b; Grenier and Nelson 1995; Hamer 1995; Kuletz et al. 1995a,b; Bahn 1998; Manley 1999; Burger et al. 2000a,b; Rodway and Regehr this volume) and nest discovery by observation, tree climbing (e.g., Hamer and Nelson 1995, Manley 1999, Conroy et al. this volume), and radio-telemetry (Lougheed et al. 1998).

Two difficulties arise in any attempt to model the habitat requirements of the Marbled Murrelet. First, the connections between specific forest characteristics and breeding activity are uncertain. Audio-visual observations have large natural variability and some biases (Rodway et al. 1993a,b; Naslund and O'Donnell 1995; O'Donnell 1995; O'Donnell et al. 1995; Bahn 1998), and most nest information comes from selected, easily accessible habitats, or from nests located in areas altered by forestry (Manley 1999, Burger et al. 2000a, Conroy et al. this volume). Information about nests located by radio-telemetry in areas unaltered by forestry was unavailable at the time of our study. Second, the lack of information on Marbled Murrelet breeding strategies, such as whether they crowd into the best habitats or rather try to disperse evenly throughout all acceptable habitats, makes the relationship between densities of important forest characteristics and nesting activity difficult to predict. Therefore, it was necessary to determine whether habitat suitability could be predicted – despite the two difficulties noted above – before building an elaborate habitat suitability model to be used to guide the management of murrelet habitat in Clayoquot Sound.

The objective of our study was to test whether inland activity of Marbled Murrelets that is associated with nesting could be predicted based on a mapped forest characteristic. We did not attempt to build an elaborate model for this purpose. This study was done in preparation for the building of a more sophisticated model of habitat suitability (Bahn and Newsom this volume Ch. 6).

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Methods

Habitat Model

In our *a priori* analysis we re-examined data from 118 standard 30 m x 30 m vegetation plots that had been surveyed in the Ursus, Upper Bulson and Flores #6 watersheds in 1995, 1996 and 1997 using the Resources Inventory Committee (RIC 1997) methods (Burger et al. 1995, 1997; Beasley et al. 1997; Rodway and Regehr 1999; Bahn et al. 1999). We used these data to identify which forest characteristic from the Vegetation Resource Inventory (VRI) maps would be most useful in predicting relative frequencies of Marbled Murrelet detections. We looked for a mapped forest characteristic that was available on standard VRI maps and that was strongly correlated with the habitat micro-structures that were important for nesting Marbled Murrelets but not available on maps, such as epiphyte abundance and the density of potential platforms (Nelson 1997). In addition, we tested the relationship between the characteristics from the VRI maps and the frequencies of Marbled Murrelet detections observed according to RIC (1997) standards at stations within those polygons during 1995-1997.

We located each vegetation plot used in the earlier studies on VRI maps and, for each plot, recorded the values for each variable contained in the VRI database. We created a correlation matrix between these VRI characteristics and the habitat characteristics measured in the field at the vegetation plots. Based on this analysis, we chose as our predictor the average height of the dominant or second-dominant tree species (whichever was higher) as outlined on the VRI maps. We compared Marbled Murrelet activity in polygons where mean tree height was less than 26 m (SHORT) with those where it was greater than 35 m (TALL). We chose these contrasting categories of tree heights because our objective was to test whether habitat suitability could be predicted, not which tree heights were best for breeding murrelets or which height categories were most adequate for predicting habitat suitability.

Site Selection

We identified all polygons in the two height categories within the Upper Bulson and Flores #6 watersheds and used 11 “pairs” to test against one another (8 pairs in Bulson and 3 in Flores; Figures 5-1 and 5-2). We selected these two watersheds in Clayoquot Sound because they offered accessible areas with the features required for our research. Each of the TALL and SHORT stands within each pair consisted of one or more adjacent polygons. The pairs of stands were located as close together as possible (no further than 500 m apart). Paired stands had approximately equal elevations, distances to the ocean and distances to the nearest large stream, to minimize the effects of topographic variables known to affect murrelets (Rodway et al. 1993a, Nelson 1997, Bahn 1998). In addition, we interspersed the two different kinds of stands so that aspects and side of the valley varied among pairs. This sampling design minimized the risk of biases arising from unknown systematic sources (Hurlbert 1984). Stands consisting of clustered polygons ranged in size from 8 to 48 ha.

Field Work

Two teams of two people performed standard audio-visual surveys for Marbled Murrelets and vegetation plots (RIC 1997) at each pair of stands between 31 May and 6 July 1998. Each team simultaneously performed two surveys per stand per morning, giving a total of four surveys for one pair of stands. Each team camped within its stand and found survey stations the day before surveying. The survey stations were selected for accessibility, acceptable canopy opening for bird observations (Visibility Field) and sufficient distance from the border of the polygon clusters to avoid detections of birds outside the stand. We recorded various physical and biological characteristics of each survey station (Table 5-1).

Because polygon clusters were often quite small, stations were placed to ensure that all visual and auditory detections came exclusively from birds flying or calling above the habitat being tested, and not from above adjacent stands. Consequently, it was not always possible to place survey stations within the same stand 500-1,000 m apart, as recommended in the RIC manual (1997). However, we averaged the data from the two surveys performed within a single stand on the same morning; therefore, survey independence was not critical. Surveyors in different stands were always at least 500 m apart.

Eight pairs were sampled on one morning only, and three pairs were surveyed on two consecutive mornings, which were then averaged. To avoid possible observer bias, we randomly chose which team would survey each stand within a pair. Surveys were conducted according to RIC (1997) standards, which were derived from the Pacific Seabird Group protocol (Ralph et al. 1994). We did not follow the RIC (1997) recommendation of at least four surveys in two seasons because our goal was different from the goal for which this recommendation is intended. In contrast to RIC (1997), we did not try to determine occupancy in the polygons, but only compared relative murrelet activity levels in paired stands. Our sample size was appropriate to achieve this goal.

Surveys were started 1 h before the official sunrise and ended 1 h after sunrise or 20 min after the last detection,

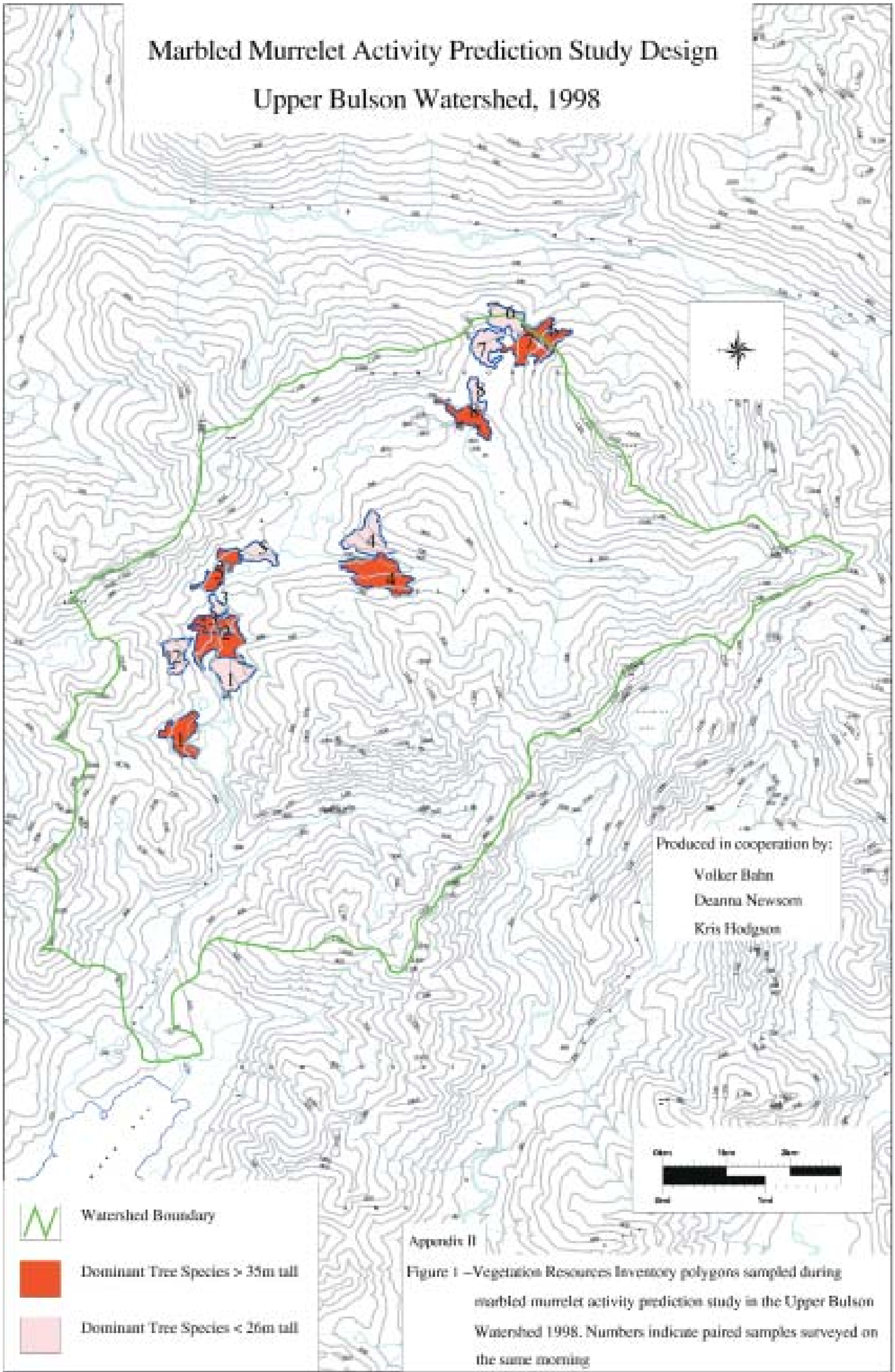

Figure 5-1. Marbled Murrelet Activity Prediction Study Design, Upper Bulson Watershed, 1998.

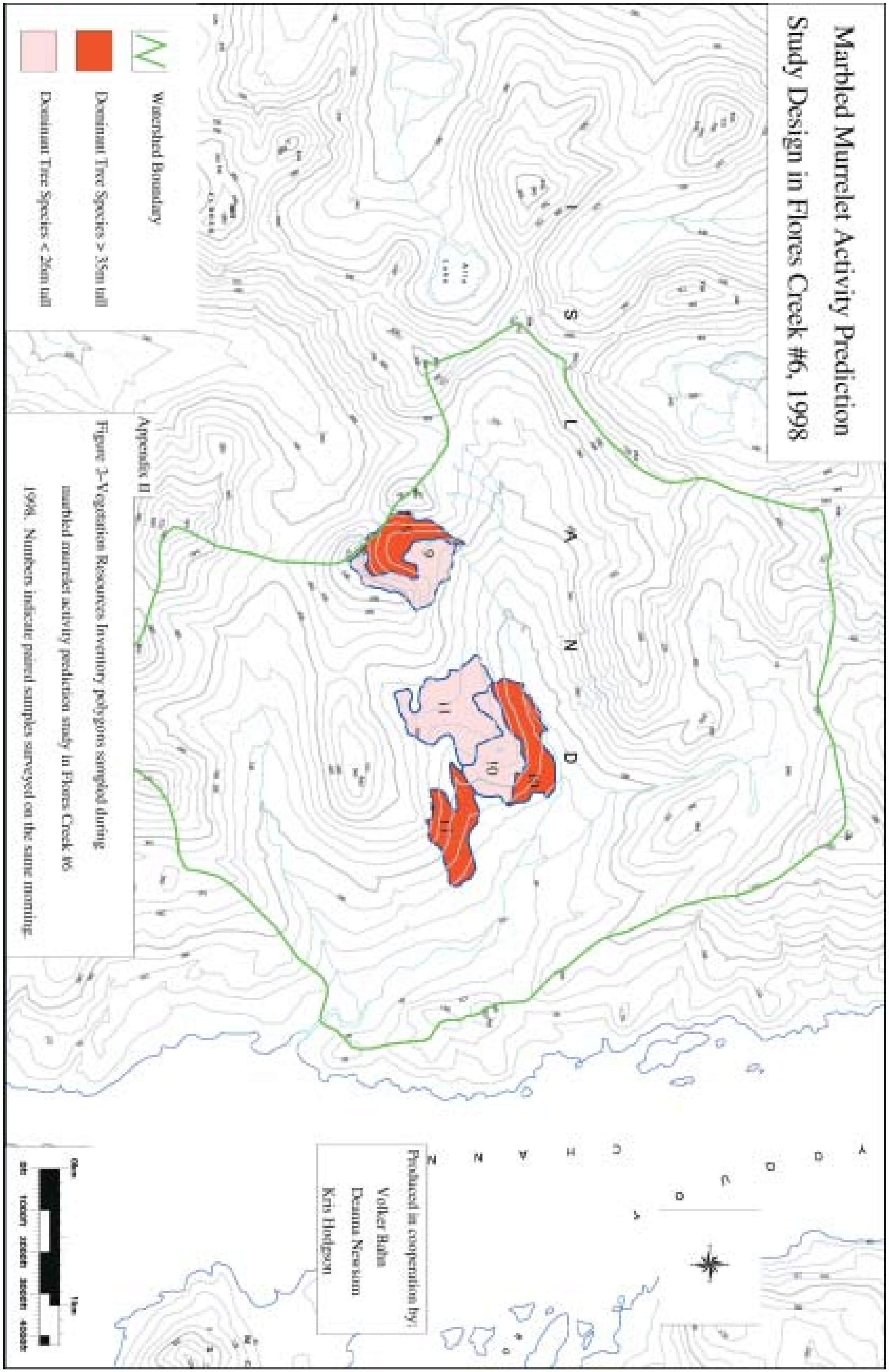

Figure 5-2. Marbled Murrelet Activity Prediction Study Design in Flores Creek #6, 1998.

Table 5-1. Names and definitions of variables used in this chapter.

Variable	Description
From the field	
Mean DBH	Mean diameter at breast height (DBH, cm) of all trees in a vegetation plot with a DBH > 10 cm.
Creek noise	Coded as 0 = none, 1 = low, 2 = moderate, and 3 = high.
Density of platforms	Number of potential nest platform limbs per ha.
Mean epiphyte cover	Mean epiphyte cover index on horizontal surfaces of the tree, coded as 0 = none, 1 = trace, 2 = 1-33% cover, 3 = 34-66% cover, and 4 = 67-100% cover.
Occupied detections	Subset of total detections: number of times one or more Marbled Murrelets acting in the same manner were seen circling and/or flying below the top of the canopy (Paton 1995, RIC 1997).
Standard deviation of tree height	A measure of a vertically well-structured forest with several canopy layers, calculated from the heights (in m) of all trees recorded in a vegetation plot.
Subcanopy detections	Subset of occupied detections: number of times one or more Marbled Murrelets acting in the same manner were seen flying below the top of the canopy (Paton 1995, RIC 1997).
Total detections	The number of times one or more Marbled Murrelets acting in the same manner were seen and/or heard during a survey (Paton 1995, RIC 1997).
Visibility Field	A measure of opening size –- the total area in which birds flying just above canopy level could potentially be detected (estimated in width and length and multiplied into m^2).
From maps	
Basal area	VRI map variable: the cross-sectional area (in m^2 per ha) of all living trees visible to the photo interpreter in the dominant, codominant and high intermediate crown positions in each tree layer in the polygon.
Distance to flight corridor	Distance in m from the survey station to the nearest major drainage channel; measured on 1:20 000 TRIM maps.
Distance to the ocean	Measured along the creek bed in km using 1:50 000 NTS topographic maps.
Elevation	Read off a 1:20 000 TRIM map in m above sea height.
SHORT	VRI map polygons with average height of the dominant tree species < 26 m.
TALL	VRI map polygons with average height of the dominant tree species > 35 m.
Tree age	VRI map variable: average age in years of the dominant tree species.
Tree height	VRI map variable: average height in m of the dominant or subdominant tree species (whichever was higher).
Vertical complexity	VRI map variable: measure of relative height difference between the highest and the lowest trees in a polygon; designed to differentiate between even-aged and uneven-aged stands; (based on four classes: 1-4).

whichever was later. During this period we recorded every Marbled Murrelet detection, which is defined as the seeing and/or hearing of one or more Marbled Murrelets acting in the same manner (Ralph et al. 1994, Paton 1995, RIC 1997). A subset of the detections, called occupied detections (because they are thought to indicate near-nest behaviour and stand occupancy), includes circling and subcanopy flights (Paton 1995). Subcanopy detections are defined as the sighting of a murrelet below the average upper canopy height around the survey station, and indicate nesting activity close by. Observers conducted surveys lying down with their heads raised to provide optimal viewing conditions. Observations were tape-recorded and the data were transcribed to data sheets later in the day.

Teams sampled two 30 x 30-m vegetation plots at each survey station, following RIC (1997) standards. Each plot was 50 m from the observation station; the first along a randomly selected compass bearing and the second at 180° to that bearing. We positioned the plots 50 m from the survey stations to ensure that they were within the chosen stand, but well distanced from the survey stations. Survey stations were selected according to specific criteria, such as acceptable Visibility Field, which might have biased the vegetation plots if they were too near to the survey station.

All trees with a diameter at breast height (DBH) of 10 cm or larger were described according to the RIC (1997) protocol. Standing dead trees were included if they were at least 15 m tall. The variables sampled at the plots are listed in Table 5-1.

Statistical Methods

We used paired t-tests to test the null hypothesis that there was no difference in detections of murrelets between SHORT and TALL polygon clusters. To test whether the stands within each pair were similar to each

Table 5-2. Pearson correlation coefficients between variables measured in the field and variables from VRI maps, based on analysis of 118 vegetation plots and 53 stations surveyed during Marbled Murrelet studies in Clayoquot Sound in 1995-1997. The vegetation plots and survey stations fell into 93 different VRI map polygons.

	Characteristics surveyed in the field				
Characteristics from VRI maps	Mean DBH	Mean epiphyte cover	Number of potential platforms per hectare	Standard deviation of tree height	Occupied detections
Height of dominant tree species	0.422**	0.538**	0.316**	0.559**	0.460**
Tree basal area	0.332**	0.354**	0.232*	0.451**	0.255
Vertical complexity of canopy	0.328**	0.534**	0.163	0.458**	0.357**
Age of dominant tree species	0.315**	0.234*	0.274**	0.225*	0.248
n	93	93	93	87	53

* P < 0.05
** P < 0.01

other in as many ways as possible except for tree height, we recorded the distance to ocean, distance to the nearest major stream and elevation of each survey station using 1:20 000 topographical maps. We averaged these characteristics for each stand and performed paired t-tests to compare SHORT and TALL stands. We also tested for differences in Visibility Field (the size of visible sky at the survey station) at each station, averaged for each stand, with a paired t-test. Creek noise data were ordinal scale and we tested for differences with a Mann-Whitney U-test. We tested the difference between each pair of SHORT and TALL stands, each measure of Marbled Murrelet detections, and each habitat characteristic of the polygon clusters for normality (Zar 1996). We used SPSS 9.0 to calculate statistical tests and considered a test to be significant when $\alpha < 0.05$.

Results

In our *a priori* analysis, the average height of the dominant tree species in the plot (based on the VRI map) showed significant correlations with many habitat characteristics that have been associated previously with Marbled Murrelet nesting activity (Table 5-2).

Not surprisingly, many strong correlations existed among habitat characteristics from the VRI maps. Height of dominant tree species, the variable selected to categorize murrelet habitat, was significantly correlated with tree basal area (Pearson correlation, $R = 0.738$, $P < 0.001$, $n = 94$), vertical complexity ($R = 0.681$, $P < 0.001$, $n = 94$) and the age of the dominant tree species ($R = 0.608$, $P < 0.001$, $n = 94$).

Significantly more occupied and subcanopy detections were observed during surveys in TALL than in SHORT stands (Table 5-3, Figure 5-3). Total detections did not differ significantly between TALL and SHORT stands. With the exception of Visibility Field, which was larger in the SHORT stands, the physical characteristics of the two types of stands were not significantly different.

Discussion

There are many studies on habitat use of nesting Marbled Murrelets (Rodway et al. 1993a, Ralph et al. 1995b, Nelson 1997, Bahn 1998, Manley 1999, Burger 2002). However, until now it was unclear whether the forest characteristics determined to be essential for murrelet nesting provided enough information to predict murrelet breeding activity at a stand level from mapped information. This was a crucial question to be answered before attempting to build a sophisticated habitat suitability model to be used in the management of Marbled Murrelet nesting habitat. Several points make the prediction of murrelet breeding activity based on mapped forest characteristics problematic.

First, the micro-habitat characteristics that have been associated with murrelet nests, such as platforms and epiphyte cover, are typically not available on maps, which is a requirement for landscape-level habitat evaluation. Therefore, those forest characteristics that are available on maps must be used as proxies for the micro-habitat characteristics known to be important to murrelet nesting. This was one step we executed and tested in this study.

Second, an index for habitat suitability based on the abundance of forest characteristics known to be important to murrelet nesting assumes that a higher density of these characteristics leads to a higher nest density. If the only selection strategy that murrelets use when looking for nest sites is to search for the best site with a given set of characteristics, this assumption will hold true. However, if murrelets used other strategies as well, such as optimal spacing for predator avoidance, a higher density of suitable micro-habitat characteristics would not necessarily lead to a higher nest density.

Third, the results of the habitat studies cited above are not unequivocal and have come under scrutiny for different reasons. The effectiveness of studies based on audio-visual surveys typically was limited by high natural variability in murrelet detections (Rodway et al. 1993b, Burger 1995, Naslund and O'Donnell 1995,

Table 5-3. Comparison of Marbled Murrelet activity and physical characteristics in 11 paired SHORT and TALL stands sampled on the same morning. Means are given ± SD.

Parameter compared	SHORT	TALL	*Statistic**	*P*-value
Activity Indices				
Total detections	20.6 ± 16.9	20.7 ± 12.1	$t = 0.04$	0.970
Occupied detections	0.27 ± 0.55	2.39 ± 2.30	$t = 3.39$	0.007
Subcanopy detections	0.02 ± 0.08	0.77 ± 1.01	$t = 2.60$	0.026
Physical Characteristics				
Distance to ocean (km)	5.5 ± 2.0	5.5 ± 2.3	$t = 0.26$	0.800
Distance to nearest travel corridor (km)	0.28 ± 0.18	0.20 ± 0.20	$t = 1.84$	0.096
Elevation (m)	430 ± 122	401 ± 182	$t = 1.16$	0.270
Creek noise	0.64 ± 0.60	1.18 ± 0.98	$U = 452$	0.180
Visibility Field (m^2)	5623 ± 3194	2559 ± 1601	$t = 2.40$	0.037

*Paired *t*-tests were used for all data except creek noise, which was measured on an ordinal scale and was tested with the Mann-Whitney test.

O'Donnell et al. 1995, Bahn 1998) and various observer and station location biases (O'Donnell 1995, Rodway and Regehr 2000). Studies based on nest locations suffered from low sample sizes, unequal sampling effort among available habitats, or were in study areas that were significantly altered by forestry (Manley 1999, Conroy et al. this volume). Although general trends observed in these studies are congruent, there is often disagreement in details. Testing a model based on the habitat associations of murrelets observed in these studies will also indirectly test the results of the studies.

Fourth, habitat associations in BC were typically determined at the scale of 900-m^2 vegetation plots (RIC 1997), whereas habitat suitability on a landscape level would be determined on the scale of the mapped polygons, in our case 8-48 ha on VRI maps. The relevance of forest characteristics to murrelet nesting could be different at such different spatial scales.

Our finding, that stands with TALL tree height had significantly greater numbers of occupied and subcanopy detections than stands with SHORT tree height, indicates that, at the scale of our VRI polygon clusters (8-48 ha), differences existed in murrelet breeding activity. The observation of a significant difference indicates that the confounding effects of the above four issues do not preclude habitat suitability modelling for murrelets based on mapped forest characteristics.

Higher occupied and subcanopy activity was observed in the TALL stands than in SHORT stands, despite slightly smaller average Visibility Field in the TALL stands. Our finding that total detections did not vary significantly between height classes was not unexpected, considering that total detections included birds that were commuting

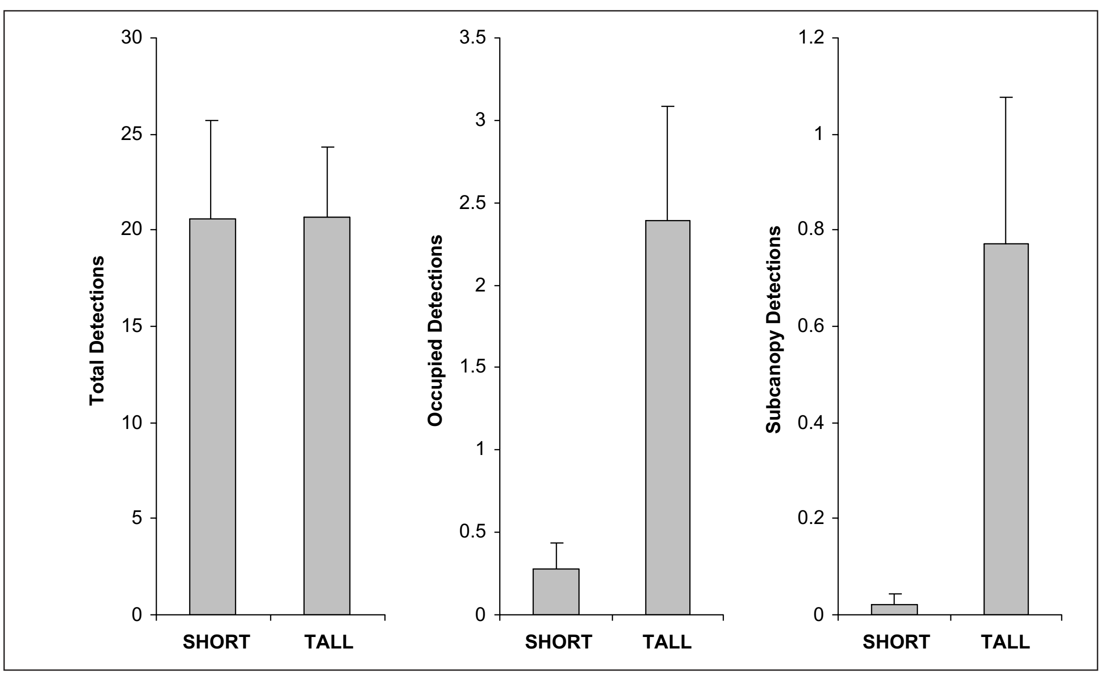

Figure 5-3. Comparison of mean values for total, occupied and subcanopy detections in 11 TALL and 11 SHORT forest stands. The error bars show the standard error of the means.

to other stands and involved in other activities unrelated to nesting. Total detections are generally not a useful measure for smaller scale habitat comparisons (Bahn 1998, Burger et al. 2000b, Rodway and Regehr this volume). Furthermore, this result indicated that overall murrelet activity was similar in the larger area containing the paired stands, eliminating the possibility that one height class was biased by consistently being in high-activity areas such as flight paths.

The significant difference in activity between TALL and SHORT stands also indicates that the underlying habitat associations used to create these categories, and the occupied and subcanopy detections from audio-visual surveys used as measure for nesting activity, were correctly selected. If either one of these inputs into our study had been wrong, one would have expected a random distribution of occupied detections between the two habitat categories. Theoretically, there could also be a different explanation for the connection between occupied murrelet activity and habitat with tall trees than the implied relationship between nesting activity and suitable structures. However, we were neither able to contrive one nor did we find any such suggestions for one in the literature.

Our study had some weaknesses. The ultimate dependent variable to measure habitat suitability would be reproductive output (i.e., number of fledged offspring per unit area of nesting habitat per season). Reproductive output is a function of both nest density and the success of the nests. Audio-visual detections are more likely to reflect nest density than nest success, and are therefore imperfect surrogates. Future research should strive to find more direct measures for reproductive output than audio-visual detections. However, for our purposes, occupied and subcanopy detections were likely an adequate measure because our goal was only to compare relative levels of nest-related activity between two height categories and not to measure exact reproductive outputs.

We addressed all known biases in audio-visual survey data (Rodway et al. 1993a,b; Burger 1995; Naslund and O'Donnell 1995; O'Donnell 1995; O'Donnell et al. 1995; Bahn 1998; Rodway and Regehr 2000). Our surveys in the paired stands were conducted simultaneously so that known effects of date and weather, and unexplained variability among days were irrelevant. Alternating observers between the two height categories eliminated observer biases. We also alternated exposure, aspect and side of stream between the height categories, and kept elevation and distance from the ocean similar, so that these factors could not have biased our results. The only unresolved issue was a potential bias due to the ruggedness of the terrain, which put constraints on the possible locations of study sites. For example, murrelets could exhibit systematically different habitat preferences and behaviour in very steep terrain which is inaccessible to observers (see cliff nests in Bradley and Cooke 2001). However, such a bias would likely have been equal in TALL and SHORT stands and thus should have cancelled itself out in our comparison.

Tree height, the mapped variable we chose to model habitat suitability, was significantly related to murrelet inland detection rates at the stand level in only a few studies (Hamer 1995, Kuletz et al. 1995b, Bahn 1998, Burger 2002). However, it was correlated significantly with other habitat characteristics, such as mean DBH, mean epiphyte cover, standard deviation of tree height and number of platforms per hectare (Table 5-2), that were related significantly to murrelet inland activity in many studies (Rodway et al. 1993a; Grenier and Nelson 1995; Hamer 1995; Kuletz et al. 1995a,b; Bahn 1998; Manley 1999; Burger et al. 2000a; Burger 2002; Rodway and Regehr this volume). In our study the significant relationships between tree height and these other habitat variables were not particularly strong, suggesting caution in the use of mapped variables, such as tree height, as proxies for nest habitat characteristics.

Our sample size was small. With a larger sample size, our approach could have been used for testing a more advanced model with more than two tree height categories. The two tree height categories had a gap of 10 m between them. Some of the most interesting forests for management would fall into this 10-m height gap. Therefore, the preliminary model we used for this study was not directly applicable to management. However, that was not the point of our study. Our goal was to determine whether it was possible to predict relative Marbled Murrelet breeding activity based on mapped forest characteristics. We showed that this was possible, a result that set the stage for the more sophisticated habitat model developed by Bahn and Newsom (this volume Ch. 6).

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Marbled Murrelet habitat in Ursus Valley. (photo by Volker Bahn)

Habitat Suitability Mapping for Marbled Murrelets in Clayoquot Sound

by Volker Bahn and Deanna Newsom

Abstract

Digitally mapped information on the habitats of threatened wildlife species, in particular the Marbled Murrelet (*Brachyramphus marmoratus*), is important to the management of forest resources in this region. We created habitat suitability maps for Marbled Murrelets based on a Habitat Suitability Index model, which evaluates forest polygons from Vegetation Resource Inventory (VRI) maps. The VRI maps, which contain detailed land cover information with a focus on forest cover, were determined to be better suited as a basis for the model than the Terrestrial Ecosystem (TEM) maps, which contain biogeoclimatic information on vegetation associations. We reached this conclusion by comparing mapped vegetation data with field data and by considering the relevance of the mapped information to murrelet nesting. Information on habitat requirements of murrelets, which was the basis for the model, came from past murrelet inventories and from the literature. This information guided our selection of vegetation characteristics used to represent habitat suitability. We sampled these characteristics in vegetation plots in stratified, randomly-selected polygons from VRI maps. The sampled variables describing habitat suitability were summarized in two factors by a Principal Component Analysis (PCA) and related to mapped variables available for these polygons. The significant relationships between mapped and PCA factor variables were modelled with 90th quantile least absolute deviation regressions. Based on these regressions and information from literature we selected seven mapped variables to be included in a habitat suitability model. We constructed non-linear, individual suitability indices (SI), which assigned evaluation scores to the values of the seven selected mapped variables. The seven individual SIs were combined in a single equation whose output is a habitat suitability index (HSI) between 0 and 1 for each mapped polygon. We divided the HSI scores into four categories: "Excellent" (HSI >0.875); "Good" (HSI between 0.78 and 0.875); "Sub-optimal" (HSI between 0.65 and 0.78); and "Unsuitable" (HSI <0.65). The application of this Habitat Suitability Model to 335,127 ha of land area (everything except for the ocean and fresh water bodies) on 36 1:20 000 map sheets in Clayoquot Sound resulted in: 34,833 ha (10.4% of the land area) of Excellent habitat; 40,466 ha (12.1%) of Good habitat; 59,388 ha (17.7%) of Sub-optimal habitat; and 200,440 ha (59.8%) of Unsuitable habitat. The model identified 75,299 ha (22.5% of land area) of Excellent and Good habitat, and 259,828 ha (77.5%) of Sub-optimal and Unsuitable habitat.

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Introduction

The Marbled Murrelet (*Brachyramphus marmoratus*), a threatened species, was identified as one of the important forest values for ecosystem management decisions in Clayoquot Sound. The BC Ministry of Environment, Lands and Parks initiated an inventory of Marbled Murrelets in the Ursus Valley in 1995 and expanded the project over the next three years to include 14 watersheds across Clayoquot Sound (Burger et al. 1995, 1997; Beasley et al. 1997; Rodway and Regehr 1999; Bahn et al. 1999; see also other chapters in this volume). These inventories provided the baseline data and understanding on murrelets in the area for this study.

Key attributes of breeding habitat for Marbled Murrelets are adequate nest-site platforms (usually formed by branches), some epiphyte and litter cover on these platforms, and aerial access to the platforms requiring a multi-layered canopy and canopy gaps (Hamer and Nelson 1995, Nelson 1997, Bahn 1998, Manley 1999). None of these attributes were mapped; therefore, an evaluation of Marbled Murrelet habitat over the entire Clayoquot Sound study area would have meant either doing extensive amounts of ground sampling or using mapped variables as proxies for the key attributes.

For the sake of clarity, two concepts – habitat suitability and Marbled Murrelet activity – need to be defined. Habitat suitability refers to the potential of an area to support successful Marbled Murrelet nests; in this study, we use indirect measures as proxies for success. A more suitable area would be able to support a higher density of successful nests than a less suitable area. Marbled Murrelet activity refers to birds commuting between the ocean and their nests, and other behaviour associated with nesting. Activity is measured by detections, which are defined as the seeing and/or hearing of one or more

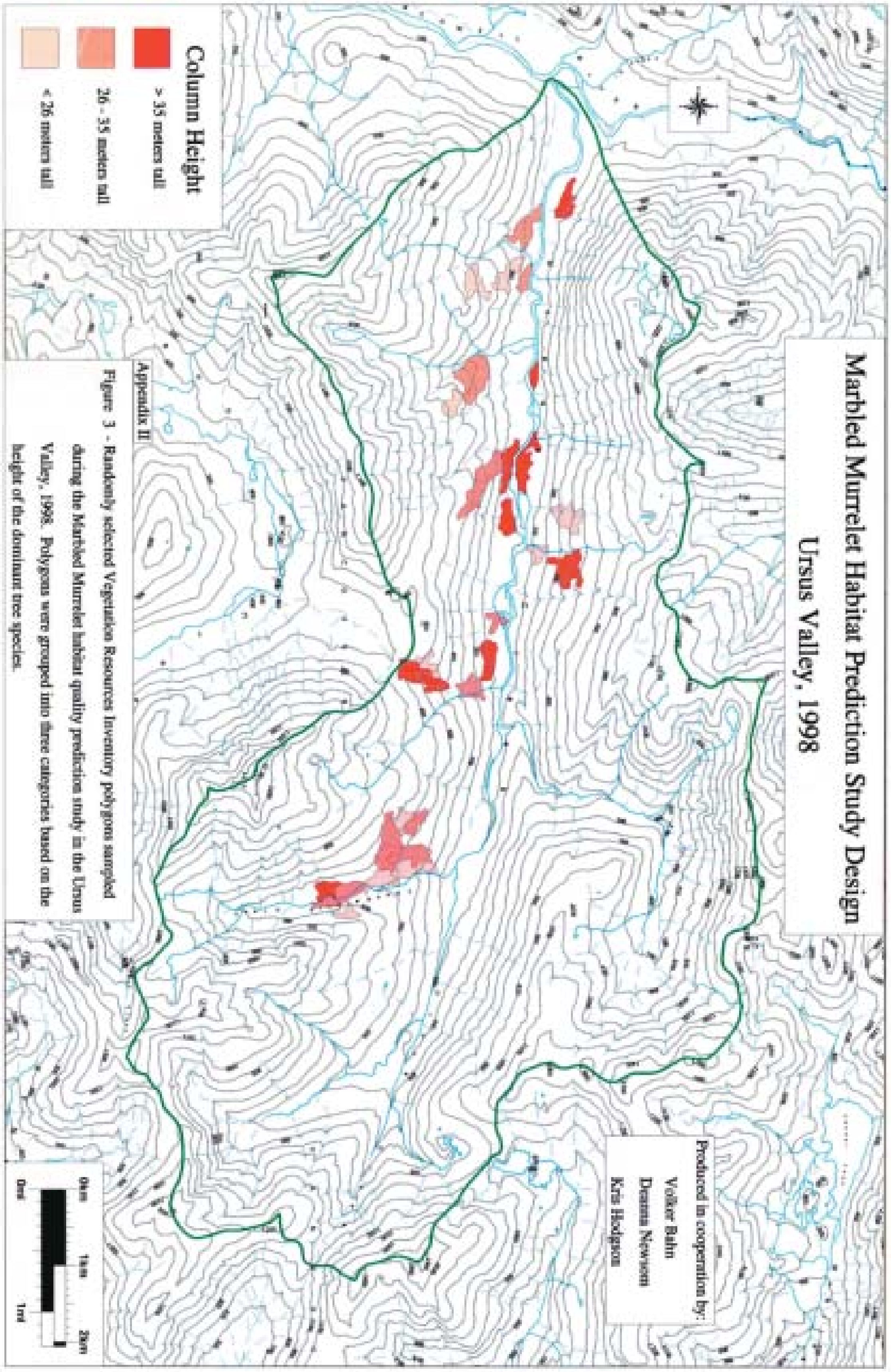

Figure 6-1. Marbled Murrelet Habitat Prediction Study Design, Ursus Valley, 1998

Marbled Murrelets acting in the same manner (Ralph et al. 1994, Paton 1995, RIC 1997a). A subset of the detections, called occupied detections (because they are thought to indicate near-nest behaviour and stand occupancy), includes circling and subcanopy flights (Ralph et al. 1994, Paton 1995). Subcanopy detections are defined as the sighting of a murrelet below the average canopy height around the survey station and indicate nesting activity close by.

To achieve the goal of a large-scale habitat evaluation based on mapped variables, we built a model that can evaluate habitat in a standardized and transparent way, and which can be updated relatively easily when new information becomes available. We used the Habitat Suitability Index (HSI) approach (US Fish and Wildlife Service 1981), which is a standardized model for habitat evaluation that has been applied widely in North America (Gray et al. 1996), and which was used by Bahn (1998) in a preliminary model of murrelet habitat. Bahn and Newsom (this volume Ch. 5) set the stage for a model by showing that a mapped habitat suitability predictor (tree height) can be used to predict Marbled Murrelet activity associated with nesting.

There were several different types of maps available for Clayoquot Sound that contained information relevant to habitat evaluation. Terrain Resource Information Management (TRIM) maps (Base Mapping and Geomatic Services Branch 2001) are digitally based contour maps, which show features such as elevation, water bodies and streams. Terrestrial ecosystem mapping (TEM; Clement 1995, RIC 1998) was not available for all of Clayoquot Sound, but was examined as a potential basis for the HSI because habitat evaluations for other species had been based on these maps (Anon. 1996). TEM maps contain a biogeoclimatic classification of each polygon based on nutrient and moisture regime and the potential assemblages of vegetation (Green and Klinka 1994). Vegetation Resource Inventory (VRI) maps (RIC 1997b) have a strong focus on the tree layer of the mapped polygons and contain information on leading tree species, average height and age of trees, and structural features such as vertical canopy complexity. The VRI maps were most promising in terms of relevance for suitability of murrelet nesting habitat; therefore, we used information from VRI maps to stratify our vegetation samples.

The main objective of our study was to provide a tool for the evaluation of rainforest as breeding habitat for Marbled Murrelets. As steps towards this overall goal we strove to: 1) determine the most useful map type to use as a source of information; 2) collect unbiased habitat information as a basis for the model; and 3) identify the best habitat and mapped variables for the construction of the model. Basing the model on information from digital maps enabled us to display the output of the evaluation model as GIS maps. These maps could be overlaid with maps evaluating other aspects of the Clayoquot Sound landscape, such as recreational areas, scenic corridors and riparian areas, and used for land management purposes.

Methods

Acquisition of Information

Truthing of VRI Maps and Comparison with TEM Maps

The first step in creating a habitat evaluation model was to determine which map type would best fit our purposes. To compare the degree of correspondence between our own vegetation plots and TEM maps (Clement 1995), we counted the cases in which site series on the maps were consistent with our own findings. To test how well the VRI maps corresponded to our vegetation plots, we counted the cases in which the leading tree species on the map was consistent with our field results. "Leading species" was defined as the tree species occupying the greatest basal area in a plot or polygon. As well, we correlated variables from the VRI maps (Basal Area, Tree Height, Canopy Closure, Tree Density, Snag Density; see variable definitions in Table 6-1) with equivalent variables from our plots, which we calculated using the same methods as those used for the VRI maps (RIC 1997b). We determined the VRI maps to be better suited as basis for the habitat evaluation model. Therefore, the rest of this study exclusively dealt with VRI maps.

Stratified Random Vegetation Sampling

We sampled vegetation in the Ursus Valley to assess habitat suitability, which we later related to information on VRI maps. We used a stratified random sampling design following the approach of Bahn and Newsom (this volume Ch. 5). We categorized each VRI polygon (the unit used for mapping and containing a homogenous forest stand of 1.2-188 ha [mean 61.3 ± SD 8.3 ha]) on the basis of the height of the leading tree species (TOPHT; see Table 6-1 for variable definitions). Categories of predicted habitat suitability were: a) Low (0-25 m TOPHT); b) Medium (26-35 m TOPHT); c) High (>35 m TOPHT). We surveyed 10, 11 and 10 polygons of low, medium and high predicted habitat suitability, respectively (Figure 6-1).

The rationale behind stratifying with a variable that can predict habitat suitability (see Bahn and Newsom this volume Ch. 5) was to achieve a balanced design and increase the power of statistical tests. Furthermore, this design can improve the dispersion of samples over a completely random approach; more complete dispersion decreases the probability of including unknown systematic biases (Hurlbert 1984).

Table 6-1. Names and definitions of variables used in this report.

Variable	Description
From the field	
BASEHA	The cross-sectional basal area (in square meters per hectare) of all trees recorded in our vegetation plots.
DBH	Diameter of trees measured at breast height in cm.
DBHMN	Mean DBH in cm.
DBHVAR	Variance of DBH as a measure of an uneven-aged, well-structured forest with big trees.
DENSNAG	Number of snags per ha taller than 10 m and with DBH > 10 cm.
DENSTEM	Number of trees per ha with DBH > 10 cm.
DENTR2PL	Number of trees per ha with more than 2 potential nest platforms.
DENTRPLT	Number of trees per ha with potential nest platforms.
EPIMN	Mean index of epiphyte cover = sum of epiphyte cover ratings / number of trees in the plot.
EPITHKMN	Mean index of epiphyte cover thickness = sum of epiphyte thickness rating / number of trees in plot.
EPITOT	Mean epiphyte development on limbs of trees in vegetation plot; product of codes for epiphyte thickness and epiphyte cover for each tree.
HTMN	Mean height (m) of all trees measured in vegetation plots.
HTVAR	Variance of tree height, a measure of a vertically well-structured forest with several canopy layers.
MAMU 1 and 2	Two factors derived in a PCA on habitat characteristics (see text).
POPLAHA	Number of potential nest platforms per hectare.
TREEPCT	The percentage of ground area covered by the vertically projected crown cover of the trees in the plot.
From maps	
See RIC (1997b) for detailed definitions of VRI map variables.	
ELEVAT	Elevation in m above sea height, read off a 1:20 000 TRIM map.
BAS.AREA	The cross-sectional basal area (in square meters per hectare) of all living trees visible to the photo interpreter in the dominant, codominant and high intermediate crown positions in each tree layer in the polygon.
DENSITY	Mean number of living trees per hectare visible to the photo interpreter in the dominant, codominant and high intermediate crown positions in each tree layer in the polygon.
DISSEA	Distance (km) from the centre of the polygon to the ocean.
ELEVEG	Elevation of vegetation plot (m).
SNAGFREQ	Number of standing dead trees per hectare visible to the photo interpreter in the dominant, codominant and high intermediate crown positions in each tree layer.
TOPAGE	Age (years) of the leading or the second- leading species, whichever was higher.
TOPHT	Mean height of the dominant or second- dominant tree species, whichever was higher.
TREECC	Percentage of ground area covered by the vertically projected crowns of the tree cover in the polygon.
VERT.COMP	Vertical complexity of the forest canopy (based on four classes: 1-4). This variable was a measure of the relative height difference between the highest and the lowest trees in a polygon, and was designed to differentiate between even-aged and uneven-aged stands.

We randomly chose 60 polygons (20 per height class) and included more polygons than we intended to sample because we had to eliminate some polygons that were inaccessible by foot, too steep (slope >100%) or did not contain trees. Furthermore, we wanted to ensure that our sample included all habitat types, especially rare ones such as high-elevation habitat with tall trees (>35 m tall). An examination of the distribution of our randomly selected polygons on the map showed that most polygons in the >35 m tree height (TOPHT) category tended to be in the valley bottom. Conversely, polygons in the 0-25 m tree height category tended to be at high elevations. For proper interspersion of sampled polygons (Hurlbert 1984), we deliberately chose some 0-25 m tree height polygons at low elevations and some >35 m tree height polygons at high elevations. Thus we implemented a double stratified (by tree height and elevation) random design with a sample of 31 polygons.

Within each polygon, we surveyed three vegetation plots using standard protocols (RIC 1997a). Locations of plots were selected randomly except that inaccessible sites were ignored. We included vegetation plots (22 of 93) assessed in previous years (using the same protocol) if they occurred within one of our 31 study polygons.

Analyses

All statistical analyses were done on SPSS 9.0 except for the LAD regressions (see Regressions below), which were calculated with BLOSSOM (Cade and Richards 2001). We stored and manipulated data in EXCEL 97. Unless otherwise noted, statistical tests were considered to be significant for $\alpha < 0.05$.

Correlations and Selection of Variables

The choice of habitat suitability variables (derived from field work) was based on earlier analyses done on the Clayoquot Sound Marbled Murrelet inventory data (Rodway and Regehr 1999, Bahn 1998) and the literature (Hamer and Nelson 1995, Nelson 1997, Drever et al. 1998). We considered the following variables as proxies for suitability of murrelet breeding habitat: epiphyte cover; epiphyte thickness; number of platforms per area; density of trees with one or more platforms; layering of the canopy measured by standard deviation of tree height; mean height of trees; and mean diameter at breast height (DBH) of trees.

To examine the relationship between Marbled Murrelet habitat suitability and VRI map information, we correlated Marbled Murrelet habitat variables, as recorded in our vegetation plots, with all relevant variables from the VRI maps. Normally distributed variables were tested with Pearson correlations, and those significantly deviating from the normal distribution (determined by Kolmogorov-Smirnov one-sample test) were tested using Spearman rank correlations. Pairs of habitat and mapped variables that had the highest correlation coefficients and the greatest support in literature on murrelet habitat requirements (Rodway et al. 1993, Burger 1995, Nelson 1997, Bahn 1998) were selected for regression analyses.

Due to the strong intercorrelation among Marbled Murrelet habitat variables assessed in our vegetation plots, we combined the variables EPIMN, EPITHKMN, EPITOT, POPLAHA, DENTRPLT, DENTR2PL, HTMN and HTVAR in a Principal Component Analysis and derived two factors with eigenvalue >1, MAMU1 and MAMU2 (variable definitions in Table 6-1). This data-reduction method condensed the information from several variables into fewer variables by creating factors, which replaced the original scales of the variables and were able to explain the variation in the variables more efficiently. For example, high density of platforms, high average cover of epiphytes,and multiple canopy layers were attributes that were generally found together in tall old-growth forests. Therefore, these tall old-growth stands could be more efficiently characterized by a single variable, which combined the three named variables and was a proxy for the size, age and structure of a stand.

Regressions

We used MAMU1 and MAMU2 as dependent variables in regression analyses with independent variables from the VRI map, to examine the relationship between mapped information and Marbled Murrelet habitat suitability. Regression methods were least squares (LS) and least absolute deviation (LAD) regressions (Cade and Richards 1996) with the 90th quantile regression line (Terrell et al. 1996). The LS regressions are the standard regression, but the LAD regression models need further explanation. They are distribution-free statistics, which have higher power than ordinary least squares regressions when assumptions such as normal distribution and homoscedasticity are violated (Cade and Richards 1996). Furthermore, they are more resistant to the influences of outlying values.

In ecological field data on habitat suitability, the assumption of homoscedasticity in regular regression analyses (LS) is often violated. A habitat variable that can effectively limit the density of a species in a habitat will invariably be associated with low densities at low values. However, high values of the same variable do not guarantee high densities of the species in the habitat, as there might be other habitat variables that could limit the density of the species. The resulting pattern of graphing this variable against the density of a species is typically wedge-shaped (see, for example, Figure 6-2: Tree Age vs. PCA factor MAMU1), with consistently low densities of the species at low values of the habitat variable and a high range of densities at high values of the habitat variable (Terrell et al. 1996). This pattern is heteroscedastic and thus violates the assumptions of regular least squares regression analyses.

The standard analysis methods have a limited capability of modelling wedge-shaped relationships between variables. Besides the violation of the assumption of homoscedasticity, regular least squares regressions measure the central tendency, which in the described case would be an indeterminate mixture of the effects of several limiting factors that may interact. The resultant regression line would not describe the effects of the limiting habitat variables (i.e., the upper limits of data points) as accurately as the LAD line. Ideally, all habitat variables with limiting effects should be assessed together in a multiple regression or general linear model. In reality, however, the set of measured habitat variables will always be incomplete, so that the problem described for individual regular regressions will always occur.

An alternative method is to isolate the effect of a single limiting habitat variable in the described wedge-shaped graph. Terrell et al. (1996) found that the upper edge of the wedge describes the limiting effect of a habitat variable. They suggested using the 90th regression quantiles in an LAD regression to estimate the upper edge of a wedge-shaped relationship between a limiting habitat variable and the density of a species. The 50th quantile is the median, the 90th quantile is a plane that splits the frequency distribution into unequal parts containing 90% and 10% of the observations.

Elevation and Tree Size

During our fieldwork we observed that trees at higher elevations were capable of producing structures relevant to Marbled Murrelets at lower average tree heights than trees at lower elevations. Therefore, we tested the average tree height among stands at different elevations with equal densities of trees with platforms, as a measure of habitat suitability for murrelets. Statistically, we examined the relationship between mean tree height (HTMN) and elevation of the stand (ELEVEG), while controlling for the number of trees with platforms per hectare (DENTRPLT). To achieve this, we performed a regression with DENTRPLT as independent and HTMN as dependent variables to control for the variation in tree height among stands, which corresponded to differences in platform densities. Then we used the residuals of the regression as the dependent variable and ELEVEG as the independent variable in a second regression.

Habitat Evaluation Model

We constructed a Habitat Suitability Index (HSI) for the Marbled Murrelet that included mapped variables (VRI maps) selected because of their correspondence to habitat suitability variables recorded in our vegetation plots (see Correlations and Selection of Variables above). We anticipate future changes in the model as more information on murrelet habitat associations becomes available from the tree climbing study in the Ursus Valley (Conroy et al. this volume) and from other studies in BC and in the United States.

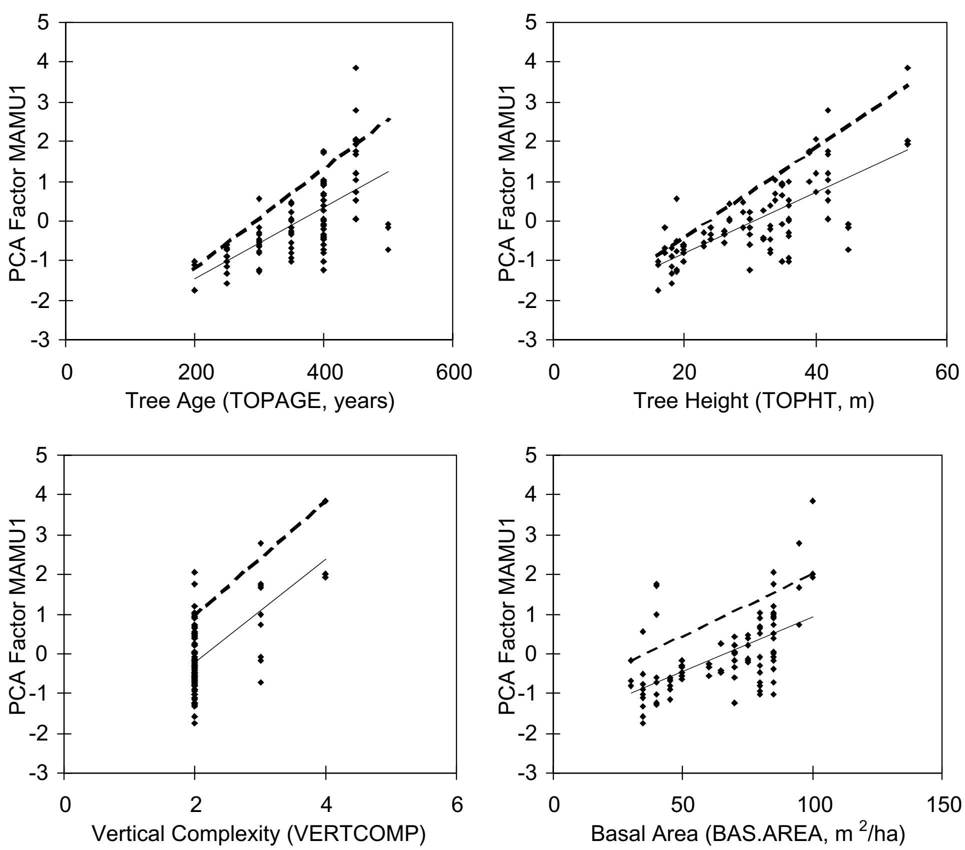

Figure 6-2. Least squared (lower solid line in each graph) and 90th quantile least absolute distance regressions (upper dashed line in each graph). The dependent variable MAMU1 was the first factor from a Principal Component Analysis with eight important Marbled Murrelet habitat variables. The independent variables are from VRI maps. Data from 93 plots.

The construction of the HSI followed the steps outlined in the standards for the development of Habitat Suitability Index models (US Fish and Wildlife Service 1981) and was adapted from Bahn (1998). The model takes into account only inland breeding habitat and does not consider any other habitat requirements of the Marbled Murrelet (e.g., marine foraging habitat). The ideal evaluation output from the HSI model would be linearly related to nest density and breeding success of Marbled Murrelets.

The HSI model included the following variables, all taken from VRI maps except for elevation (ELEVAT) and distance from ocean (DISSEA), which were derived from TRIM maps (Base Mapping and Geomatic Services Branch 2001):

- height (m) of the leading or the second-leading tree species, whichever was taller (TOPHT). This variable was corrected for elevation (see Elevation and Tree Size under Results);
- age (yr) of the leading or the second-leading tree species, whichever was older (TOPAGE);
- basal area (m^2/ha) of canopy and emergent trees (BAS.AREA);
- vertical canopy complexity (based on four classes: 1-4) of the forest canopy (VERT.COMP). This variable was a measure of the relative height difference between the tallest and shortest trees in a polygon and was designed to differentiate between even-aged and uneven-aged stands (RIC 1997b);
- canopy closure (%) of the tree crowns (TREECC);
- average distance (km) of the polygon from the ocean (DISSEA);
- average elevation (m above sea level) of the polygon (ELEVAT).

We excluded distance to nearest major forest edge from the HSI for several reasons: the lack of an operable definition for “major forest edge”; the lack of information on effects of different types of forest edges (e.g., gravel bars, rivers, clear cuts, roads, bogs) on the breeding success of murrelets; and, the need to map out all forest edges before distances to polygons can be calculated with GIS.

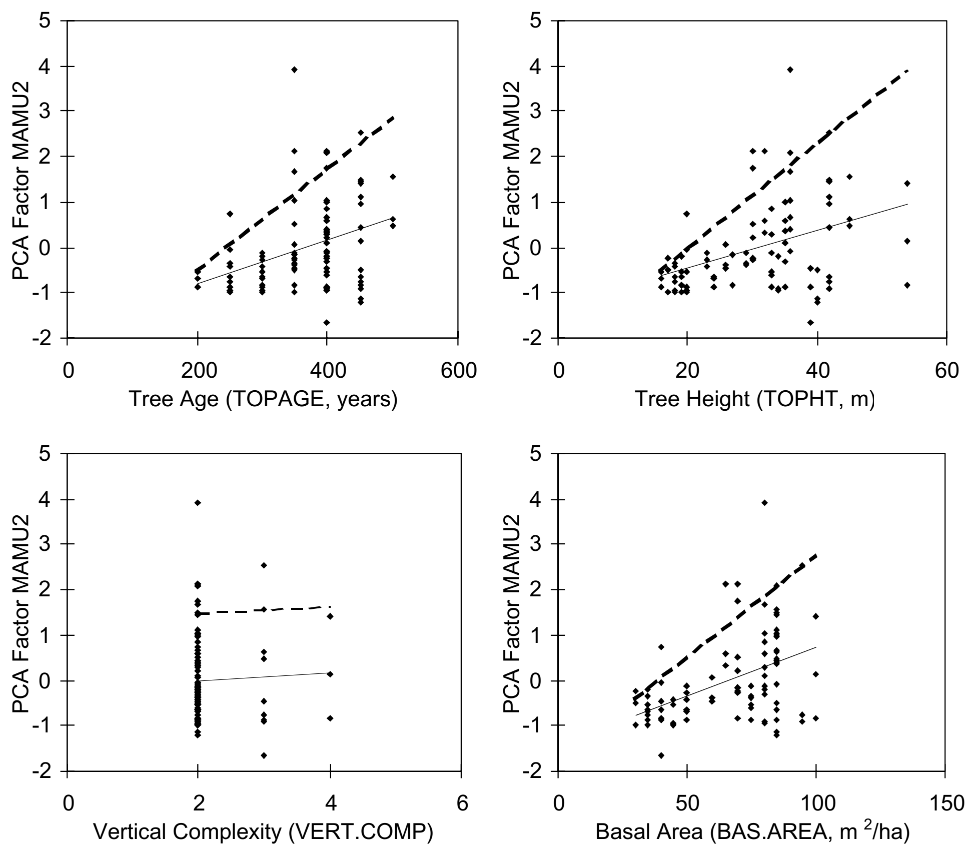

Figure 6-3. Least squared (solid line) and 90th quantile least absolute distance regressions (dashed line). The dependent variable MAMU2 was the second factor from a Principal Component Analysis with eight important Marbled Murrelet habitat variables. The independent variables are from VRI maps. Data from 93 plots.

The next step in building the model was the creation of individual suitability indices (SI). SIs are functions that assign a score from 0 to 1 to each value of the individual mapped variables. We designed the SI functions for the VRI variables TOPAGE, TOPHT and BAS.AREA as follows: a) each value of the variable that corresponded to a MAMU1 value < -0.8 and a MAMU2 value < -0.6 in the 90th quantile LAD regressions (Figures 6-2 and 6-3) was assigned the score 0; b) values of the three VRI variables corresponding to -0.8 ≤ MAMU1 ≤ 1.8 and -0.6 ≤ MAMU2 ≤ 2.1 were represented by a linear SI function with slope and constant equivalent to the average between the LAD regression lines on MAMU1 and MAMU2; c) values corresponding to MAMU1 > 1.8 and MAMU2 > 2.1 were assigned an SI of 1. The SI function for the variable VERT.COMP was based on the 90th quantile LAD regression with MAMU1 only, because the equivalent regression with MAMU2 was not significant. In addition, VERT.COMP was a categorical variable. Therefore, the SI function assigned four discrete SI values to the four possible values of VERT.COMP determined with the same methods as for the three variables described above.

Three habitat characteristics in the model, DISSEA, ELEVAT and TREECC, had non-linear, non-monotonous relationships to habitat suitability. They did not relate to other Marbled Murrelet habitat variables and could therefore not be derived from graphs with the dependent variables MAMU1 and MAMU2. Consequently, the suggested SI functions were estimates (adapted from Bahn 1998), related to both data from Ursus Valley and data from literature (Hamer and Nelson 1995).

We let the SI of DISSEA be 0 for distances 0-200 m from the ocean, and increase linearly from 0 to 1 for distances 200-800 m from the ocean, because of several observations of reduced murrelet activity in near-shore habitats (Hamer 1995, Burger et al. 2000, Rodway and Regehr this volume). The SI stayed at 1 for distances of 0.8-50 km, and decreased linearly from 1 to 0 for distances 50-100 km from the ocean, because long flight distances are likely to reduce the habitat suitability for murrelets (Nelson 1997).

The SI of ELEVAT stayed at 1 for elevations of 0-900 m. Effects of elevation on vegetation up to 900 m were solely represented in the direct measures of vegetation (TOPAGE, TOPHT, BAS.AREA, VERT.COMP and TREECC). From 900 to 1,400 m of elevation the SI declined logistically from 1 to 0, representing declining murrelet activity at such elevations (Hamer 1995, Hamer and Nelson 1995) and representing the rationale that there is a physiological cost to breeding birds of having to fly to such elevations from sea level.

The SI of TREECC increased linearly from 0 to 1 for measures of crown closure from 0 to 30%, stayed at 1 up to 70%, and decreased linearly to 0 for crown closures from 70 to 100%. This was based on data from Hamer and Nelson (1995) and the rationale that very low crown closures represent a lack of suitable nest trees and cover over nest sites, and very high crown closures represent a lack of access to the canopy for murrelets.

Finally, the seven individual SIs were combined in one formula, which generated a single Habitat Suitability Index between 0 and 1. The formula is a combination of arithmetic and geometric means among the individual SIs. The arithmetic mean (e.g., m = (a + b)/2) was used for compensatory relationships between variables; i.e., high values of one variable can compensate for low levels of another variable (all SIs except for SI(DISSEA)). The geometric mean (e.g., m = square root(a * b)) was used when a low value of a certain variable could not be compensated by other variables (SI(DISSEA)). The variables TOPHT, TOPAGE, BAS.AREA, VERT.COMP, TREECC and ELEVAT were first arithmetically averaged and then combined with DISSEA in a geometric average. To give the arithmetic mean of the six variables an adequate weight in the geometric mean with DISSEA it was raised to the power of 6 before the multiplication with DISSEA (resulting in seven factors for the geometric mean analogous to the seven variables). To complete the geometric mean we took the seventh root of the multiplication.

Mapping

The mapping of the HSI results was done on the same spatial database as the VRI maps from which the information for the HSI was derived. For a visually informative map it was necessary to group HSI scores into categories, so that each category could be displayed as a different colour on the maps. In addition to the informative value, this grouping procedure was the point at which HSI scores were interpreted biologically. The two highest categories were rated as “Important-Excellent” (HSI >0.875) and “Important-Good” (HSI between 0.78 and 0.875) habitat, hereafter referred to simply as Excellent and Good. These two categories distinguish between habitat in which the quantities of all structures relevant to Marbled Murrelet breeding are outstandingly high, and sufficient for nesting, respectively. Habitat with an HSI between 0.65 and 0.78 was classified as “Sub-optimal” and habitat with habitat with an HSI <0.65 as “Unsuitable”.

This classification of polygons was based on murrelet activity and vegetation data, as well as our experience with this ecosystem and our judgement. Ideally, evaluation should be based on nest density and breeding

Table 6-2. Pearson correlation coefficient (R) and coefficient of determination (R^2) for variables from VRI maps that could also be calculated from our vegetation plots (n = 93 plots).

Variables compared (map vs. plot)	R	R^2
Basal Area (BAS.AREA vs. BASEHA)	0.768**	0.518**
Tree Height (TOPHT vs. HTMN)	0.858**	0.736**
Canopy Closure (TREECC vs. TREEPCT)	0.538**	0.289**
Tree Density (DENSITY vs. DENSTEM)	0.718**	0.516**
Snag Density (SNAGFREQ vs. DENSNAG)	-0.352	0.124

* P < 0.05
**P < 0.01

Table 6-3. Spearman correlation coefficients between variables from VRI maps and Marbled Murrelet habitat variables derived from our vegetation plots (n = 93 plots).

VRI map				Vegetation plot variables				
variables	DENTRPLT	DENTR2PL	POPLAHA	EPIMN	EPITHKMN	EPITOT	HTMN	HTVAR
BAS.AREA	0.407**	0.575**	0.590**	0.638**	0.505**	0.611**	0.674**	0.737**
TOPHT	0.364**	0.547**	0.548**	0.689**	0.572**	0.668**	0.764**	0.787**
VERT.COMP	-0.019	0.161	0.168	0.408**	0.294**	0.379**	0.461**	0.424**
TOPAGE	0.375**	0.520**	0.534**	0.652**	0.547**	0.634**	0.729**	0.745**
TREECC	0.266**	0.140	0.158	0.020	0.005	0.017	-0.040	0.010
DENSITY	-0.273**	-0.452**	-0.454**	-0.661**	-0.569**	-0.646**	-0.735**	-0.743**

* P < 0.05
**P < 0.01

success of murrelets. We expect that our model will be refined as new information is obtained. The habitat categories can be changed once this information is available.

Results

Truthing of VRI Maps and Comparison with TEM Maps

Both the TEM and the VRI maps showed limitations. In 41% of the 51 vegetation plots conducted between 1995 and 1998, the site series determined by the field crew matched the primary site series, and in 49% it matched either the primary or secondary site series, as mapped by Clement (1995) using TEM.

In 48% of the 31 VRI polygons, the map indicated the same leading tree species as we recorded in the field. The accuracy of the VRI maps was better when we compared the three leading species on the map with those recorded in our vegetation plots, without considering the ranking in which they were listed (83% of the cases matched, n = 89). The VRI maps included five variables that we were able to compare directly to our own vegetation plots (Table 6-2). All variable pairs (BAS.AREA vs. BASEHA, TOPHT vs. HTMN, TREECC vs. TREEPCT, and DENSITY vs. DENSTEM) were significantly correlated except for SNAGFREQ vs. DENSNAG. Based on these results we used VRI for modelling.

Correlations and Selection of Variables

Most of the correlations between variables derived from field work and from VRI maps were highly significant (Table 6-3). Only VERT.COMP and TREECC were not significantly correlated to some variables from vegetation plots. All measures of platform availability (DENTRPLT, DENTR2PL, POPLAHA) had their strongest correlations with BAS.AREA, whereas the measures of epiphyte cover (EPIMN, EPITHKMN, EPITOT) and tree height (HTMN, HTVAR) correlated best with TOPHT. These results indicated that habitat variables known from past research to be important for Marbled Murrelets, can be reliably represented by the information found in VRI map variables.

The strong intercorrelations among many variables from the VRI maps (Table 6-4) were of concern as they suggested that the information provided by the different variables was very similar. Similarly, the highly significant intercorrelation among all variables of Marbled Murrelet habitat suitability derived from our vegetation plots (Table 6-5) indicated that most variables important to Marbled Murrelets were closely linked.

To offset the intercorrelation among the Marbled Murrelet habitat variables and to reduce the number of variables we had to consider in the analysis, we performed a Principal Component Analysis (PCA). It extracted two factors (MAMU1 and MAMU2) with eigenvalue >1. These two factors accounted for 81.2%

Table 6-4. Spearman correlation coefficients between variables from VRI maps. The high R-values show the intercorrelations among the mapped variables. (n = 93 plots).

	BAS.AREA	TOPHT	VERT.COMP	TOPAGE	TREECC	DENSITY
BAS.AREA	1.000	0.812**	0.346**	0.816**	0.197*	-0.669**
TOPHT		1.000	0.654**	0.924**	-0.172	-0.956**
VERT.COMP			1.000	0.536**	-0.653**	-0.700**
TOPAGE				1.000	-0.049	-0.856**
TREECC					1.000	0.321**
DENSITY						1.000

* P < 0.05
**P < 0.01

Table 6-5. Spearman correlation coefficients between Marbled Murrelet habitat variables derived from vegetation plots (n = 93 plots).

	DENTRPLT	DENTR2PL	POPLAHA	EPIMN	EPITHKMN	EPITOT	HTMN	HTVAR
DENTRPLT	1.000	0.791**	0.855**	0.362**	0.432**	0.399**	0.410**	0.419**
DENTR2PL		1.000	0.943**	0.510**	0.510**	0.522**	0.556**	0.594**
POPLAHA			1.000	0.554**	0.556**	0.573**	0.583**	0.630**
EPIMN				1.000	0.735**	0.953**	0.781**	0.796**
EPITHKMN					1.000	0.890**	0.721**	0.653**
EPITOT						1.000	0.796**	0.767**
HTMN							1.000	0.848**
HTVAR								1.000

* P < 0.05
**P < 0.01

Table 6-6. Pearson correlation coefficients between the Principal Component Analysis factors MAMU1 and MAMU2 and the eight Marbled Murrelet habitat variables on which the analysis was based. The last column (%) indicates the percentage of variation in the habitat variables accounted for by the PCA factors (n = 93 plots).

	DENTRPLT	DENTR2PL	POPLAHA	EPIMN	EPITHKMN	EPITOT	HTMN	HTVAR	%
MAMU1	0.373**	0.401**	0.484**	0.899**	0.753**	0.909**	0.839**	0.847**	62.6
MAMU2	0.903**	0.866**	0.872**	0.247*	0.329**	0.288**	0.370**	0.339**	18.6

* P < 0.05
**P < 0.01

Table 6-7. LAD 90th quantile linear regression line statistics. The dependent variables MAMU1 and MAMU2 stemmed from PCA analyses on eight Marbled Murrelet habitat characteristics. The independent variables were read off VRI maps. P is the probability that the modelled line was equal to a line with slope zero (n = 93 surveyed vegetation plots).

	PCA Variables					
	MAMU1			MAMU2		
VRI Variables	Constant	Slope	P	Constant	Slope	P
TOPAGE	-3.80	0.01	<0.001	-2.81	0.01	0.050
TOPHT	-2.74	0.11	<0.001	-2.41	0.12	0.002
DENSITY	3.24	-0.01	<0.001	4.32	-0.01	0.049
BAS.AREA	-1.10	0.03	<0.001	-1.78	0.05	0.001
VERT.COMP	-2.02	1.47	<0.001	1.32	0.07	0.551
TREECC	4.60	-0.06	0.145	-2.61	0.07	0.159

of the information in the eight Marbled Murrelet habitat variables on which the PCA was based (Table 6-6). The first factor (MAMU1) represented the measures for epiphyte cover (EPIMN, EPITHKMN and EPITOT) and for size and canopy structure of the forest (HTMN and HTVAR). The second factor (MAMU2) contained information mainly on platform density and the density of trees with platforms (POPLAHA, DENTRPLT and DENTR2PL).

Regressions

Many of the VRI map variables showed wedge-shaped relationships when plotted against the PCA factors MAMU1 and MAMU2 (Figures 6-2 and 6-3). Specifically, TOPAGE, TOPHT and BAS.AREA were well modelled by the 90th quantile LAD regression lines as indicated by the difference in slope between LAD and LS regressions. Cade and Richards (1996) noted that a difference in slopes between LAD and LS regressions indicated violations in the assumptions of the LS regression and a superior performance of the distribution-free LAD regression. A comparison of R^2 values between LS and LAD regressions was not possible because they cannot be calculated for LAD regressions.

Most of the other regressions tested were also highly significant (Tables 6-7 and 6-8). An exception was the habitat variable MAMU2 vs. VERT.COMP. MAMU1, which represented the standard deviation of height (the habitat parameter that should be most closely related to the VRI map variable vertical complexity), was significantly related to VERT.COMP, but MAMU2, which did not represent vertical structure variables, was not significantly related, as expected. In addition, VERT.COMP conveyed relatively little information, having only three values (2, 3 and 4) with most polygons having the value 2 (see Figure 6-2).

The relationships between the Marbled Murrelet habitat variables, condensed into two PCA factors, and the VRI map variables were the starting point for the habitat suitability model based on mapped information.

Elevation and Tree Size

The average tree height, controlled for the variation attributed to different habitat qualities (here expressed as density of trees with platforms), decreased with an

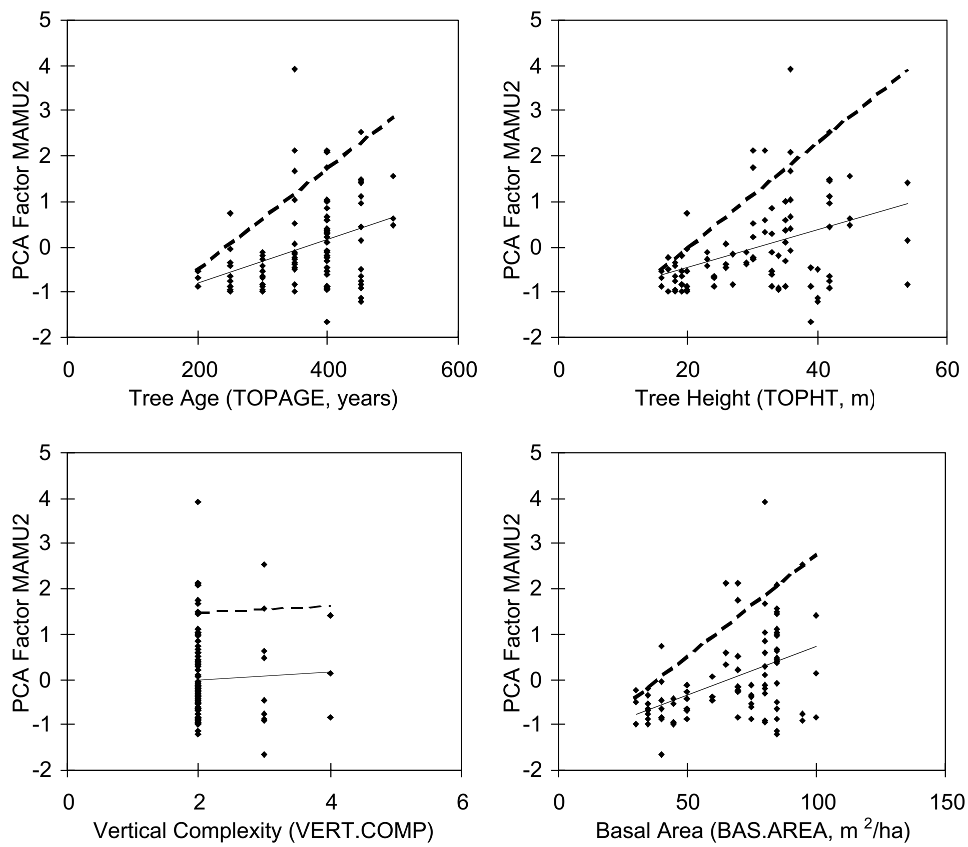

Figure 6-4. Linear regressions between number of trees with more than two platforms per ha (DENTRPLT) and the mapped mean tree height (TOPHT; left graph) and elevation above sea level vs. the residuals from the left regression (right graph). The left regression shows how average tree height varies with Marbled Murrelet habitat suitability (here expressed as trees with more than 2 platforms per ha). The residuals of the left regression contain the variation in tree height that was unrelated to murrelet habitat suitability. The right regression shows how elevation can explain variation in these residuals of tree height. It shows how tree height in equally suitable habitats varies with elevation. The equation of the regression line was important in correcting for different elevations when evaluating murrelet habitat by tree heights. The R^2 of the left and the right regression are 0.250 and 0.297, respectively ($P < 0.001$ and $n = 93$ vegetation plots in both cases).

Table 6-8. Least squared means linear regression statistics. The dependent variables MAMU1 and MAMU2 stemmed from PCA analyses on eight Marbled Murrelet habitat characteristics. The independent variables were read off VRI maps. P is the probability that the modelled line was equal to a line with slope zero (n = 93 surveyed vegetation plots).

	PCA Variables			
	MAMU1		MAMU2	
VRI Variables	R^2	P	R^2	P
TOPAGE	0.409	<0.001	0.118	<0.001
TOPHT	0.534	<0.001	0.152	<0.001
DENSITY	0.478	<0.001	0.091	0.003
BAS.AREA	0.334	<0.001	0.203	<0.001
VERT.COMP	0.340	<0.001	0.002	0.659
TREECC	0.000	0.880	0.042	0.049

Table 6-9. Suitability Index (SI) functions based on the seven mapped variables in the habitat evaluation model. The SIs range from 0 to 1 for all values of the input variables. The final equation for the habitat suitability index (HSI) incorporating all seven SIs is given in the last row.

Mapped Variable	Mapped variable value	SI Function
TOPHT* (m)	< 16.7	0
	16.7-39.6	0.0435 * TOPHT - 0.722
	> 39.6	1
TOPAGE (yr)	< 226	0
	226-438	0.00470 * TOPAGE - 1.06
	> 438	1
BAS.AREA (m^2/ha)	< 15.2	0
	15.2-91.7	0.0130 * BAS.AREA - 0.197
	> 91.7	1
VERT.COMP	1	0.0949
	2	0.659
	3 and 4	1
TREECC (%)	< 30	TREECC / 30
	30-70	1
	> 70	-TREECC / 30 + 10/3
DISSEA (km)	0-0.2	0
	0.2-0.8	DISSEA /0.6 -1/3
	0.8-50	1
	50-100	DISSEA /(-50) + 2
	> 100	0
ELEVAT (m)	0-900	1
	> 900	$101 * e^{(18 - 0.02 * Elev)} / (1 + 100 * e^{(18 - 0.02 * Elev)})$

$$HSI = \sqrt[7]{SI(DISSEA) * \left[\left(SI(TOPAGE) + SI(TOPHT) + SI(BAS.AREA) + SI(VERT.COMP) + SI(TREECC) + SI(ELEVAT)\right)/6\right]^6}$$

* TOPHT was corrected for elevation in the final calculation: TOPHT’ = TOPHT + 0.01 * ELEVAT

increase in elevation (Figure 6-4). This result was important for the evaluation of high-elevation habitats using average tree height. It showed that adequate nest structures could be found in trees with lower average height with increasing elevation. According to our calculations, a forest stand at 500 m elevation that had the same density of trees with more than two platforms as a stand at 0 m elevation was, on average, 10.5 ± 3.3 m (± 95% CI) shorter than the stand at 0 m elevation. This result was incorporated in the model below.

Habitat Evaluation Model

The individual suitability index (SI) functions are shown in Table 6-9. Note that TOPHT was corrected according to the effect described in the previous section. The equation joining the individual SIs into a single habitat suitability index (HSI) was derived (see Habitat Evaluation Model under Methods for methodology) and is given at the bottom of Table 6-9.

Maps

We applied our model to the data from the VRI map and derived a value between 0 and 1 for each mapped polygon in Clayoquot Sound. Using the categories explained under Methods (Mapping), the Ministry of Environment and Ministry of Forests staff produced a set of 36 maps covering all of Clayoquot Sound. Hard copies of the maps are available from Trudy Chatwin at the BC Ministry of Water, Land and Air Protection, Nanaimo, and electronic versions at the BC Ministry of Forests FTP site: ftp://ftp.for.gov.bc.ca/vancouver_region /!regional_office/external/!publish/clay/mamu .

The application of this Habitat Suitability Model to 335,127 ha of land area on 36 1:20 000 map sheets in Clayoquot Sound resulted in:

- 34,833 ha (10.4% of the total area) of Excellent habitat;
- 40,466 ha (12.1%) of Good habitat;
- 59,388 ha (17.7%) of Sub-optimal habitat; and
- 200,440 ha (59.8%) of Unsuitable habitat;

  or
- 75,299 ha (22.5%) of Excellent and Good habitat; and
- 259,828 ha (77.5%) of Sub-optimal and Unsuitable habitat.

The land area includes all mapped terrestrial polygons, even those without tree cover (e.g., snow fields, avalanche chutes, alpine areas), but not ocean and fresh water bodies.

Discussion

Comparison between VRI and TEM Maps

Several aspects have to be considered to determine which of the two map types has a higher potential for predicting habitat suitability for Marbled Murrelets: a) the accuracy of the mapping; b) the biological meaning of the mapped information; and c) the correlation between mapped variables and Marbled Murrelet habitat suitability.

Comparisons of the accuracy of each of the two map types and our field results revealed approximately equal levels of correspondence among mapped and vegetation plot variables. However, it was difficult to compare the accuracy of the two map types, because the methods of comparing field data to map data were different for each. Based on our observations, site series (Green and Klinka 1994) changed on a fine scale. Sometimes we found two or more different site series in a 30 x 30-m vegetation plot. Accordingly, the mapping of site series, which was mostly based on aerial photographs, did not reflect our results very well. However, Marbled Murrelets probably do not react to such fine-scale vegetation differences. Consequently, the TEM maps might be useful and sufficiently accurate at a broader scale (e.g., site series grouped into productivity classes; Green and Klinka 1994:197).

The VRI maps reflected our field data at a scale that was likely meaningful for evaluating Marbled Murrelet habitat. Many of the variables from the VRI maps (basal area, tree height, tree age and tree density) correlated significantly with equivalent variables calculated from our field data.

Furthermore, the VRI maps seemed more biologically relevant than the TEM maps. Ecosystem maps, such as TEM, are based on soil nutrient and moisture conditions, as well as plant species composition. Animals that rely on plants as food have often been successfully associated with site series (e.g., black bears (*Ursus americanus*) and Roosevelt elk (*Cervus elaphus roosevelti*) in the Ursus Valley; Anon. 1996), but the relevance of site series to Marbled Murrelets, which are mostly dependent on structures found in large trees, was not readily apparent. VRI maps contain information on tree characteristics (e.g., height, age and basal area), which were linked closely to the structures required by Marbled Murrelets (e.g., nesting platforms and epiphyte cover). Furthermore, TEM maps indicate potential vegetation, not current state of vegetation as VRI maps do. Predictions of habitat quality based on TEM maps would therefore reveal *capability* (i.e., the quality of habitat that could occur at a certain location, but not necessarily the conditions present when the site was assessed), whereas VRI maps would reveal *suitability* (i.e., quality of the current habitat at a certain location). This is an important difference to resource managers, because forest stands suitable for Marbled Murrelet nesting can take more than 200 years to develop (Nelson 1997). The potential (capability) of a site to develop into suitable murrelet habitat is irrelevant within current planning time-frames, except to identify buffer zones and protected areas now in second growth that in the future could be recruited as murrelet habitat.

Another advantage of the VRI maps was that their forest cover information correlated better with Marbled Murrelet habitat suitability and Marbled Murrelet activity than the vegetation information from TEM maps. Rodway and Regehr (1999, this volume) found few significant relationships between Marbled Murrelet habitat variables and site series, and grouped site series by productivity to interpret their results. They did not find a significant relationship between Marbled Murrelet activity (rates of detections) and site series. In the Ursus Valley, Bahn (1998) found significant differences in Marbled Murrelet activity between productivity groups of site series, as defined by Green and Klinka (1994), but not among individual site series. In contrast, many of the variables available on VRI maps were related significantly to habitat suitability and to activity of Marbled Murrelets (see Correlations and Selection of Variables under Results, Table 6-3). Therefore, we conclude that the information on VRI maps is likely more relevant to the prediction of suitable nesting habitat for murrelets than the information contained on TEM maps.

Data Acquisition

The ideal measures of habitat suitability for Marbled Murrelets are nest density and breeding success. However, the determination of breeding success in relation to an area or habitat type would be difficult and expensive, and was well beyond the scope of our project. The most commonly applied surrogate for breeding activity is audio-visual detections (e.g., Rodway et al. 1993, Paton 1995, Burger et al. 2000). We decided to use habitat characteristics as determined by vegetation surveys as a basis for our model. The advantage of using forest characteristics instead of audio-visual survey data to predict nesting habitat suitability was that vegetation characteristics are easier to measure and interpret than audio-visual data. Furthermore, audio-visual data can be biased or affected by station placement, field of visibility, weather, and seasonal and yearly variability (Naslund and O'Donnell 1995, O'Donnell 1995, O'Donnell et al. 1995, Rodway and Regehr 2000). Limitations to the use of vegetation characteristics also exist; we can not assume that a stand with double the amount of nesting structures supports twice as many nesting birds. More likely, there is a non-linear relationship between density of nesting structures and nest density, with some saturation at higher densities.

Our sampling design would have been more robust by including polygons randomly selected from all of Clayoquot Sound, but this was beyond the scope and budget of our project. In the Ursus watershed, our double-stratified random design ensured that we covered all habitat types and thereby also covered most habitat types found elsewhere in Clayoquot Sound.

Selection and Processing of Variables

The relatively large number of variables used to characterize Marbled Murrelet habitat, and the correlations among them, presented a problem for the selection of appropriate variables. A large number of variables makes it difficult to evaluate every possible combination of variables in a multivariate model with reasonable sample sizes. High intercorrelations among independent variables mean that several variables contain similar information, which is undesirable in a multivariate analysis and might lead to spurious results (Zar 1996). Therefore, it is necessary to make a selection among the intercorrelated variables, before entering them into a multivariate model. The selection is often based upon the variables' performance in an *a priori* analysis, such as a correlation. This selection is problematic because the variables might perform quite differently in an initial univariate test than in a subsequent multivariate analysis, such as a General Linear Model (GLM), where other independent variables account for a part of the variability in the dependent variable.

Rodway and Regehr (this volume) addressed this problem with a hierarchical GLM. They built a model with Marbled Murrelet activity, indicating nesting as a dependent variable, and all measured habitat variables as independent variables, to determine which of the measured habitat variables were the strongest predictors of habitat suitability. Our goal was different and we used the habitat variables determined by Rodway and Regehr (this volume) as dependent variables and the mapped habitat variables as independent variables to model habitat suitability based on mapped variables. Thus we not only had many independent, but also several dependent, variables. We reduced the number of dependent variables using a Principal Component Analysis, which condensed most (83%) of the information contained within the habitat variables into two uncorrelated factors (MAMU1 and MAMU2). In combination, high values of the two factors represent a forest with a complex vertical canopy structure, large trees and large mossy limbs. The significant correlations between our PCA factors (which were a proxy for habitat suitability) and VRI map variables gave us confidence in the reliability of our model.

Using these factors as dependent variables in 90^{th} quantile LAD regressions, we derived relationships between mapped variables and the factors. Following Terrell et al. (1996), we modelled individual relationships between habitat suitability and predictive mapped variables in a biologically meaningful way. In our case, this approach was preferable to a multivariate approach such as multiple regressions or GLMs because strong intercorrelations among all variables and incomplete knowledge about breeding habitat selection by Marbled Murrelets would have violated the assumptions and theories behind these approaches. Furthermore, the individual Suitability Indices of our model can be easily updated as new information becomes available.

Habitat Suitability Model

The three most important VRI variables included in our model (TOPAGE, TOPHT and BAS.AREA) were highly intercorrelated (Table 6-4). Aerial-photo interpreters used tree height as a guide when estimating tree age and basal area on the VRI maps (RIC 1997b), which explains part of the strong correlations. Another part is explained by the interrelation among the basic characteristics of old-growth forests; large trees tend to be tall, old and have a large basal area. Keeping all intercorrelated variables in the model would have meant including the overlapping information several times, thereby giving it a higher weight than other information (see below) included in the model. However, these map variables had the strongest correlations with our habitat variables so that a higher weight seemed justified and we decided to keep them all.

Other variables available on maps and significant to Marbled Murrelet habitat suitability were vertical complexity, canopy closure, elevation, distance to the nearest forest edge and distance to ocean. Hamer and Nelson (1995) found multi-layered canopies to be important factors for breeding habitat suitability. Vertical complexity, divided into four categories on the VRI maps, should be a measure of the degree of layering, but was disappointing in that almost all the polygons that we examined fell into the same category. Accordingly, the regression analyses done with vertical complexity did not exhibit high R^2 values (Table 6-8). The low variation in this variable could be partly due to its broad categories (RIC 1997b) and partly due to the dominance of old forests in Clayoquot Sound, which all have vertically complex canopies. With finer categories and a more balanced distribution of polygons across the range of vertical complexity, we would have expected better results from this interesting variable.

We could not model canopy closure (TREECC) with our standard method because canopy closure was not directly related to the structural characteristics that comprised our dependent variables. Hamer and Nelson (1995) and Manley (1999) found that most nests were in areas with lower canopy closure than nearby randomly selected locations. They argued that high canopy closure offered good visual protection for the nest, but it impeded access to potential nest sites by murrelets. Most nests are found in medium to low canopy closures, which offer easy access and modest visual protection.

Distance to the ocean does not directly relate to other habitat variables and can only be judged on the basis of few data. Nelson (1997) noted that 136 of >160 nests found in North America were within 50 km of the coast, most of them within 30 km. Burger et al. (2000) found coastal fringes within 250 m of the shore to be sub-optimal for Marbled Murrelet breeding.

Elevation exhibits a complex relationship to Marbled Murrelet habitat suitability because of its effects on vegetation characteristics. We kept mean elevation equal among the sampled polygons to avoid interactions between elevation and the predicted effects of mapped tree height. Low-elevation stands have, on average, more of the vegetation characteristics required for murrelet nesting than higher-elevation stands, and most habitat suitability variables are negatively correlated to elevation (Bahn 1998, Burger 2002). In addition, murrelets expend less energy to fly to low-elevation stands than to high stands, assuming equal distances from the ocean. However, in landscapes where low-elevation stands are fragmented and habitat is degraded, murrelets will nest in high-elevation stands that have suitable habitat structures (Drever et al. 1998, Burger 2002). Hamer (1995) found that occupied activity dropped quickly above 1,000 m elevation in Washington. All 45 nests from the Pacific Northwest reviewed by Hamer and Nelson (1995) were below 945 m. Of 119 nests found by telemetry in BC, 84% were below 1,000 m, and there was a rapid drop-off in nests with increasing elevation above 1,000 m (Burger 2002). In the Caren Range (Sunshine Coast, BC), considerable occupied activity and a successful nest were detected above 1,000 m elevation (V. Bahn, personal observations). Based on this information on distribution of nests and stand occupancy, our Suitability Index remained at 1 for 0-900 m and decreased in a sigmoid curve starting at 900 m to end at 1,400 m elevation with a suitability of 0 (Table 6-9). The relationship between elevation and structural characteristics in the vegetation important to Marbled Murrelets is considered more directly through other variables.

Given equal numbers of trees with platforms, trees in a stand at 500 m elevation were on average 10.45 ± 3.34 m (± 95% CI) shorter than in a stand at sea level. Similarly, the guidelines for Marbled Murrelets in the Identified Wildlife Management Strategy of 1999 consider height class 4 (28.5-35.4 m) as acceptable Marbled Murrelet habitat in the higher-elevation Mountain Hemlock biogeoclimatic zone compared to height class 5 (37.5-46.4 m) to 6 (46.5-55.4 m) at lower elevations. The rationale is that trees at higher elevations grow slower and stay shorter than trees at low elevations, but do not necessarily lag in development of large branches suitable as platforms. A habitat suitability model must account for the fact that forest stands at high elevations can develop habitat characteristics suitable for murrelets at lower average tree heights than stands at low elevations. In our model, we used an average tree height corrected for this differential growth in the evaluation of Marbled Murrelet habitat.

Another important variable that may be retrieved from digital maps in the future is the distance from the polygon to the next major forest edge. Edge effects on Marbled Murrelet nesting have been discussed by several authors (Hamer and Nelson 1995; Burger 1995, 2002). Nesting close to an edge, rather than in the interior forests, means not only reduced cover, but also higher densities of species that prey on eggs and hatchlings of Marbled Murrelets (e.g., corvids). The edge effect may not influence nest density as much as nesting success. Therefore, studies that quantify nesting success should understand and model habitat suitability relative to the distance from the nearest forest edge. Another important question is whether the effects of induced and natural edges on Marbled Murrelet nesting must be evaluated separately. Including forest edge in the evaluation model could show the potential degradation of Marbled Murrelet habitat in the forestry planning stage, before any logging activities begin (i.e., planned forest edges could be drawn onto the map resulting in decreased scores in the HSIs of adjacent polygons). Unfortunately, we were unable to find computer-operable definitions for this variable and therefore did not include it in our model. Although the effects of forest edges have not been quantified for Clayoquot Sound, and consistent definitions of edge types are lacking, it is likely that this variable influences Marbled Murrelet nesting habitat, but was not captured by any other variable.

The individual Suitability Indices were based on habitat features known to be important to Marbled Murrelets, but many of the underlying assumptions are untested. For example, Marbled Murrelets use limb platforms for nesting, and Manley (1999) observed that the density of platforms was significantly higher in patches that contained a nest than in randomly selected patches. There is, however, no known quantitative relationship between density of potential platforms and nest density. More accurate relationships between the density of important habitat characteristics and nest density can only be established by studies of nest density that ideally would include reproductive success.

Data used in our model were from the Ursus Valley and may not be representative of other areas. For example, the relationship between average tree height and Marbled Murrelet habitat suitability likely changes with latitude, because forests further north tend to have smaller trees. Therefore, adjustments are necessary before applying this model to other regions. Our model is likely applicable, with due verification, within the Coast and Mountains ecoprovince.

Murrelets spend much of their time at sea and it would be desirable to include marine habitats in models, including spatial connections to the inland breeding habitats. When feeding a chick, murrelets face the triple burden of feeding themselves, feeding the chick and flying to and from the nest several times a day. Therefore, the proximity of productive marine forage areas to nesting habitat is probably important. At the time we developed our model, we had little information about marine habitat use in Clayoquot Sound and so did not include this.

The next step will be the verification of the HSI model. Testing of nesting habitat suitability for Marbled Murrelets, predicted by the preliminary model, could also provide new information on the species' habitat requirements. Tests should compare nest densities and breeding success, as determined by random-design tree-climbing studies. Radio-telemetry is a good method to find nests, but does not permit the calculation of nest densities. The outputs of the model can be used to guide land planning and management decisions from the watershed to polygon spatial scales.

Habitat Suitability Mapping

Continuous HSI values needed to be placed into discrete categories for display on maps. One approach would have been to divide the HSI scores evenly (e.g., in quartiles) to obtain habitat categories. This approach would have ignored any subjective interpretation of biologically relevant groupings of scores, and would also have left the interpretation of the categories to land managers. We preferred to contribute our experience with Marbled Murrelets to identify categories that were biologically based.

Interpretation of the HSI scores has to consider the breeding behaviour of this species. In contrast to other alcids, Marbled Murrelets nest solitarily (Nelson 1997), possibly to avoid the generation of a search image by their nest predators. Consequently, Marbled Murrelets probably do not concentrate in the "best" habitat (as defined by our criteria), but likely disperse among all suitable habitats, unless loss of forest forces them to concentrate in smaller areas. An attempt to conserve Marbled Murrelets by saving "key breeding habitat" – which presumably would consist of a small percentage of all potential habitat and would feature the highest density of vegetation structures known to be relevant to murrelets – may not be compatible with the birds' reproductive strategies. Artificially forcing the birds to concentrate in such areas would likely reduce their reproductive success (which is already among the lowest in the Alcidae; Nelson 1997) due to higher exposure and predator densities close to edges (Hamer and Nelson 1995).

Accordingly, we deem all habitat in the categories "Excellent" and "Good" to be potentially important to Marbled Murrelet reproduction. These areas have structural characteristics potentially important as Marbled Murrelet breeding habitat, but murrelets might reject these areas for reasons unknown to us. The separation between "Excellent" and "Good" habitat should not be misunderstood to necessarily imply higher nest densities in "Excellent" habitats. For example, it should not be concluded from our evaluation that 1 ha of "Excellent" habitat could replace 2 ha of "Good" habitat.

We classified areas as "Sub-optimal" if they contained too few structural characteristics in trees to support substantial murrelet nesting, and as "Unsuitable" if they had virtually none of these structures. Murrelets can nest on the ground (Nelson 1997, Bradley and Cooke 2001) and although these nest sites are uncommon, a habitat evaluation system based on tree characteristics cannot absolutely identify areas unsuitable to breeding. However, from California through to Alaska, most known nests of Marbled Murrelets occur in large, old trees, and these trees occur primarily in old-growth stands.

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Kevin Jordan climbing a Sitka Spruce. Tree-climbing in random plots was used to locate nests of Marbled Murrelets. (no photo credit)

Climbing Plot in Important Excellent habitat in Ursus River. (photo by Mike Rodway)

Marbled Murrelet nest located in Western Red Cedar in Important Excellent habitat in Ursus watershed. (photo by Kevin Jordan)

Estimating Nest Densities for Marbled Murrelets in Three Habitat Suitability Categories in the Ursus Valley, Clayoquot Sound

by Catherine J. Conroy, Volker Bahn, Michael S. Rodway, Laurie Ainsworth and Deanna Newsom

Abstract

We investigated nest densities and breeding habitat preferences of Marbled Murrelets (*Brachyramphus marmoratus*) in unfragmented old-growth habitat in the Ursus Valley, Clayoquot Sound in 1998, 1999 and 2000. The study covered three habitat suitability categories, ranked as Excellent, Good and Sub-optimal by the habitat suitability model of Bahn and Newsom (this volume Ch. 6). Our objectives were to: 1) compare habitat structure and abundance of potential murrelet nest structures in the habitat categories; 2) document micro-habitat and forest structures which describe murrelet nest habitat preferences; and 3) estimate murrelet nest densities by climbing randomly selected clusters of trees with potential nest platforms. Trees were sampled in a manner similar to stratified cluster sampling. In total, 44 vegetation plots were randomly selected and 467 trees with potential nest platforms were climbed. Vegetation plot data indicated that trees in habitat rated as Excellent had thicker epiphyte growth, were taller and had greater diameter at breast height than trees in Good or Sub-optimal habitats. Tree density was lower and canopy closure was higher in Excellent habitat than in Good and Sub-optimal habitats. Good and Excellent habitats had higher densities of platforms and higher densities of trees with platforms than Sub-optimal habitat. Trees with platforms climbed in Excellent habitat were taller, had larger diameters, greater numbers of mossy platforms per tree and more abundant and thicker epiphyte cover than trees with platforms climbed in other habitat classes. Of 240 trees with potential nesting platforms that were climbed in Excellent habitat, five nests were found; no nests were found in Good (n = 139 trees) or Sub-optimal (n = 88) habitats. The five nests found included one used in the current year and four used in previous years. All nest-site characteristics were within the ranges found in other nest sites in BC. Within Excellent habitat, trees with nests (n = 5) had significantly larger stem diameters than trees that had potential nest platforms but no visible nests (n = 235); no other tree characteristics were significantly different. The density of trees (± SD) with potential nest platforms was 30 ± 14, 37 ± 27 and 12 ± 11 per ha in Excellent, Good and Sub-optimal habitats, respectively. Considering only nests active in the year of discovery, nest density was 0 for Good and Sub-optimal habitats and 0.11 ± 0.12 per ha (95% CI = 0 to 0.35) in Excellent habitat. Future work should increase sample sizes and optimize study design in order to improve density estimates, and should examine the applicability of these findings to fragmented and more modified landscapes.

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Introduction

Marbled Murrelet (*Brachyramphus marmoratus*) breeding habitat has primarily been evaluated on the basis of relative activity levels (detections) during audio-visual surveys, and on the measurement of habitat structures for murrelets by ground personnel (Hamer 1995, Kuletz et al. 1995, Bahn 1998, Rodway and Regehr this volume). To date, research has not determined a clear relationship between occupied behaviours of murrelets and nest densities within the forest stands where occupied behaviours are detected (Paton 1995, Bahn 1998, Rodway and Regehr 1999). Ultimately, the association of Marbled Murrelets with particular forest types should be based on nest densities and reproductive success within a habitat. Doing

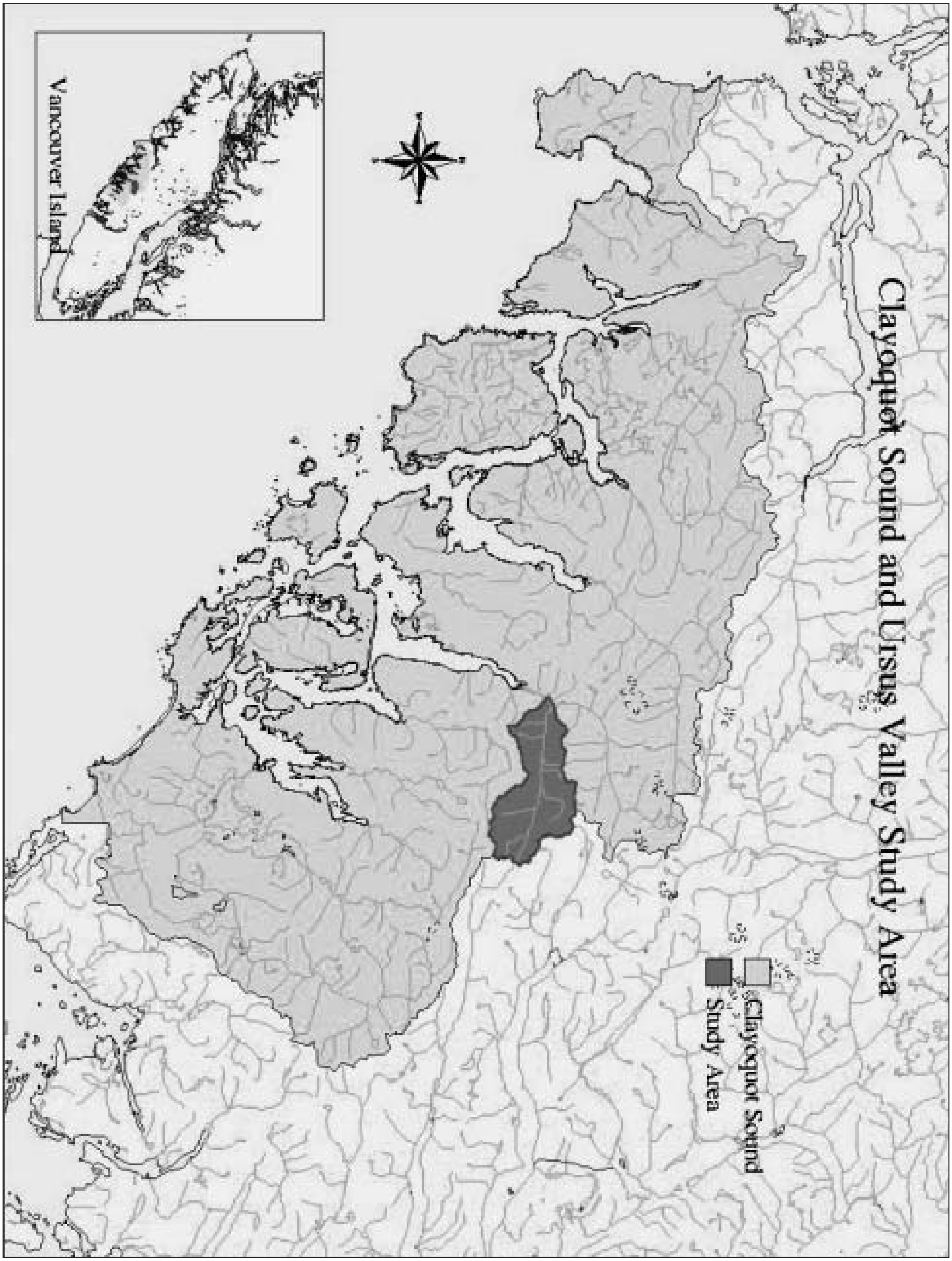

Figure 7-1. Map of the Ursus Valley, showing its location within Clayoquot Sound on Vancouver Island.

otherwise results in a risk that forest and wildlife managers will protect sub-optimal habitats where murrelets do not successfully breed in adequate numbers to maintain or recover populations.

At present, climbing potential nest trees is the only reliable method that allows a determination of nest densities in an area (Rodway and Regehr 1999). One of the challenges in the long-term management of Marbled Murrelets is to characterize the habitats used by murrelets for nesting and the nest densities that can be expected in different habitats under natural and modified conditions. Studies conducted where forests have been logged or other habitat fragmentation has occurred provide uncertain information on natural optimal conditions for nesting murrelets, making it important to undertake initial studies in unfragmented forested areas such as occur in Clayoquot Sound.

Bahn and Newsom (this volume Ch. 5) found that activity levels of murrelets and habitat quality for murrelets in forest stands could be predicted from data found on Vegetation Resource Inventory (VRI) maps, such as tree height. They also reported significant associations among habitat variables available on VRI maps, such as tree height and vertical complexity, and a range of micro-habitat variables important to nesting murrelets, such as availability of mossy platforms or density of trees with such platforms. Bahn and Newsom (this volume Ch. 6) subsequently built a habitat suitability model that allowed habitat in Clayoquot Sound to be ranked into four categories (Important-Excellent, Important-Good, Sub-optimal and Unsuitable). Our study focused on the first three categories, hereafter referred to simply as Excellent, Good and Sub-optimal.

Our objectives for this climbing project were to: compare habitat structure and the abundance of potential murrelet nest structures in three habitat suitability categories (Excellent, Good and Sub-optimal; Bahn and Newsom this volume Ch. 6); document the physical characteristics of confirmed murrelet nests and nest trees, and compare with the characteristics of trees without known nests; estimate nest densities in three different habitat suitability categories (Excellent, Good and Sub-optimal); and estimate the density of Marbled Murrelet nests in unfragmented old-growth habitat in the Ursus Valley.

Methods

Study Site

Research was conducted in the Ursus Valley (49°23' N, 125°38' W) of Clayoquot Sound, on the western side of Vancouver Island (Figure 7-1). The Ursus Valley is oriented east-west, ranges in elevation from 40 to 1612 m, and contains extensive tracts of unfragmented old-growth forest within the Coastal Western Hemlock (CWHvm1 and CWHvm2 subzones) and Mountain Hemlock (MHmm1) biogeoclimatic zones (Green and Klinka 1994).

Bahn and Newsom Habitat Suitability Model

Bahn and Newsom (this volume Ch. 6) assigned each forest polygon on VRI maps to one of four habitat suitability categories according to their Habitat Suitability Index (HSI) score. “Excellent” habitat is outstanding in terms of quantities of murrelet-relevant structures within forest stands (HSI score > 0.88; see Bahn and Newsom this volume Ch. 6). “Good” habitat provides sufficient amounts of murrelet-relevant structures and is likely to support murrelet breeding (HSI score 0.78-0.88). “Sub-optimal” habitat is of questionable quality for murrelets (HSI score 0.65-0.78). Habitat not likely to contain murrelet-relevant structures was classified as “Unsuitable” and was not examined in this analysis (HSI score < 0.65).

Vegetation Plots

In order to describe the habitat characteristics and abundance of potential murrelet nest structures, we sampled trees in each Habitat Suitability Class. Circular vegetation plots (15-m radius) were located 6 to 12 km from Bedwell Sound in the valley bottom on lower slopes, and at two higher elevation sites on the north and south sides of the Ursus Valley (Figure 7-2).

During 1998 and 1999, 20 vegetation plots were randomly selected within the lower slopes and valley bottom along a 4-km east-west transect line that was centred on the stream channel, in habitat rated as Excellent. Along that transect, perpendicular lines were placed at 200-m intervals, with the lines extending from the valley bottom up to 200 m elevation on the lower valley slope. Plot centres were located at a random distance along the 200-m perpendicular interval lines in a random direction (either north or south of the stream channel).

In 2000, 1:30,000-scale maps were used to identify polygons at higher elevations in the Good and Sub-optimal habitat categories. In each category, 12 vegetation plots were sampled by randomly selecting a direction and distance from one of two higher elevation helicopter landing sites. If a randomized plot centre presented unwarranted risks to personnel, then another location was chosen within 100 m at a random distance and bearing. One plot each in Good and in Sub-optimal habitats required reassignment in this manner; both reassignments were due to cliffs at the plot location. For larger contiguous habitat polygons, we located plots at 125-m intervals on a selected compass bearing, with the first plot located at a random distance and bearing from

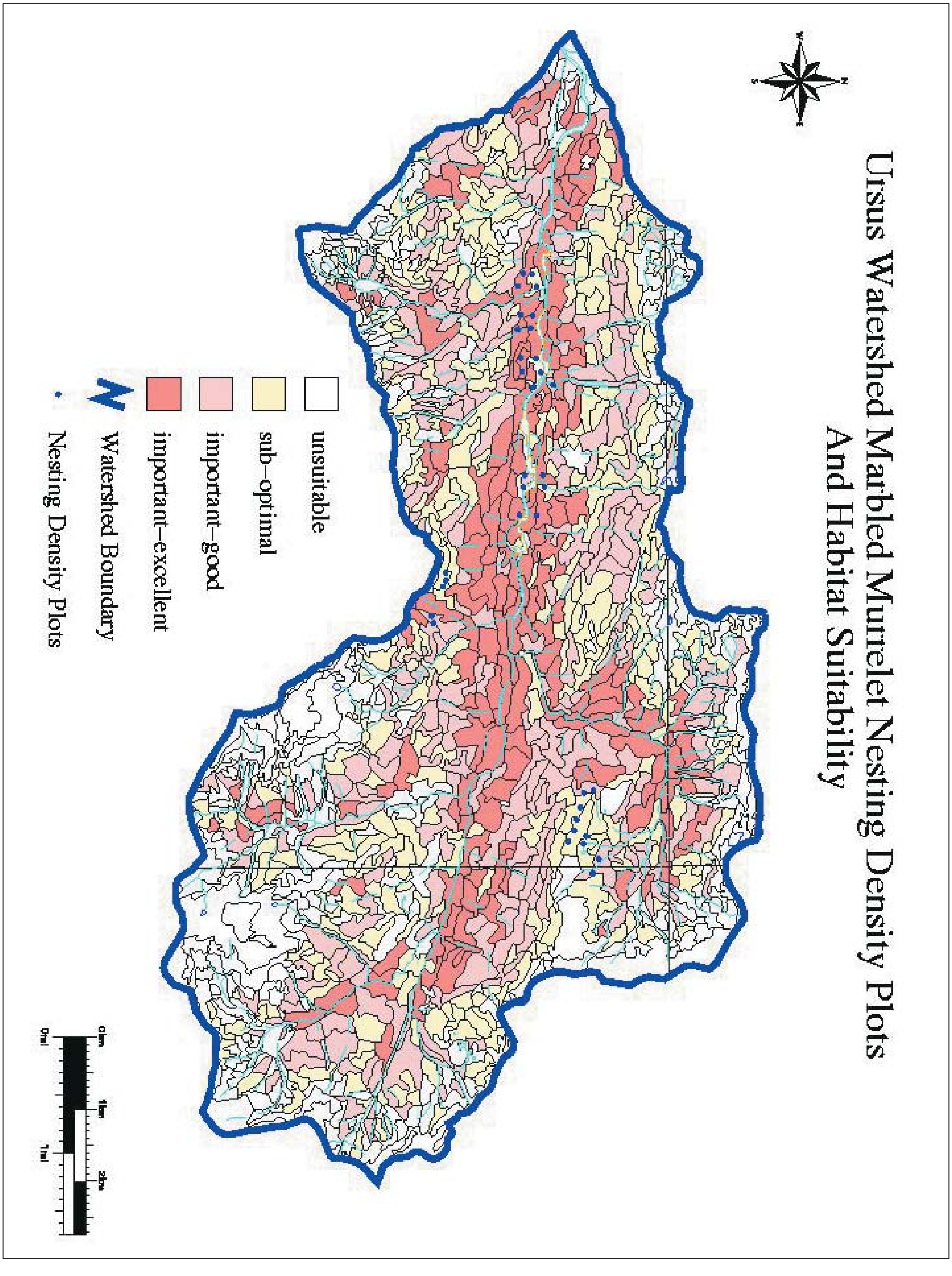

Figure 7-2. Results of Marbled Murrelet habitat suitability model applied within the Ursus Valley, Clayoquot Sound, BC.

an identifiable feature such as a creek or lake. This ensured no overlap of plots.

In each vegetation plot we collected data on the forest and tree attributes, characteristics of murrelet-relevant structures, and identified 12 trees with potential nest platforms for climbing. In this study a potential platform was defined as a branch >18 cm in diameter, including epiphyte, and at least 15 m above the ground. For our vegetation data, all trees with a diameter at breast height (DBH) >10 cm were measured and described in 15-m radius (0.07 ha) circular vegetation plots according to the Resources Inventory Committee (RIC 1997) protocol. We estimated the mean canopy closure by averaging four visual estimates at each plot centre, where we also recorded slope and aspect. The elevations for each plot were obtained from 1:20,000 TRIM maps, and distance from ocean was measured from 1:30,000 habitat suitability maps and/or 1:20,000 TRIM maps.

We recorded the following variables for each tree in the vegetation plots and for all trees climbed: species; DBH (measured to the nearest 1 cm with a DBH tape); height (estimated to the nearest 1 m after accurately measuring a sample of trees in the plot with a clinometer); position within the canopy stratum (emergent, canopy or sub-canopy); estimated number of potential nest platforms; and epiphyte cover and thickness. Ground observers estimated epiphyte cover and thickness on tree limbs for trees >10 cm DBH, with epiphyte cover based on four classes (RIC 1997): 0 = none; 1 = trace; 2 = 0-33%; 3 = 33-66%; 4 = >66%. Epiphyte thickness estimates were based on three classes: 1 = sparse mats; 2 = intermediate mats; 3 = thick mats.

Tree Climbing

Our objectives for the tree climbing were to locate recent or previously used murrelet nests and to document micro-habitat and forest structures that described nesting habitat of murrelets. Data on nest sites were collected according to Hamer and Naslund (1993).

To achieve random cluster sampling, we selected clusters of trees, which were the 12 trees closest to the centre of each randomly positioned vegetation plot that, from the ground, appeared to have at least one potential nest platform (defined above). Twelve suitable trees were found at all plots in Excellent habitat. In Good and Sub-optimal habitats, trees with platforms were identified for climbing up to a maximum distance of 50 m (slope corrected) from plot centres. Due to the low density of suitable trees, fewer than 12 trees were climbed at some plots in these two habitats and density calculations were adjusted accordingly. Although plot layout differed slightly among habitat categories, plots were always chosen randomly within the habitat polygons and the criteria for selecting trees to climb were identical.

Ground observers, using binoculars, recorded the number of potential nest platforms per tree. Tree climbers counted potential platforms, measured epiphyte thickness to the nearest 0.5 cm, and estimated the percentage epiphyte cover on limbs for all trees climbed. Climbers and ground observers could see different numbers of platform limbs per tree, and in some trees climbed, the climbers did not find platforms, especially in Good and Sub-optimal categories. Thus, our sample of trees climbed includes some trees with no qualifying platforms.

The climbers' counts were used to calculate platform density (platforms per tree), and the ground-based observations used to calculate densities of trees with platforms (platform trees per ha). For both measures we averaged plot values across each habitat category and compared differences among habitat categories using one-way ANOVA followed by Tukey-Kramer post-hoc comparisons. Results with $P < 0.05$ were reported as statistically significant.

Nest Density

To estimate the nest density (nests per ha) for each habitat category, we multiplied the proportion of trees with nests in the sample of trees climbed (i.e., nests per tree with platforms) by the density of trees with at least one platform (i.e., trees with platforms per ha). We sampled trees with potential platforms in a manner similar to stratified cluster sampling. Cluster sampling requires partitioning the entire strata into mutually exclusive and exhaustive clusters, then randomly sampling from the clusters. Our method differed from this; a point (the centre of the vegetation plot) was chosen at random and the cluster size was then determined by the radius required to capture 12 trees with platforms (as identified by ground crew), or a distance of 50 m in Good and Sub-optimal habitat, whichever was less.

Thus, clusters of trees were sampled with a probability of being selected that was proportional to the density of trees or the size of the cluster (i.e., the distance from plot centre to the furthest tree with a platform). The number of nest trees in each cluster was recorded and the proportion of nest trees was estimated by a multistage estimator. The first estimator was for cluster sampling; this included the probability that the cluster would be selected (this was proportional to the size of the cluster, or the total area that was sampled). The second estimator accounted for stratification of the data into the different sampling locations within each habitat type.

The estimated proportion of nest trees was $(\hat{\theta}) = \frac{1}{k}\sum_{j=1}^{k}\hat{P}_j$ where k was the number of polygons sampled ($j = 1,2,\ldots k$), and the estimated proportion of nest trees in polygon j was $\hat{P}_j$. The variance of the proportion of nest-trees in polygon j (i.e. $\hat{P}_j$) was $\text{var}\left(\hat{P}_j\right) = \left(s.e.\left(\hat{P}\right)\right)^2$, the square of the standard error estimate:

$$s.e.\left(\hat{P}\right) = \sqrt{\left(\frac{K-k}{K}\right)\frac{s_1^2}{k} + \frac{1}{Kk}\sum_{j=1}^{k}\text{var}\left(\hat{P}_j\right)}$$

where $s_1^2 = \frac{1}{(k-1)}\sum_{j=1}^{k}\left(\hat{P}_j - \hat{\theta}\right)^2$ and K was the total number of polygons in the area of interest.

Unfortunately, because no nests were found in Good and Sub-optimal habitat, and few plots in Excellent habitat contained nests, standard formulae for confidence intervals from the multi-stage estimator could not be used. Instead, we used a simulation technique (Ripley 1987, Johnson and Braun 1999, Chen 2000, Manzato and Tadei 2000), where we applied a random effects model and did a Monte Carlo simulation in order to estimate the confidence intervals of the proportions of trees with nests. The simulation model we chose for our data incorporated the cluster sampling used in our actual field sampling methods. We used a random effects model in order to account for the cluster-to-cluster variation in nest density. The proportion of nest trees in each habitat was considered to be a function of the overall habitat proportion, as well as a function of a random effect for each cluster. Thus we were able to model the cluster-to-cluster variation within each habitat type. This was a realistic model because trees in dense clusters may have had a different probability of containing a nest than trees in sparse clusters, or trees found within a cluster containing a nest may have had a different probability of having a nest compared to trees from a cluster without a nest.

In a simple case, upper confidence interval on a proportion can be obtained using the binomial distribution to find the proportion that gives a 0.05 cumulative probability for the observed number of events. That is, one finds the proportion that gives a 5% chance of producing the observed number of events or fewer events. Similarly, lower and upper bounds can be obtained by finding the values that give cumulative probabilities of 0.025 and 0.975 for the observed number of events. This was the basic idea we used in our simulation. Our model was somewhat more complicated because our data were collected in clusters; thus we generated data from our random effects model and then used the cumulative probabilities from the simulated data to determine our confidence interval estimates.

We divided our data into four strata: valley bottom; lower slope; and two upper valley sites – one each on the north and south sides of the Ursus. Our data showed no differences in the proportion of nests between the valley bottom and the lower slope so, for simplicity, we assumed that each stratum in our simulation had the same proportion of trees with nests.

The observed variation (SD) among proportions of trees with nests in Excellent habitat was 0.04 (see Results). Based on this estimate, several values of cluster-to-cluster variability were chosen for our simulation, in order to reflect small (SD = 0.01), moderate (SD = 0.05) and large (SD = 0.10) amounts of random variation among plots. This helped us determine the sensitivity of our estimates to variation among plots within the same habitats. There was no variation in Good and Sub-optimal habitat because no nests were observed – so either there are no nests and no variation exists, or we could not estimate the variation because our cluster sizes were too small to find a nest.

For our simulation, the number of nest trees in each cluster was generated from a binomial distribution, where N was the number of trees in that cluster, and the mean was generated from a Beta distribution. The Beta distribution, which produces values between 0 and 1, was chosen with means in increments of 0.0001 and standard deviations of 0.01, 0.05 and 0.10 in order to reflect our three levels of variation. Twenty thousand values were generated for each combination of habitat, variance and mean. These data were used to calculate the cumulative probabilities used to estimate the confidence intervals.

The nest density was estimated as the proportion of nest trees ($\hat{p}$) multiplied by the estimated density of trees with platforms ($\overline{X}$). For Excellent habitat, we obtained a 95% CI by assuming the density was normally distributed and using a Taylor series expansion for the product of two estimates (Casella and Berger 1990). The variance estimate for the density was:

$$\text{Var}(\hat{p}\,\overline{X}) = \hat{p}^2\ \text{Var}(\overline{X}) + \overline{X}^2\ \text{Var}(\hat{p}) + 2\,\hat{p}\,\overline{X}\,\text{Cov}(\hat{p}, \overline{X})$$

The variability of tree density, Var($\overline{X}$) and the variability of the proportion, Var($\hat{p}$), were estimated based on cluster-to-cluster variability in our data. The covariance between the proportion of nest trees and tree density, Cov($\hat{p}, \overline{X}$), was also estimated from the observed data.

Two separate analyses were made of nest density in Excellent habitat. First, using only our data from 1998-2000, and second, with our data pooled with those from the 1997 study (Rodway and Regehr 1999). The 1997 data were not included in our habitat analysis.

Table 7-1. Comparison of topographic, forest and tree attributes for three habitat suitability categories in the Ursus Valley. One-way ANOVA was used to test differences among categories. Means are given ± standard deviation, followed by letters indicating significant differences for pairwise comparisons among categories at the 0.05 level.

Variable	Habitat suitability category Excellent (n = 20 plots)	Good (n = 12 plots)	Sub-optimal (n = 12 plots)
Slope (%)	17 ± 17a	59 ± 22b	24 ± 13a
Elevation (m)	72 ± 23a	706 ± 155b	793 ± 191b
Canopy closure (%)	50 ± 10a	28 ± 11b	23 ± 13b
Mean epiphyte thickness class	1.84 ± 0.43a	1.26 ± 0.15b	1.14 ± 0.09b
Mean tree height (m)	25 ± 6a	15 ± 2b	13 ± 4b
Mean variance of tree height	180 ± 102a	57 ± 16b	43 ± 23b
Mean diameter at breast height (cm)	48 ± 16a	34 ± 4b	34 ± 7b
Epiphyte cover class of large trees >80cm DBH	3.48 ± 0.51a	1.86 ± 0.69b	0.71 ± 0.69c
Total tree density (trees/ha)	342 ± 148a	599 ± 121b	463 ± 139b
Density of platforms (platforms/ha)	301 ± 280a	224 ± 197a	79 ± 126b
Density of trees with platforms (trees/ha)			
a) from vegetation plots	41 ± 24a	46 ± 28a	22 ± 25a
b) from variable radius clusters*	30 ± 14a	37 ± 27a	12 ± 11b

*Estimates derived from variable radius clusters (trees climbed) were used for nest density estimates.

Table 7-2. Frequency of tree species climbed in each habitat suitability category in the Ursus Valley in 1998-2000.

Tree Species	Habitat suitability category Excellent	Good	Sub-optimal
Western hemlock *Tsuga heterophylla*	76	26	4
Mountain hemlock *Tsuga mertensiana*	0	15	11
Amabilis fir *Abies amabilis*	69	3	0
Western red cedar *Thuja plicata*	56	0	0
Yellow cedar *Chamaecyparis nootkatensis*	0	92	71
Sitka spruce *Picea sitchensis*	32	0	0
Douglas-fir *Pseudotsuga menziesii*	7	3	2
Total all species	240	139	88

Results

Application and Testing of the Habitat Suitability Model

Habitat suitability maps for the Ursus valley from Bahn and Newsom's model (this volume Ch. 6) were produced at 1:30,000. The Ursus has an estimated total area of 7,735 ha, of which 1,586 ha (20.5%) were rated Excellent, 1,827 ha (23.6%) Good, 1,868 ha (24.1%) Sub-optimal, and 2,454 ha (31.7%) Unsuitable (Figure 7-2). Twelve, seven and eight VRI polygons were sampled in Excellent, Good and Sub-optimal habitat categories, respectively.

In vegetation plots, trees in Excellent habitat had significantly higher mean epiphyte thickness, greater mean height, greater variance of tree height (an indication of canopy complexity) and larger mean stem diameters than trees in Good or Sub-optimal habitats (Table 7-1). Epiphyte cover on large (>80 cm DBH) trees was greatest in Excellent and lowest in Sub-optimal habitat. The total tree density was lowest in Excellent habitat. Platform density was lowest in Sub-optimal habitat, with no significant differences between Excellent and Good habitats. The density of trees with platforms did not differ significantly among the three habitats in the vegetation plot data, but this measure was lower in Sub-optimal habitat in the data from the clusters of trees climbed (Table 7-1). To keep data consistent in our simulation modelling of nest densities, we used the density of trees with platforms measured at the clusters of climbed trees, rather than in the 15-m radius vegetation plots, for calculating nest density.

A total of 467 trees were climbed, including seven species of conifers (Table 7-2). The species providing platforms differed among the three habitat categories. Further details on each tree climbed are archived with the Ministry of Water, Land and Air Protection, Nanaimo, BC.

One-way ANOVA was used to compare trees climbed (with or without nests) in the three habitat categories (Table 7-3). In the climbed trees, epiphyte cover and mean tree height differed significantly among all three habitat classes and both measures were highest in Excellent habitat. Epiphyte depth was significantly higher in Excellent than in Good or Sub-optimal categories. Trees climbed in Excellent habitat had more platforms per tree and were larger in diameter than those in Good or Sub-optimal habitats.

Table 7-3. Comparison of the attributes of trees climbed in the three habitat suitability categories in the Ursus Valley. One-way ANOVA was used to test differences among categories. Means are given ± standard deviation, followed by letters indicating significant differences for pairwise comparisons among categories at the 0.05 level. Sample sizes for each test are given in parenthesis.

Variable	Habitat suitability category Excellent (n = 240)	Good (n = 139)	Sub-optimal (n = 88)	F value	P
Epiphyte cover (%)	77 ± 19a*	39 ± 31b	20 ± 23c	214	<0.001
Epiphyte depth (cm)	3.1 ± 1.5a	2.1 ± 1.2b	2.0 ± 1.2b	35	<0.001
Number of potential nest platforms per tree	10 ± 11a	6 ± 7b	3 ± 3b	18	<0.001
Mean height (m)	45 ± 9a	27 ± 5b	23 ± 4c	451	<0.001
Mean diameter at breast height (cm)	121 ± 52a	80 ± 29b	74 ± 24b	61	<0.001

* n = 216; 24 trees in Excellent had epiphyte cover data collected as cover class, not % cover.

Table 4. Attributes of trees climbed in the Ursus Valley. Trees with Marbled Murrelet nests (a) were compared with those climbed with no nests in all habitats (b), and those climbed with no nests in Excellent habitat (c). Means are given ± standard deviation. One-way ANOVA was used to compare the nest trees with the two samples of climbed trees with no nests.

Variable	a) Trees climbed with nest (n = 5)	b) Trees climbed with no nest in all habitats (n = 456)	ANOVA (a vs. b) F	ANOVA (a vs. b) P	c) Trees climbed with no nests in Excellent habitat (n = 232)	ANOVA (a vs. c) F	ANOVA (a vs. c) P
Epiphyte cover (%)	72 ± 27	54 ± 34*	1.5	0.23	78 ± 19*	0.4	0.52
Epiphyte depth (cm)	3.6 ± 1.8	2.6 ± 1.4	2.4	0.12	3.1 ± 1.5	0.5	0.46
Number of potential nest platforms per tree	9.8 ± 5.2	7.2 ± 9.3	0.4	0.53	9.5 ± 11.4	0.003	0.96
Height (m)	42 ± 4	35 ± 12	1.7	0.19	45 ± 9	0.4	0.52
Diameter at breast height (cm)	171 ± 92	99 ± 46	12	<0.001	120 ± 51	4.8	0.03

* 24 trees in Excellent did not have % epiphyte cover data.

Characteristics of Trees with Nests

We located five Marbled Murrelet nests (details in Appendix 7-1). One was active in the year of discovery and four had apparently been used in previous years (nests remain visible for about four years; K. Jordan unpubl. data). All nests were in habitat rated as Excellent and none were in Good or Sub-optimal habitat. Three of five nest trees were located on sloping terrain, two on north-facing slopes (bearings 358° and 23°), one on a south-facing slope (193°), and two were located on the valley bottom.

Trees in which murrelet nests were found were significantly larger in diameter than trees climbed in which no nests were found (Table 7-4). Although other attributes were not statistically significant, trees with nests had, on average, more platforms per tree, more abundant and thicker epiphyte cover, and were taller than climbed trees without nests. When these comparisons were restricted to trees in Excellent habitat, in which all the nests occurred, diameter of the nest trees remained significantly larger than trees without nests, but no other characteristics differed (Table 7-4).

Nest Density

From the nests found by climbing in the stratified cluster samples we calculated the proportion of trees with nests as 0.018, 0.000 and 0.000 for Excellent, Good and Sub-optimal habitats, respectively. The possible range in the proportions of trees with nests for each habitat category as estimated by the random effects and binomial models are shown in Table 7-5.

We calculated the density of trees with at least one potential nest platform as 30 ± 14 trees per ha in Excellent habitat (Table 7-1). From the proportion of trees with nests in Excellent habitat (0.018), using the Taylor expansion, we calculated the mean nest density as 0.53 ± 0.24 (SD) visible nests per ha (95% CI, 0.05 to 1.0; Table 7-6). We only observed one nest apparently active in the year of discovery in 240 trees climbed, giving a density of active nests as 0.11 ± 0.12 (95% CI = 0-0.35) nests per ha per year. The upper bound of the density of active nests was somewhat underestimated because the assumption of normality does not hold with such a small density estimate.

We calculated the density of trees containing at least one potential nest platform to be 37 ± 27 per ha in Good, and 12 ± 11 per ha in Sub-optimal habitat (Table 7-1). No nests were found in those habitats, therefore the estimated nest densities were 0. However, using the upper confidence bounds from the random effects model with moderate variation among clusters (Table 7-5), and

Table 7-5. Proportions of trees with nests in each habitat type as estimated from 1998-2000 tree climbing data using a random effects model, and a binomial model. Simulations in the random effects model used three different estimates of the standard deviation of nest density (0.01, 0.05, and 0.10). The 95% confidence intervals (CI) are shown in parentheses.

	Random effects model			
Habitat	SD = 0.01 (95% CI)	SD = 0.05 (95% CI)	SD = 0.10 (95% CI)	Binomial model (95% CI)
Excellent	0.018 (0.006 to 0.048)	0.018 (0.001 to 0.056)	0.018 (0 to 0.061)	0.018 (0.007 to 0.048)
Good	0.00 (0 to 0.022)	0.00 (0 to 0.030)	0.00 (0 to 0.047)	0.00 (0 to 0.021)
Sub-optimal	0.00 (0 to 0.034)	0.00 (0 to 0.042)	0.00 (0 to 0.058)	0.00 (0 to 0.034)

Table 7-6. Summary of nest density estimates for Excellent habitat using tree climbing data from a) 1998-2000; and b) pooled data from 1997 (Rodway and Regehr 1999) and 1998-2000 (this study). Visible nests included some used in previous years, but active nests included only those active in the year discovered. The means ± SD and 95% confidence intervals (CI, in parentheses) are given.

Data source (Method in parentheses)	Visible nests per ha ± SD (95% CI)	Active nests per ha ± SD (95% CI)
1998 – 2000 only (Taylor Expansion)	0.53 ± 0.24 (0.05 to 1.0)	0.11 ± 0.12 (0 to 0.35)
All Data Pooled (Taylor Expansion)	0.66 ± 0.29 (0.08 to 1.24)	0.13 ± 0.13 (0 to 0.39)
All Data Pooled (Simple Binomial)	0.69 ± 0.31 (0.23 to 1.60)	0.14 ± 0.14 (0.0035 to 0.77)

the upper confidence bound on tree densities (mean + 2 SE), we calculated the upper bounds of estimated nest density as 1.56 and 0.78 nests per ha, for Good and Sub-optimal habitat, respectively.

We combined data from the 70 trees climbed in 1997 (Rodway and Regehr 1999), which were almost entirely within Excellent habitat in the Ursus Valley, with our data from that habitat (the criteria for selecting the climbing trees were the same). These combined data showed a density of trees with at least one potential platform as 41 ± 31 trees per ha, and an estimated proportion of trees having nests as 0.016 ± 0.007 (5 out of 310 trees climbed with platforms, all from 1998-2000 and, as noted above, only one was active in the year discovered). Using these numbers we calculated densities of 0.66 ± 0.29 visible nests per ha, and 0.13 ± 0.13 active nests per ha per year in Excellent habitat (Table 7-6). The confidence intervals for these pooled data were calculated using the Taylor expansion, but assumed independently sampled trees (binomial model) and no correlation between the proportion of nest trees and tree density.

Early in our analysis, we used a simple Binomial model (without Taylor expansion) for preliminary estimates using the pooled data from our study and that of Rodway and Regehr (1999). With this simpler method we calculated the density of all visible nests in Excellent habitat as 0.69 ± 0.31 per ha, and the density of active nests per year as 0.14 ± 0.14 per ha (Table 7-6).

In order to assess the chance that our study would find no nests in Good and Sub-optimal habitat even if there were nest in these regions, we generated probability graphs (Figure 7-3) for Good and Sub-optimal habitats, based on the final term of a Binomial expansion for each habitat category (see Methods). These indicate that there was about a 6% chance of us not finding a nest in Good habitat, and a 20% chance of us not finding a nest in Sub-optimal habitat, if the proportion of trees with nests in those areas was the same as in Excellent habitat (0.018).

Discussion

Reliability of the Habitat Suitability Model

Our data allow some assessment of the habitat suitability model of Bahn and Newsom (this volume Ch. 6). Several forest structural characteristics thought to be important to nest-site selection in Marbled Murrelets (Grenier and Nelson 1995, Hamer 1995, Kuletz et al. 1995, Bahn 1998, Manley 1999, Bahn and Newsom this volume Ch. 5, Rodway and Regehr this volume) were more prevalent in Excellent than in Good and Sub-optimal habitats. Excellent habitat had higher epiphyte thickness on trees, greater tree height, greater variance in tree heights (indicating a more layered canopy), and larger stem diameters than Good or Sub-optimal habitats, and greater epiphyte cover on large (>80 cm DBH) trees than Sub-optimal habitat. Although our data from tree-climbing indicated that trees with platforms climbed in Excellent habitat had significantly more platforms per tree than in Good and Sub-optimal habitats, we detected no difference in platform densities per ha between Excellent and Good habitats. Density of trees with platforms identified from the ground in variable-radius climbing plot data was lower in Sub-optimal than in Excellent and Good habitats. Estimates for density of trees with platforms were derived from variable-radius climbing plot data, which underestimates the area sampled and tends to overestimate the density of trees with platforms.

These results indicate that the habitat suitability model of Bahn and Newsom (this volume Ch. 6) can predict some important characteristics at the element (tree) and micro-site scales (such as thick and abundant epiphyte cover, and very large trees). However, with our small sample size and the study design, which was aimed at selecting climbing trees, we were not able to confirm the ability of the model to predict high densities of trees with platforms and densities of platforms.

There are several possible explanations for our inability to associate high densities of platforms and platform trees with Excellent habitat. These possibilities are: 1) our data are insufficient for such a comparison; 2) there was no detectable difference in densities of trees with platforms between Excellent and Good habitats; 3) the map data underlying the model were inaccurate (e.g., photo-interpretation errors); 4) field sampling errors occurred; 5) the model itself was the source of error.

The first possibility was the most likely explanation for the failure to find significant differences in a few important habitat characteristics among the three habitat categories. Only seven forest cover polygons were sampled in Good habitat. In addition, vegetation plots sampled within the same polygon were not independent in relation to the habitat category, so these results need to be interpreted cautiously. Due to inherent high variability in the habitat, the standard deviation around our means was large and the power of our tests was typically low, so non-significant tests should not be interpreted as conclusive results.

Rodway and Regehr (this volume) found no difference in density of trees with platforms and density of platforms between valley-bottom and slope habitats in the Ursus, nor among subzone variants CWHvh1, vm1 and vm2, which lends support to the second possible explanation presented above. It was possible that differences in the densities of platforms or trees with platforms did not exist between Good and Excellent habitats, or our sample sizes were insufficient to detect subtle differences.

We found evidence in our own results pointing to inaccuracies of the map data. During 1998 and 1999, the habitat suitability model results were not available on maps, and all vegetation plots were placed on the valley bottom or lower slopes in habitat presumed to be Excellent. When the plots were carefully compared to the habitat suitability map, some plots presumed to be in Excellent, actually were found to be in habitat classified as Good (plot 16, upper slope), Sub-optimal (plots 1 and 2, lower slope) or Unsuitable (plots 8 and 9, lower slope) habitat (Figure 7-2). We compared the

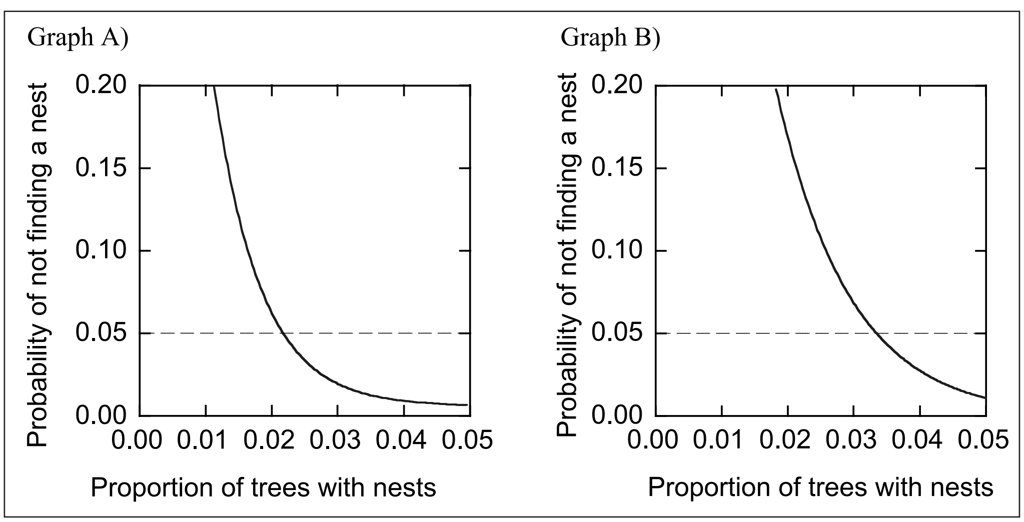

Figure 7-3. Changes in the probability of not finding a Marbled Murrelet nest with increasing proportion of trees with nests in Good (Graph A; n = 139 trees sampled) and Sub-optimal (Graph B; n = 88) habitats. These probabilities were calculated from the final term of a Binomial expansion term $Y = (1-X)^n$, where n is the number of trees sampled, and X is the proportion of trees with nests (assumed to be 0.018 as in Excellent habitat).

characteristics of these plots to other plots in Excellent habitat and found that they all fell within the range of values expected for that habitat. Furthermore, the VRI maps were based on air photo interpretation and thus might deviate substantially from the actual vegetation on the ground. Bahn and Newsom (this volume Ch. 6) discuss map accuracy. Map inaccuracies directly translate into inaccuracies in the model.

Sampling errors in the field may have contributed to large variances in the data. Possible sources of error could have been observer biases, inaccuracies in the determination of field locations on the map and sampling biases.

The last possible explanation was that the habitat suitability categories of the model do not reflect densities of platforms and trees with platforms. Tree height was one of seven mapped variables that the model was based on (Bahn and Newsom this volume Ch. 6). Although few studies have identified tree height as significantly related to murrelet inland detection rates (Hamer 1995, Kuletz et al. 1995, Bahn 1998), tree height was highly correlated with other variables consistently found in Excellent habitat that are important at the element (tree) and micro-site (nest) scales (Bahn and Newsom this volume Ch. 5). Manley (1999) indicated that, at least at the element scale in higher elevation CWH forests on British Columbia's Sunshine Coast, tree height was not a good predictor of murrelet use for nesting because many nest trees were old with broken tops, and hence shorter than their neighbours. With only five nests in our sample, we were not able to detect a difference in heights between trees with and without nests.

At this stage the data are inadequate to rigorously test and isolate these possible sources of variation. We suggest increasing our sampling in future studies, especially in the less sampled Good and Sub-optimal habitats.

Characteristics of Nests and Trees with Nests

The characteristics of the nest site, nest tree, nest branch and nest cup of the Ursus nests (Appendix 7-1) were similar to corresponding values of nests documented by Nelson (1997) and Manley (1999). Of the 136 nests in Nelson's analysis, 51 were located in British Columbia. The five Ursus nests had characteristics within the range of values from other nests in BC for diameter at breast height, tree height, trunk diameter at nest limb, nest limb diameter proximal to nest, and nest distance from trunk. The only exception was the nest in Transect 2 Tree 10, located on a broken limb 0.4 m in length, which was shorter than other nest limb lengths reported (Nelson 1997).

Although statistical comparisons of nest and non-nest climbing trees were limited by our sample size, it is valuable to look at the trends that appear in these data. Within Excellent habitat, trees containing nests were slightly shorter on average, had more abundant and thicker epiphyte cover, and had significantly larger diameters than trees climbed without nests (Table 7-6). With the exception of height, these results are consistent with other studies at the element (tree) and micro-site (nest structure) level (Hamer and Nelson 1995, Manley 1999).

Nest Density

Nest density estimates for Excellent habitat in the Ursus of 0.53 ± 0.24 visible nests per ha are comparable to a number of other studies conducted in BC. In 1997, Rodway and Regehr (1999) sampled a 64-ha area in the Ursus within Excellent habitat in the valley bottom with an estimated $1,378 \pm 936$ trees with potential nest platforms. Seventy trees were randomly climbed; no nests were located, but their analysis indicated with 95% confidence that a density of less than 1.42 nests per ha was likely if only the valley-bottom forested area was considered. For their entire study area (including stream channels, etc.) they obtained a nest density estimate of less than 0.86 nests per ha.
Based on tree-climbing, Manley (1999) found a mean nest density in fragmented habitats on the Sunshine Coast of 0.3 to 0.7 nests per ha, with a maximum nest density of 4.2 nests per ha in some areas where semi-colonial nesting seemed to occur. No distinctions were made between recently active and nests used in previous years. In the Carmanah-Walbran watersheds of southwest Vancouver Island, Bahn and Burger (unpubl. data) found a nest density of 0.60 ± 0.35 (SD; 0.25 to 0.95) nests per ha in 158 randomly chosen valley-bottom trees, which included nests active in previous years.

Comparing density estimates from studies conducted in pristine habitat (this study, Rodway and Regehr 1999, V. Bahn and A. Burger unpubl. data) with estimates from highly fragmented forests (Manley 1999), the results support the hypothesis that murrelets do not "pack" into smaller fragments of suitable habitat at higher densities (Burger 2001, this volume). Although murrelets may at times exhibit semi-colonial nesting behaviour, no evidence presently exists that supports the hypothesis that murrelets nest at higher densities in fragmented but otherwise suitable habitat.

It is also worth comparing our nest density estimates to nest densities deduced from Ursus radar data (Burger this volume). Radar estimates of murrelets entering the Ursus Valley each morning during the breeding season in 1995-1998 ranged from 249 to 554 (mean 341), which represents 75% of the total numbers of murrelets entering the Bedwell-Ursus watershed during radar counts. The proportion of breeding adults in the population is not known, but estimates range from 63 to 95% (Burger 2002). If we include immature birds flying inland and counted on radar, a rough estimate is that two-thirds of the birds will be breeding. Since both parents are likely to fly inland each morning to a nest during chick-rearing, the number of nests at any one time during the breeding season in the Ursus would be approximately one-third of the radar count (i.e., 114 nests, range 83-185).

If only Excellent habitat is considered (1,585 ha in the Ursus), our estimate of 0.11 new nests per ha per year gives an estimate of approximately 174 new nests on average in the Ursus during a breeding season. This number is consistent with the radar estimates; 114 nests at any one time mean that there could be considerably more nests over the whole breeding season, taking into account repeat nesting of failed birds. If we assume that Good habitat (1,827 ha) has at least the same proportion of trees with nests as Excellent does, then approximately 200 additional new nests could be added to the estimate for Excellent, for a total of 374. This figure is close to the upper bound of the possible radar estimates. We must therefore consider the hypothesis that nest densities in either Good and/or Sub-optimal habitats are less than in Excellent habitat.

When the nest density of a species is low, there is a high probability that the nests will be missed in a sample. For example, for the 70 trees sampled by Rodway and Regehr (1999), there was a 37% chance that no nests would be found if the proportion of trees with nests was 0.014 (one in 70). When a range of hypothetical nesting densities were examined by Rodway and Regehr, there was only a 5% chance that no nests would have been found if the proportion of trees with nests was 0.04. Thus, they had high confidence that the proportion was actually lower than that. However, there was a 30% or 21% chance of not finding a nest in 70 trees if the proportion of trees with nests in Excellent habitat actually was 0.018 or 0.021, as estimated by our method or the binomial method, respectively.

If we consider the possibility that the proportion of trees with nests in Good habitat is actually the same as in Excellent (0.018), then the probability graphs that we present in Figure 7-3 indicate that we had approximately a 6% chance of NOT finding a nest in Good habitat. Therefore, the assumption that Good habitat is at least as good as Excellent seems unlikely. The same does not hold true for Sub-optimal habitat, however. The corresponding graph in Figure 7-3B indicates that there was approximately a 20% chance of not finding a nest if the proportion of trees with nests in Sub-optimal was also 0.018. This result was partly due to the small sample size in sub-optimal.

These graphs also illustrate an important consideration for future studies: sample size. The graphs suggest that, in order to obtain good estimates of the proportion of nest trees in these habitats, and in order to detect differences in proportions among the habitat suitability classes, very large sample sizes are required. When we examined possible sample sizes that would improve our confidence intervals, we found that 2,500 trees would be required in each of two habitats to show a difference between 0.02 and 0.01 – or 1,600 trees per habitat to show a difference from 0.03 to 0.015. Demonstrating statistical differences may be an unrealistic goal for these field investigations, but increasing sample sizes would provide tighter confidence intervals for estimates of nest density.

Sampling Methods

We encountered a number of sampling problems during this study. Our sampling method involved choosing a random point as plot centre, sampling the forest in a 15-m radius, and then climbing the twelve trees with platforms clustered closest to the plot centre. Thus, cluster area was determined by the radius required to capture 12 trees, and clusters in sparsely populated areas often had larger total areas. The trees in these habitats were therefore slightly over-represented in our data. In addition, a variable-radius plot systematically underestimates the area that was sampled and overestimates the density of trees with platforms. This was a problem we could not easily overcome – our calculations required the variable-radius climbing plots to estimate proportions of trees with nests, so for consistency we used the same areas to calculate the density of trees with platforms. In our opinion, combining fixed- and variable-radius data was not a preferred method, and although we chose to use the estimates of trees with platforms from the variable-radius plots (Table 7-1), we present the data from fixed-radius vegetation plots for comparison.

Ground crews identified trees with potential platforms to be included in our sample. This method introduces a visual bias, resulting in a difference in platform counts between those estimated by ground crew and those obtained by climbers. This visual bias has been observed in other studies. Both Manley (1999) and Rodway and Regehr (1999) found that ground crews underestimated the platform count for trees with high numbers of platforms, and overestimated numbers of platforms when trees had few platforms. In our Good and Sub-optimal categories, climbers sometimes found no platforms that matched the strict qualifying criteria. Thus, our sample contains some trees with no qualifying platforms. We used the estimates of trees with potential nest platforms as obtained by ground crews, and platform counts obtained by climbers to determine densities.

Another problem, which affected the randomization of plots, was access and safety issues for field crews working in mountainous, unfragmented forest areas in Clayoquot Sound. Complete randomization of sampling was not possible due to budgetary limitations and the hazards associated with severe terrain and conditions found within the Ursus Valley. For these reasons, plot layout was conducted with a stratified randomization method; accessibility to plots in a safe and timely manner from two helicopter sites was the deciding factor in stratifying and determining the sampling locations in Good and Sub-optimal habitat. From the helicopter sites, plots were laid out randomly within the identified polygons, so that randomization within selected polygons did occur. Future work could focus on correcting these sampling errors, and could also correct elevational biases in sampling; Excellent habitat above 200 m elevation and Good or Sub-optimal habitats below 400 m were not sampled also due to logistic and budgetary limitations.

Statistical Analysis

The simulation method we used to obtain our confidence intervals for proportions of trees that contain nests (Table 7-5) provides a more realistic estimate than when independent sampling of trees was assumed, although the results are similar. The simulation allows one to assess the influence of random variation among clusters, or among plots in the same habitat type. In our case, the upper bound on the proportion of trees with nests was not greatly influenced by changes in this cluster-to-cluster variation. Therefore we chose a moderate amount of variation (SD = 0.05), which we feel gives a reasonable estimate considering that analysis of our field data resulted in a SD of 0.04.

The model we used for the simulation was somewhat simplified, as we assumed that each forest stratum within a habitat type had the same proportion of trees that contained nests. We did not have enough data to determine reliably whether this was a reasonable assumption. A more complex model may be justified in future studies with more accurate estimates for each stratum.

Lack of statistically significant differences between trees with and without nests for measures such as cover and depth of epiphytes were likely due to the small sample size of nest trees (Table 7-4). We reported results with $P < 0.05$ as statistically significant, however multiple hypotheses were tested, so our type one error rate could be as large as 0.95. Thus, our study was likely to have found at least one significant difference that was due to chance alone.

In addition, for the nest density estimate 0.11 ± 0.12 (95% CI: 0-0.35) nests per ha, we assumed a normal distribution on the proportion of trees with nests. With such a small estimate, the assumption of normality was not appropriate and probably underestimates the upper bound, with a true value probably closer to 0.40. For studies like this one (i.e., small proportions of nest trees), sampling plans need to be carefully developed to obtain unbiased estimates with confidence intervals that are meaningful.

The simpler Binomial model assumes that each tree in a given habitat has the same chance of containing a nest, and each tree in a habitat was independent of the others. Because trees were sampled in clusters of 12, we felt these assumptions were not reasonable for our data. On the Sunshine Coast, Manley (1999) did find a number of nests that were located within 120 m of at least one other nest, which suggests that, at least in the fragmented, higher elevation Cedar-Hemlock forests where that study was conducted, the birds may have exhibited semi-colonial nesting behaviour. Therefore, we had no confidence that trees within a cluster were no more similar to each other than to trees in other clusters in the same habitat type. Therefore, although the binomial method was not appropriate because of the probable lack of independence of trees, we present the results, which were used for management decisions before we had refined our statistical methods (Chatwin this volume).

Conclusions

Our results indicate that the habitat suitability model of Bahn and Newsom (this volume Ch. 6) can predict the locations of habitats with a higher prevalence of tree and micro-site characteristics important to nesting Marbled Murrelets. Such characteristics include very large trees with thick and abundant epiphyte growth. We could not confirm the ability of the model to predict high densities of platforms, or trees with platforms, nor to detect differences in estimated nest densities among the habitat suitability categories.

Our results indicate, however, that murrelets nest in very low densities in southern British Columbia. Other studies, conducted in relatively pristine habitat (Rodway and Regehr 1999, A. Burger and V. Bahn unpubl. data) and in fragmented forests (Manley 1999), show similarly low nest densities for murrelets. Drawing comparisons between studies conducted in pristine habitats to those conducted in fragmented forests has obvious limitations, but no evidence presently exists to support the hypothesis that murrelets nest at higher or lower densities in fragmented but otherwise suitable habitat. Regardless, the very low nest density estimates obtained from this study and others indicate that significant amounts of forest habitat are required as reserves in order to maintain present nesting populations of murrelets as determined by radar counts.

In addition, the very low proportions of trees with nests create significant sampling, analytical and logistic challenges. Although climbing trees is the only method that can accurately determine nest density at present, it is expensive and logistically complex. It does, however, provide information not available from other methods. Radio-telemetry can be used to locate active nests and to provide crucial information regarding habitat use and selectivity, breeding success, and patch, element and micro-site information. Radio-telemetry, however, cannot provide a reliable measure of nest densities for an area. Radar counts are probably the most cost-efficient method of obtaining general density estimates for murrelets using a watershed during the breeding season. Unfortunately, it is not always possible to conduct radar surveys due to topographical constraints. In such cases, randomized climbing of trees to search for nests is the only method currently available that provides density information. Although more costly than radar work, the cost per nest for climbing trees is comparable to telemetry studies, and this method provides similar data, including density information. Therefore, when combined with radar counts, tree climbing can provide crucial and supplemental data for an area.

This study was conducted in unfragmented forests of the west coast of Vancouver Island, and the applicability of these findings to forests that have undergone significant fragmentation and/or modification is unknown. Future studies are recommended that would examine the applicability of the model and corresponding climbing data to less pristine areas on Vancouver Island, mainland British Columbia or other parts of the murrelet's range.

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Appendix 7-1. Site, nest tree, nest limb and nest cup characteristics of five Marbled Murrelet nests found in randomly chosen climbing tree plots in the Ursus Valley.

	Transect 2 Tree 10	Transect 4 Tree 11	Transect 5 Tree 1	Transect 16 Tree 13	Transect 18 Tree 5
Climbing year	1998	1998	1998	1999	1999
Year nest was active	1996	possibly 1995	1998	1997 or 1998	unknown
Site Characteristics					
Habitat suitability category	Excellent	Excellent	Excellent	Excellent	Excellent
Elevation (m)	100	50	90	100	55
Distance to Ursus Creek (m)	403	180	288	118	95
Distance to ocean (km)	5.0	5.4	5.5	7.7	7.9
Aspect (degrees)*	23	N/A	358	193	N/A
Slope (degrees)*	35	0	31	38	0
Biogeoclimatic variant	CWH-vm1	CWH-vm1	CWH-vm1	CWH-vm1	CWH-vm1
Tree density (trees per ha)*	240.7	141.6	566.3		
Canopy closure (%)*	45	50	50	45	50
Stand age (years)**	300	300	350	-	-
Nest Tree Characteristics					
Species	western redcedar	Sitka spruce	western redcedar	amabilis fir	western hemlock
Tree condition	declining	alive	declining	alive	alive
Diameter at breast height (cm)	310	190	163	60	133
Height (m)	44	44	38	38	48
Canopy layer	Overstorey	Overstorey	Middlestorey	Middlestorey	Overstorey
Canopy lift (m)	25	13	15	13	15
Crown ratio (%)	43	70	60		
Nest height/Crown height (%)	30	75	80		
No. of potential nest platforms	15	18	8	8	4
Trunk diameter at nest limb (cm)	57.3	89.7	87.9	30	36.4
Height at nest limb (m)	38.2	40.2	19	25	34.5
Moss cover (%, all limbs)	40	70	30	95	95
Lichen cover (%, all limbs)	20	10	2	trace	0
Nest Limb Characteristics					
Limb condition	broken, short stub	healthy	dead	healthy	healthy
Landing pad present?	yes	yes	yes	no	no
Landing pad dimensions (cm)	12.8 x 6.8	16 x 23	5.3 x 15.8	N/A	N/A
Nest limb length (m)	0.40	5.15	0.5 horiz, 9 vertical	3.5	5
Limb diameter at trunk (cm, including moss)	74.3	33.6	43.8	14.5	13.5
Limb diameter at nest (cm, proximal and distal)	23.7, 16	24.5, 24.5	43.8, 42.6	15, 15 (w/moss)	15, 13
Moss cover on nest limb (%)	99	75	100	100	98
Lichen cover on nest limb (%)	trace	trace	trace	trace	0
Limb aspect (degrees)	138	325	310	235	238
Nest Cup Characteristics					
Distance from trunk (cm)	0	58.2	0	34	44
Inside of nest rim (mm)					
Length	90	70	102	90	90
Width	95	72	88	90	90
Depth	22	28	27	N/A	26
Platform (cm)					
Length	29	135	38	69	N/A
Width	26	23	32	13	N/A
Depth	19	21.8	28	3	3
Nest cup materials	moss, needles	moss mat depression	shell fragments, faeces, dry moss	moss, needles, feathers	needles, fine debris
Average depth materials (mm)	11	18	14	20	30
Vertical cover (%)	60	80	10	80	40
Downy feathers present?	yes	?	no	yes	no
Excrement present?	no	no	yes	no	no
Eggshells present?	yes	yes	yes	no	no

*These data derived from one 15 m-radius circular vegetation plot performed at each tree-climbing plot.
**These data derived from the Vegetation Resources Inventory map polygon in which each tree-climbing plot fell.

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Management of Marbled Murrelet Nesting Habitat in Clayoquot Sound

by Trudy A. Chatwin

Abstract

I applied the 1995-2000 research and inventory data to implement the Clayoquot Sound Scientific Panel's recommendation relating to planning for sustainable ecosystem management and protection of Red- and Blue-listed species. I assessed the adequacy of protection of Marbled Murrelet (*Brachyramphus marmoratus*) nesting habitat in the Existing Reserve Network of four planning units (Bedingfield, Cypre, Flores Island and Tofino-Tranquil). My goal was to ensure that the quantity and quality of the reserves would sustain present nesting populations of murrelets. A combination of audio-visual and vegetation surveys defined nesting habitat attributes for Marbled Murrelets, which were then used to construct a Habitat Suitability Model applied to Vegetation Resource Inventory maps. Population estimates (from radar counts) and nest density data (from the tree-climbing study) were combined to evaluate how much nesting habitat ranked as "Important" (Important-Excellent + Important-Good) by the Habitat Suitability Model was needed to sustain the existing population of murrelets in Clayoquot Sound. There was a high degree of uncertainty around the nest density data, which affected the estimate of habitat required. The mean nest density from the field study indicated that at least 21,400-28,600 ha (28-38%) of Important habitat was needed in the five planning units to sustain the present nesting population. More than 38% of Important habitat was in the Existing Reserve Network, but was not in the large patches (≥200 ha) recommended for Marbled Murrelets. To minimize risk and ensure that 17-26% of the Important habitat was reserved in areas >200 ha, I proposed additional Marbled Murrelet reserves for the four planning units. The proposed new reserves, combined with the smaller existing reserves, would protect approximately half of the Important habitat identified in these planning units. Larger reserves should minimize edge-related nest failures and provide some compensation for loss of nesting habitat outside reserves due to forest harvesting. If, through adaptive management research, it can be shown that Marbled Murrelet populations do not decline when their habitat is fragmented, the inclusion of larger reserves allows later changes in reserve design. However, if, as current research indicates, murrelet numbers decline as their habitat is fragmented, the larger reserves will provide source habitats to help recolonize modified areas. If recently harvested watersheds show declines in murrelet populations despite the inclusion of reserves, then additional reserves will be needed. Reserve design based on these multi-scaled, science-based research and inventory techniques has application to ecosystem management of nesting habitat throughout the Marbled Murrelet's range.

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Introduction

The Marbled Murrelet (*Brachyramphus marmoratus*) is a small seabird that is distributed along the Pacific coast from the Aleutian Islands in Alaska, to Santa Cruz, California (Ralph et al. 1995, Nelson 1997). It dives for small fish in the nearshore area, mostly within a couple of kilometres of the coast. Unlike other seabirds, Marbled Murrelets do not usually nest on the ground in colonies, but usually nest on the mossy limbs of old-growth trees. Their unusual mottled brown plumage, high-speed flight through the forest in the dark pre-dawn period, dispersed nests and secretive behaviour make the Marbled Murrelet very difficult to observe, but suggest that its breeding pattern has evolved to avoid predators. Marbled Murrelets are listed as Threatened in Canada and throughout most of their range, including British Columbia, Washington and Oregon. In California their status is Endangered, and in Alaska, Marbled Murrelets are being considered for listing. The main factors and threats considered in listing this species in Canada included loss of nesting habitat through logging and fragmentation of old-growth forest, low reproduction rates (only one egg per pair per year), high nest predation by corvids, declining abundance in many areas and susceptibility to oil spills and entanglement in fishing gear (Rodway 1990, Kaiser et al. 1994). Due to its Threatened status and interaction with forestry, the Marbled Murrelet has become the focus of both controversy and the study of its complex habitat relationships, at sea and in forests.

Clayoquot Sound provides a combination of productive nearshore marine feeding habitat and large tracts of old-growth forest used as nesting habitat. Clayoquot Sound harbours over one-third of Vancouver Island's Marbled

Murrelets and over one-tenth of British Columbia's population (Burger 2002). Forest management in Clayoquot Sound is therefore provincially significant to conservation of Marbled Murrelets. The recognition of this significance and the recommendations of the Clayoquot Sound Scientific Panel for Sustainable Ecosystems provided the stimulus to research and develop a multi-scaled conservation strategy for Marbled Murrelets in Clayoquot Sound.

The major goals of the studies completed in 1995-2000 were to determine habitat relationships and population numbers for Marbled Murrelets at multiple spatial scales, and to then use this information to manage forests for conservation of the murrelet. Spatial scales included regional, sub-regional, stand and micro-site (tree) scales. At the regional scale (which includes the entire Clayoquot Sound region), the population during the breeding season was estimated and compared to the overall BC and range-wide populations (Burger this volume). Planning for reserves occurs at the sub-regional level within large planning units made up of aggregations of watersheds, such as the Bedingfield, Cypre, Flores Island or Tofino-Tranquil Planning Units. Logging plans are developed at the stand level (stand defined as a community of trees sufficiently uniform in species composition, age, arrangement and conditions to be distinguishable as a group from the adjacent forest or vegetation, thus forming a silvicultural entity; Clayoquot Sound Scientific Panel 1995). At the smallest scale, individual trees have a variety of micro-site conditions that affect their suitability for nesting, such as height, moss cover, and number and type of potential nest platforms. Identification of individual nest trees is valuable as an indicator of habitat selection and such trees can be protected in the context of a large or stand-level reserve.

Under the Clayoquot Sound planning process, the identification and designation of reserves for a variety of ecosystem and cultural values is a primary objective and occurs prior to planning forest harvesting activities. The management goals for Marbled Murrelets were based upon the recommendations of the Clayoquot Sound Scientific Panel (1995) and the provincial importance of the area for the species. At the landscape level, our goal was to ensure that Clayoquot Sound's reserves contained adequate amounts and quality of nesting habitat, set aside in a well-distributed pattern. Each planning unit's reserve network should provide enough high-quality nesting habitat to act as a "source" habitat (Pulliam 1988), where Marbled Murrelets can successfully breed. Poor-quality habitats may act as population "sinks" by attracting both murrelets and corvid predators, which can result in unsuccessful nesting and ultimately cause a decline in that murrelet population.

At the landscape level, I first defined suitability of nesting habitat using the Habitat Suitability Model, based on forest structure and attributes known to be important to nesting Marbled Murrelets (Bahn and Newsom this volume Ch. 6). Secondly, the patch size and distribution of the high-quality habitat was examined. Large patches of suitable interior forest are important to nesting murrelets to offset predation effects that are prevalent at harvest edges (Manley and Nelson 1999, Burger 2002). Because little is known regarding the distribution and success of nests in Clayoquot Sound, I wanted to have high-quality reserves distributed across a variety of elevations, landscape features and areas within the planning units.

Marbled Murrelets are distributed relatively sparsely (estimated densities range from 0 to 0.9 nests per ha per year; Conroy et al. this volume) and it is acknowledged that the reserve network could not accommodate every nesting murrelet in Clayoquot Sound. Individual Marbled Murrelet nests that are discovered will be protected at the stand level by Section 34 of the British Columbia Wildlife Act and by buffers around nest trees. The conservation strategy was to use an adaptive management research approach, and to supplement the Existing Reserve Network and stand-level nest protection with high-quality reserves providing interior forest habitat. This strategy would sustain Clayoquot Sound's Marbled Murrelet population until additional population monitoring and research indicate that modifications are required to meet management objectives.

Background Studies and Implementation of the Clayoquot Sound Scientific Panel Recommendations

The Scientific Panel for Sustainable Forest Practices published recommendations for forest practices in Clayoquot Sound (Clayoquot Sound Scientific Panel 1995). These were based upon principles of maintaining ecosystem integrity, similar to the Nuu-chah-nulth principle of *hishuk ish ts'awalk* (everything is interconnected). As Marbled Murrelets are dependent on both the old-growth forests and the nearshore waters in the Sound, they were chosen as a focal species for both inventory and reserve planning in Clayoquot Sound. The Marbled Murrelet inventory and research conducted by the former Ministry of Environment, Lands and Parks (MELP) was primarily directed towards implementing the Scientific Panel's recommendation and meeting the following objectives from the panel:

8.3.2 *Monitoring Vulnerable and Rare Indigenous Species: "to ensure that particular species known or suspected to be at risk are monitored and their habitats protected"*

7.2 *"to identify suitable ecological land units to form the basis of planning and identifying watershed-level values of biodiversity"*

7.3 *"to collect appropriate baseline information on biophysical resources and use this information to assess ecological responses to change"*

7.16 *relating to planning for sustainable ecosystem management: "map and designate reserves at the watershed level to protect . . . red- and blue listed species"*

3.6 *"to assist in identifying retention areas with significant wildlife resource values"*

3.8 *"to assist in selecting specific structures and patches to meet ecological objectives and identify ecological sensitivity".*

The inventory and research on Marbled Murrelets was conducted throughout Clayoquot Sound (see the Introduction and other chapters in this volume). In order to identify high-quality nesting habitat at the stand level, teams conducted inland surveys of murrelet activity and compared these data with vegetation features at the survey stations. These data (Bahn 1998; Rodway and Regehr 1999; Bahn and Newsom 1999, 2000; Chatwin et al. 2000; chapters in this volume) suggested that high levels of murrelet activity and known nesting habitat features were most strongly associated with unfragmented, productive, old-growth forests away from the ocean edge and at elevations between 50 and 500 m. These relationships were used to create and test a Habitat Suitability Model (Bahn and Newsom this volume Ch. 6) that operated on a Geographic Information System (GIS) platform. The model evaluated polygons on Vegetation Resource Inventory (VRI) maps based on the following mapped factors, listed in declining order of importance: height of leading or second-leading tree species; age of the leading or second-leading tree species; basal area; vertical complexity of the forest canopy; canopy closure; average distance of the polygon from the ocean; and average elevation of the polygon.

The model identified four classes of potential nesting habitat (Bahn and Newsom this volume Ch. 6): 1) Important-Excellent; 2) Important-Good; 3) Sub-Optimal; and 4) Not Suitable. For my analysis, Important-Excellent and Important-Good were combined and referred to as Important. The total area of Important habitat in Clayoquot Sound was 75,300 ha out of a total area of 272,000 ha (D. Sirk, pers. comm., from GIS analysis). This report presents Habitat Suitability maps and reserve assessment for the Bedingfield, Cypre, Flores and Tofino-Tranquil Planning Units (Figures 8-1 to 8-4).

Assessment of the Existing Reserve Network

After completing the biological studies, the next step was to determine whether or not the Existing Reserve Network was adequate to protect Marbled Murrelets in Clayoquot Sound. The existing reserves had been established for hydro-riparian features, terrain instability and ecosystem representation.

The radar study over four years estimated that 6,000-8,000 Marbled Murrelets were using the watersheds of Clayoquot Sound (Burger this volume). Management of this population will have a significant impact on the total provincial population (estimated at about 65,000 birds; Burger 2002). Radar studies in Clayoquot Sound and on northwest Vancouver Island and the Olympic Peninsula, Washington, have shown significant positive correlations between the numbers of Marbled Murrelets using a watershed and areas of low-elevation old forest in the watersheds (Burger 2001, 2002). Three of five Clayoquot Sound watersheds with extensive logging of low-elevation forest had fewer murrelets per area of original forest than unlogged watersheds or those that were less than 10% logged. Burger (2001) concluded that, "With removal of old-growth forests, murrelets evidently moved elsewhere and did not pack into the remaining old-growth patches in higher densities."

As Clayoquot Sound is nested within the larger geographic and ecological unit of western Vancouver Island, the forest management activities in this larger unit will affect the significance of reserves in Clayoquot Sound. Mather and Chatwin (2001) evaluated the protection of Marbled Murrelet habitats in eight Landscape Units on Vancouver Island, outside of Clayoquot Sound. Application of the measures in the 1999 Identified Wildlife Management Strategy (Anon. 1999) and British Columbia government policy in areas of Provincial Forest would amount to an average of only 1.6% of the originally suitable habitat in these Landscape Units. Clearly, it is important to implement significant protection of Clayoquot Sound's Marbled Murrelet habitat in order to provide a source habitat for Marbled Murrelets on the rest of Vancouver Island.

How Much Habitat Will Sustain Present Populations of Nesting Marbled Murrelets in Clayoquot Sound?

Our work (and the research of others) has successfully defined high-quality habitats for Marbled Murrelets at various scales in Clayoquot Sound, but there is scant direction on the amount of habitat necessary to sustain current murrelet populations. The first attempt at such an assessment is being undertaken by the Province of British Columbia, Canadian Wildlife Service and the Marbled Murrelet Recovery Team, through the combination of a biological conservation review (Burger 2002) and a risk assessment (Arcese and Sutherland

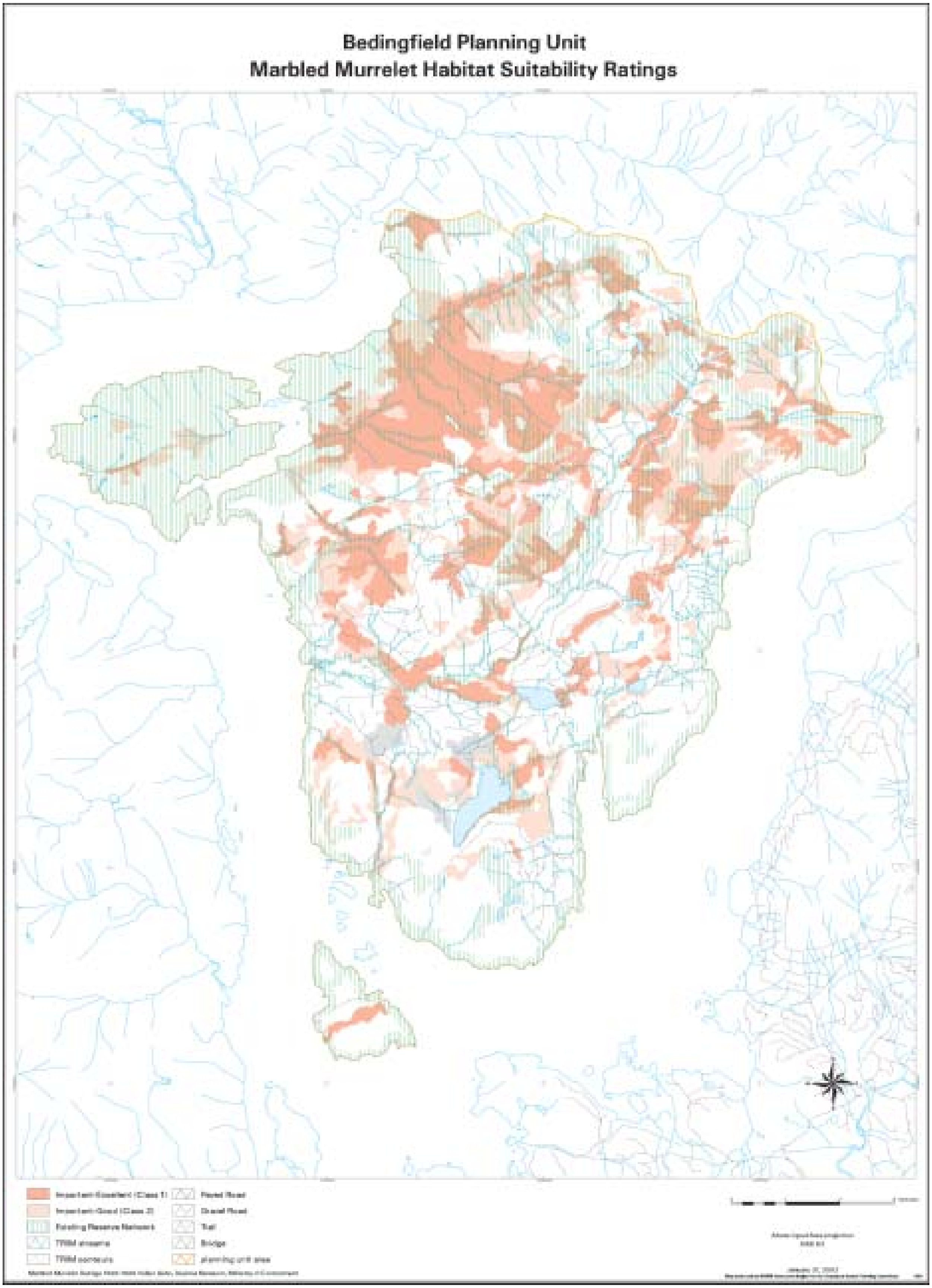

Figure 8-1. Marbled Murrelet Habitat Suitability Ratings and Existing Reserves in Bedingfield Planning Unit

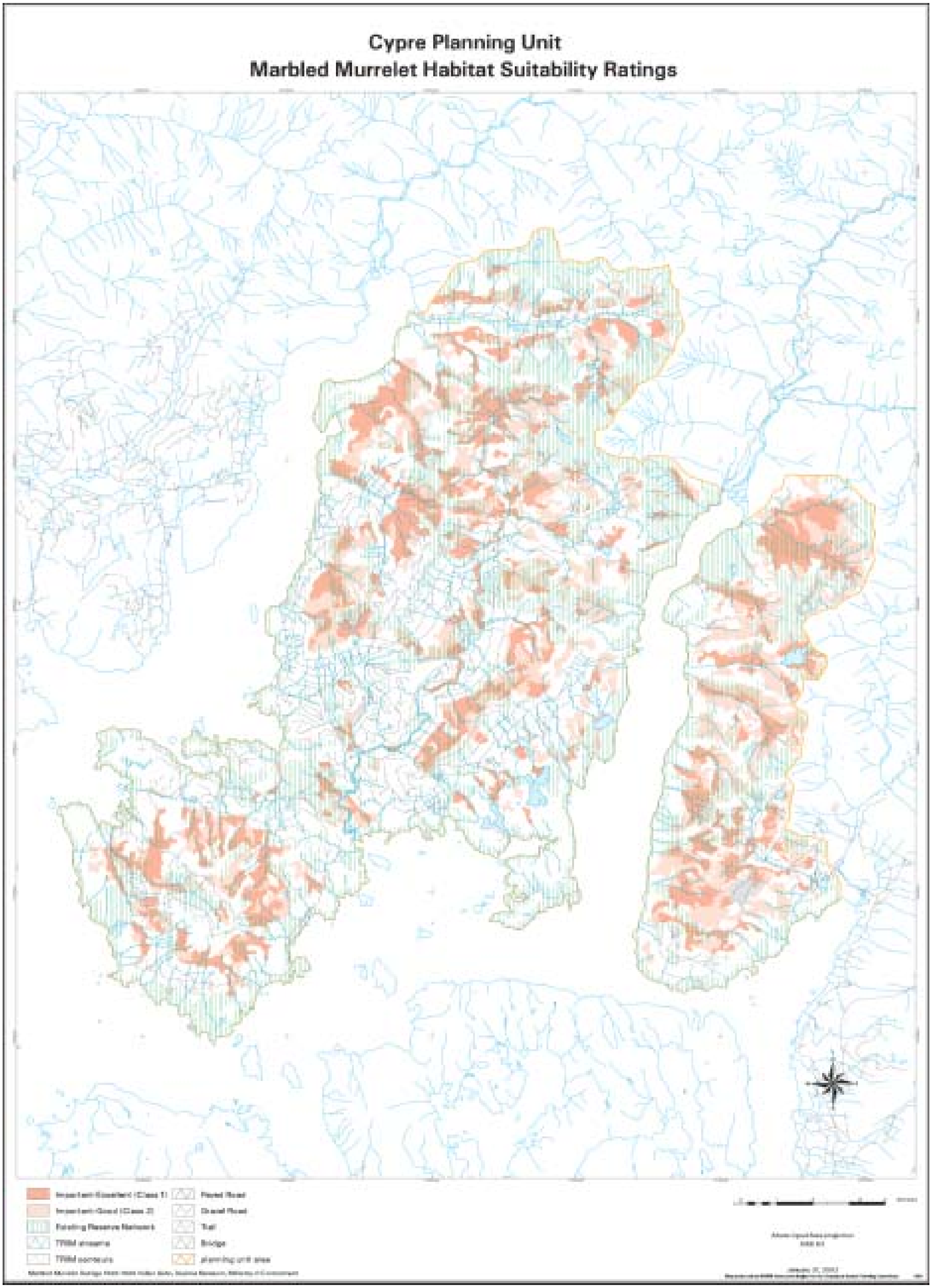

Figure 8-2. Marbled Murrelet Habitat Suitability Ratings and Existing Reserves in Cypre Planning Unit

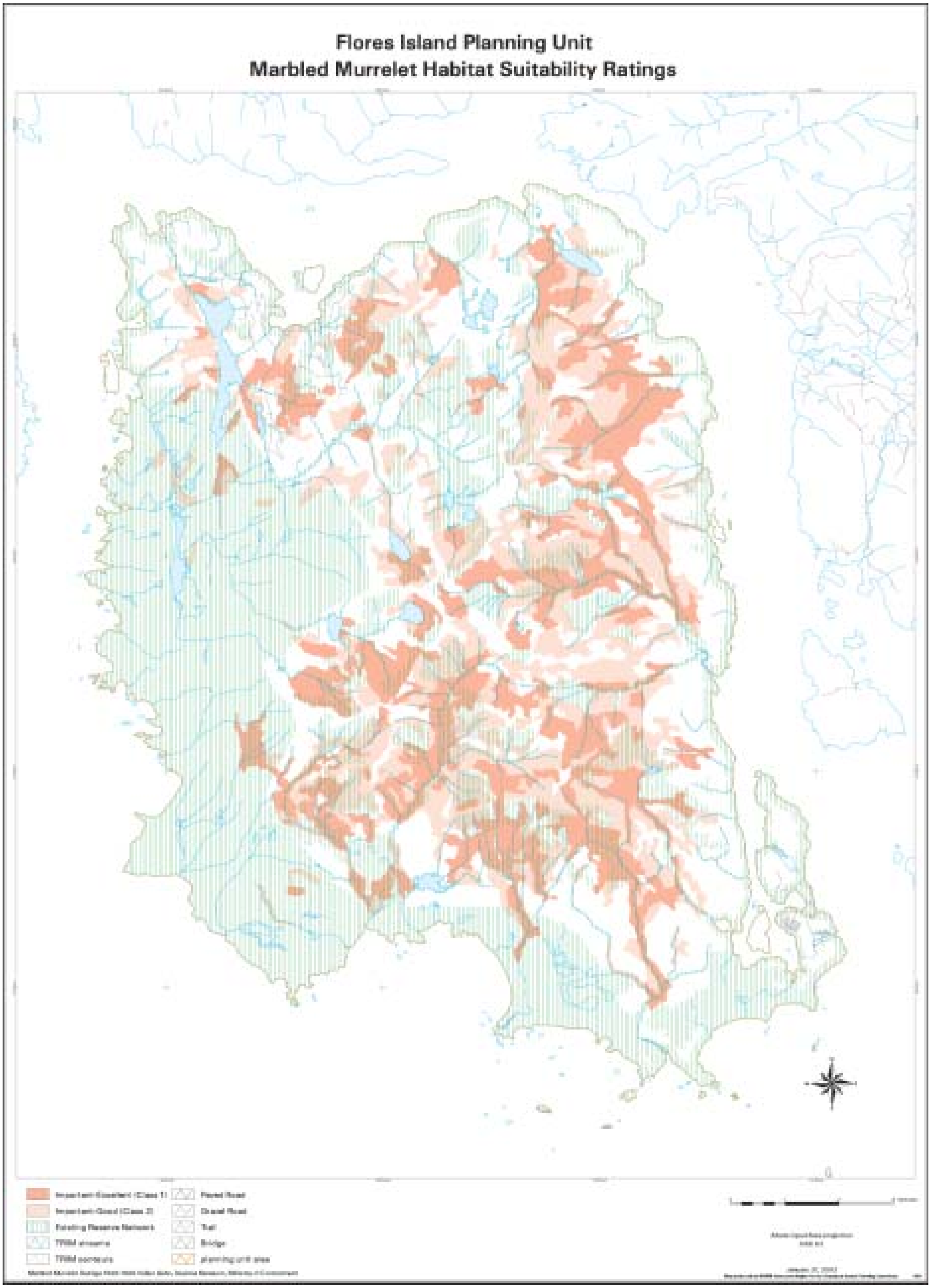

Figure 8-3. Marbled Murrelet Habitat Suitability Ratings and Existing Reserves in Flores Island Planning Unit

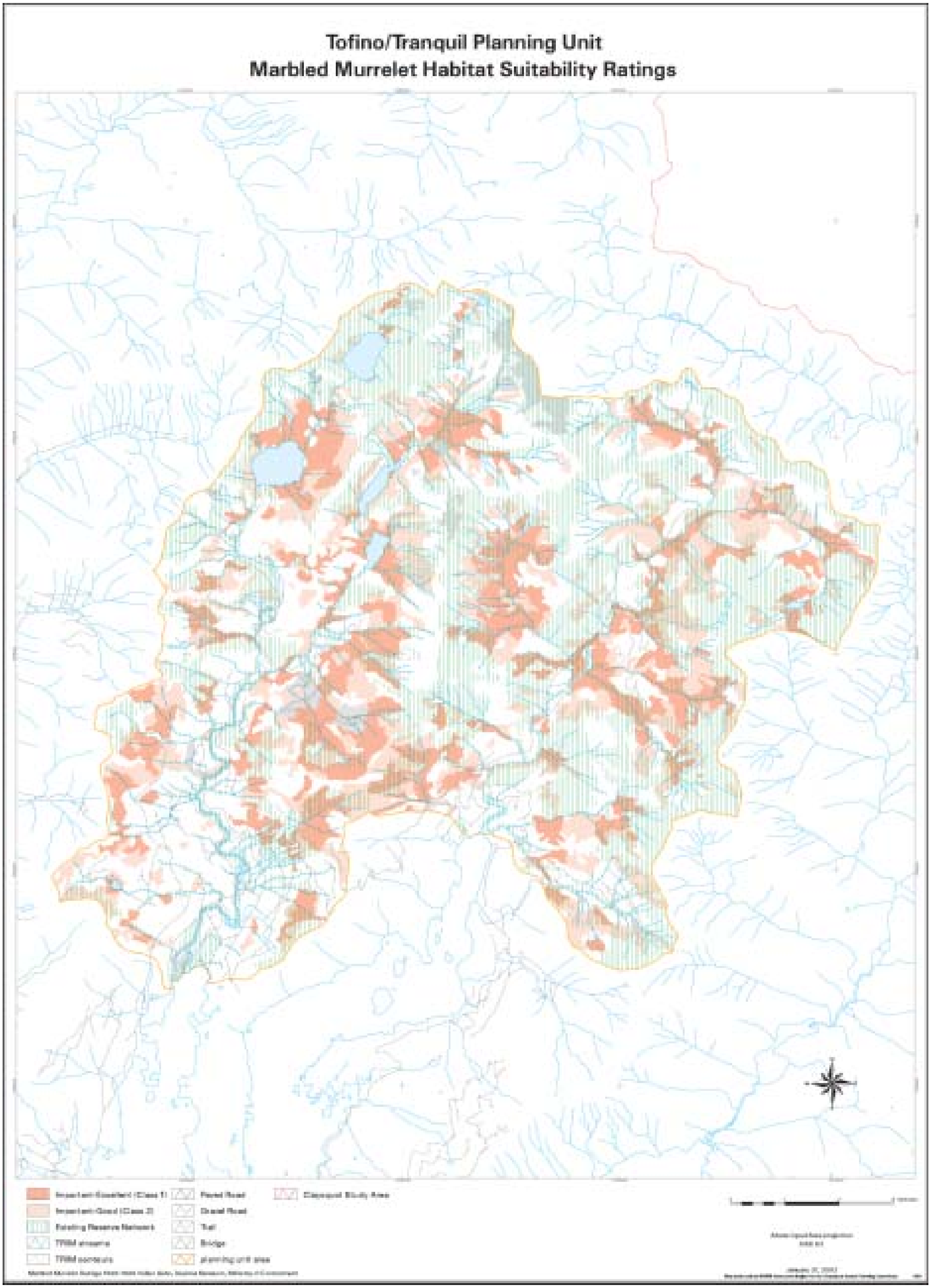

Figure 8-4. Marbled Murrelet Habitat Suitability Ratings and Existing Reserves in Tofino-Tranquil Planning Unit

2001). It is hoped that these assessments will provide guidance regarding the amount of habitat necessary to protect this species from becoming endangered. There are no other benchmarks indicating how much habitat is required to sustain current Marbled Murrelet populations, or to protect this Red-listed species as per Scientific Panel recommendation 7.16.

In the absence of clear biological direction, I used a combination of estimates of high-quality habitat (Important) from the Habitat Suitability Model (Bahn and Newsom this volume Ch. 6), along with estimates of population size (Burger this volume) and nest density (Conroy et al. this volume), to evaluate the amount of high-quality habitat protected by the Existing Reserve Network. Then, I used the biologically based recommendations of the Identified Wildlife Management Strategy (Anon. 1999) to determine if the existing reserves met the patch size criteria, and visually assessed whether reserves occurred over a range of geographical areas.

A broad-scale method of estimating the amount of habitat required by murrelets can be obtained by dividing the estimated population of 6,000-8,000 murrelets by the density of murrelets in mature forest below 600 m elevation in Clayoquot Sound (Burger 2001, this volume). Alternatively, a more fine-scale approach is to use estimates of nest density derived from tree-climbing nest searches, together with the radar population figures. An estimate of the area of habitat required by murrelets can be derived by dividing the estimated number of nests in Clayoquot Sound by nest density in the various categories of habitat. Assuming that every nest has two adults which breed each year and that approximately one-third of the population are non-breeders (F. Cooke, pers. comm.), the population estimated from the radar census should have approximately 2,000-2,667 nests annually. Conroy et al. (this volume) estimated the annual nest density as 0.14 ± 0.14 (SD) nests per ha in Important-Excellent habitat, based on application of a Binomial model to the tree-climbing data (later, more refined analyses using another statistical approach gave densities of 0.11 ± 0.12 [SD] nests per ha, but this was sufficiently close to the original estimate that a complete re-calculation of the reserve plans was not warranted). I used the Important habitat (Important-Excellent + Important-Good; Bahn and Newsom this volume) to form the core of reserves, since Conroy et al. (this volume) found no nests and recorded fewer critical micro-habitat features, such as mossy platforms, in Sub-optimal habitat. I assumed that the reserves were half Important-Excellent and Important-Good habitat, and that Important-Good habitat had about half the quality, and therefore would require twice the forest area to sustain as many murrelet nests, as Important-Excellent habitat. These assumptions are based on the lower nest density, fewer occupied detections and fewer murrelet-relevant habitat features (mossy platforms, tall trees, large DBH, abundant and thick moss cover) in Important-Good habitat (Conroy et al. this volume, Rodway and Regehr this volume). The resulting formula for the amount of habitat necessary to sustain the current nesting population was therefore:

(number of nests/nest density in Important-Excellent habitat) x 3/2.

The estimated area needed to sustain Marbled Murrelets using only the radar density of 0.067 ± 0.024 birds per ha (95% CL 0.056-0.078 birds per ha) for low-elevation forests (Burger 2001, this volume) ranges between 76,800 ha at the highest density (6,000 birds/0.078 birds per ha), to 143,000 ha at the lowest density (8,000 birds/0.056 birds per ha). The estimates of area needed using the combination of nest density and radar estimates (Conroy et al. this volume) range from 10,700 ha (2,000 nests at the highest nest density of 0.28 nests/ha in Important-Excellent habitat) to 200,000 ha (2,667 nests at the lowest practical[1] density at 0.02 nests/ha). Using the density calculated from field data (0.14 nests/ha) in Important-Excellent habitat, I estimated from the formula above that at least 21,400-28,600 ha of Important habitat (28-38% of the total 75,300 ha of Important available in all of Clayoquot Sound) would be required to sustain 2,000-2,666 nests per year. Since Important habitat is not evenly distributed throughout all the planning units and there is such a wide range of estimates of habitat to be protected, a precautionary approach was needed. I therefore decided that the upper limit of this minimum range (i.e., 38%) of Important habitat in the planning units reviewed should be reserved, until further nest density or radar studies prove otherwise.

The Need for Interior Forest Habitat

The 1999 Identified Wildlife Management Strategy (IWMS; Anon. 1999) recommends "maintaining nesting habitat with interior forest conditions throughout the range of this species." The IWMS then goes on to recommend: "that in every landscape unit with suitable or originally suitable habitat, 10-12% of the combined total area of suitable and originally suitable should be set aside…. Large (minimum 200 ha) areas of suitable habitat are preferred to provide interior forest conditions and minimize predation." The protected habitat size recommendation is based on information in Ralph et al. (1995). In addition, Manley and Nelson (1999, unpubl. data) demonstrated that nests located at or within 50 m of forest edges have lower nesting success (55% vs.

[1]The actual lowest density in the field study was 0, but lowest density that did not result in an area greater than the study area was 0.02 nests per hectare per year.

Table 8-1. Summary of Important Marbled Murrelet habitat protected in four Planning Units in Clayoquot Sound within the Existing Reserve Network and in new proposed reserves. See Appendices 1-4 for further details.

	Planning Unit			
Habitat measure	Bedingfield	Cypre	Flores Island	Tofino-Tranquil
Total area (ha)	10,601	24,508	15,307	11,630
Important habitat (ha)	3714	7540	5084	3886
Important habitat in Existing Reserve Network (ha)	1663	2986	1879	1680
Proposed additional Important habitat (ha)	265	927	827	428
Percentage of planning unit that additional habitat takes up	2.5	3.8	5.8	3.7
Percentage of Important habitat in proposed murrelet reserves	17	25	26	21
Percentage of Important habitat in existing and proposed murrelet reserves	52	52	53	54

38%) and higher predation rates compared to nests in the interior of the stand. Rodway and Regehr (this volume) found significantly higher murrelet detection rates and lower frequencies of encountering potential predators in unfragmented forest than logged landscapes in Clayoquot Sound.

As the reserve size recommendation was based upon biological criteria, I assessed each planning unit for patches ≥200 ha in existing reserves encompassing mostly Important habitat. I did not use the 10-12% of original suitable habitat recommendation, as this was based on policy direction from the original Biodiversity Guidebook of the BC Forest Practices Code, and the Bruntland Commission, rather than on biological data. Comparisons between amounts of "suitable habitat' defined by the Identified Wildlife Management Strategy and "Important" habitat as defined in this report are not necessarily compatible, as their definitions differ.

I evaluated whether the Existing Reserve Network in the Bedingfield, Cypre, Flores and Tofino-Tranquil Planning Units would maintain adequate quality and quantity of nesting habitat. First, Important Marbled Murrelet habitat was overlaid with the Existing Reserve Network (Figures 8-1 to 8-4) and the area of overlap was calculated. Second, I checked whether areas of Important habitat ≥200 ha were set aside per reserve.

In each of the four planning units, 12–16% of the entire area was in reserved Important habitat, and 37–45% of the total Important habitat was in the Existing Reserve Network (Table 8-1). Although this quantity was likely sufficient, the overlap of existing reserves and Important habitat did not occur in large areas with interior habitat; there was no overlap with patches 200 ha or larger. Existing reserves tended to be linear (established for hydro-riparian values) or in smaller areas. In all four planning units, the Existing Reserve Network was inadequate to conserve Marbled Murrelet nesting habitat. The Planning Unit/Habitat Suitability maps were therefore re-examined and additional Marbled Murrelet reserves were recommended.

Mapping and Recommending Potential Marbled Murrelet Reserves by Planning Unit

"Potential Marbled Murrelet Reserves" were mapped to locate Important habitat with interior forest conditions in the various watersheds or geographic sections of each planning unit (Figures 8-5 to 8-8). The potential reserves included large areas of the Existing Reserve Network to minimize the impacts of the new reserves on timber supply, but in most cases additional areas outside the existing reserves were needed to meet the requirements for ≥200-ha size and interior forest nesting habitat.

Verification and Rating of Potential Reserves

The habitat suitability model based on VRI attributes does not directly assess the abundance of nesting platforms and degree of fragmentation (Bahn and Newsom this volume Ch. 6). The suitability of the potential Marbled Murrelet reserves in providing adequate nest platforms and low forest fragmentation was therefore assessed through low-level helicopter flights. The helicopter flew just above the canopy or alongside the forest on slopes. This required two or more observers; one observer directed flight to and through the potential areas, and the other observer(s) made observations on nest platform density, forest fragmentation and tree species composition. The potential areas were given an overall management rank of LOW, MODERATE, GOOD or VERY GOOD based upon factors detailed in Appendix 8-1: 1) overlap with Existing Reserve Network; 2) size of potential reserve; 3) assessment of potential nest platforms; 4) forest fragmentation; 5) spatial distribution of reserves; 6) amount of Important-Excellent habitat; 7) tree species;

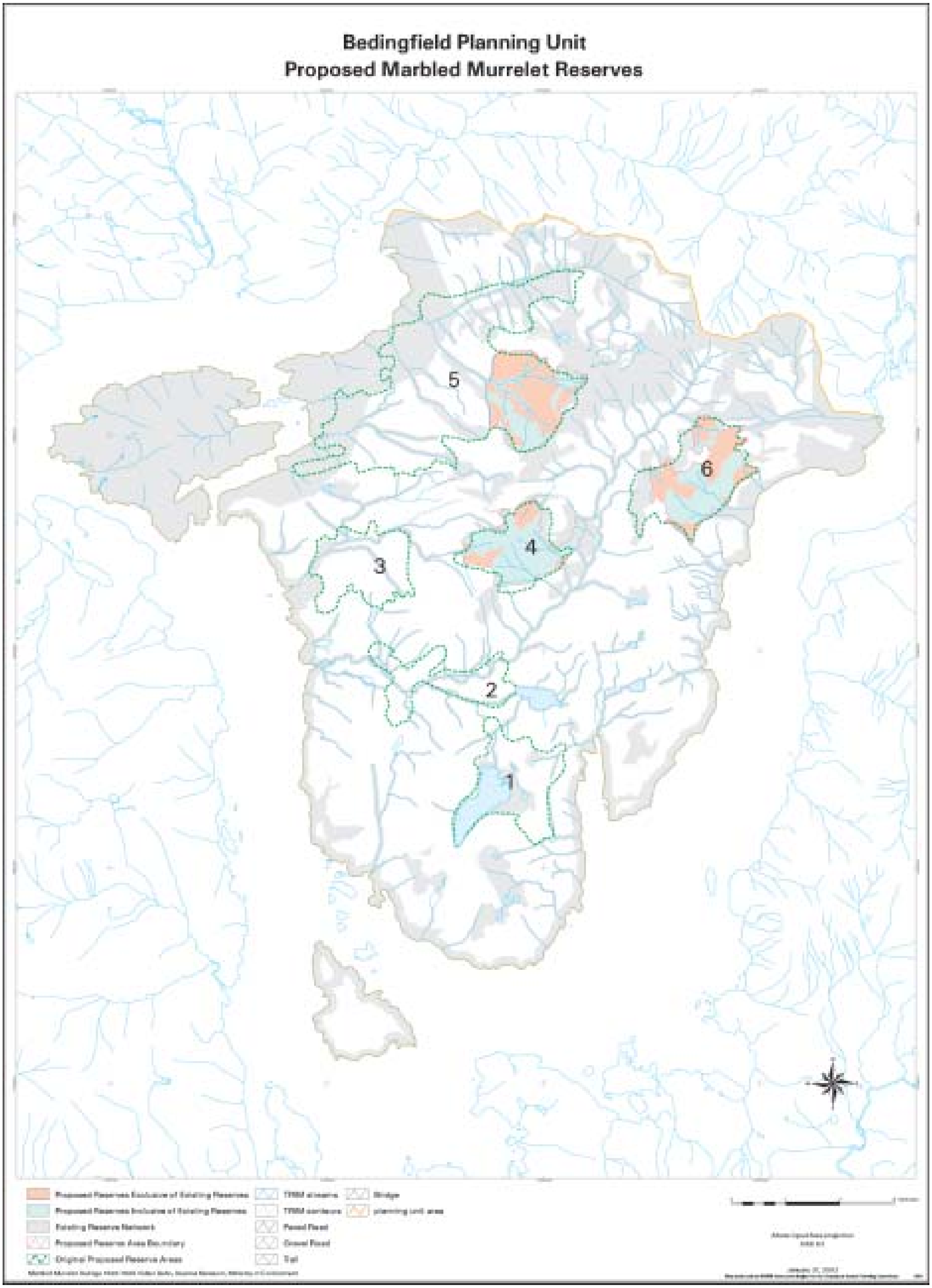

Figure 8-5. Proposed Marbled Murrelet Reserves in Bedingfield Planning Unit

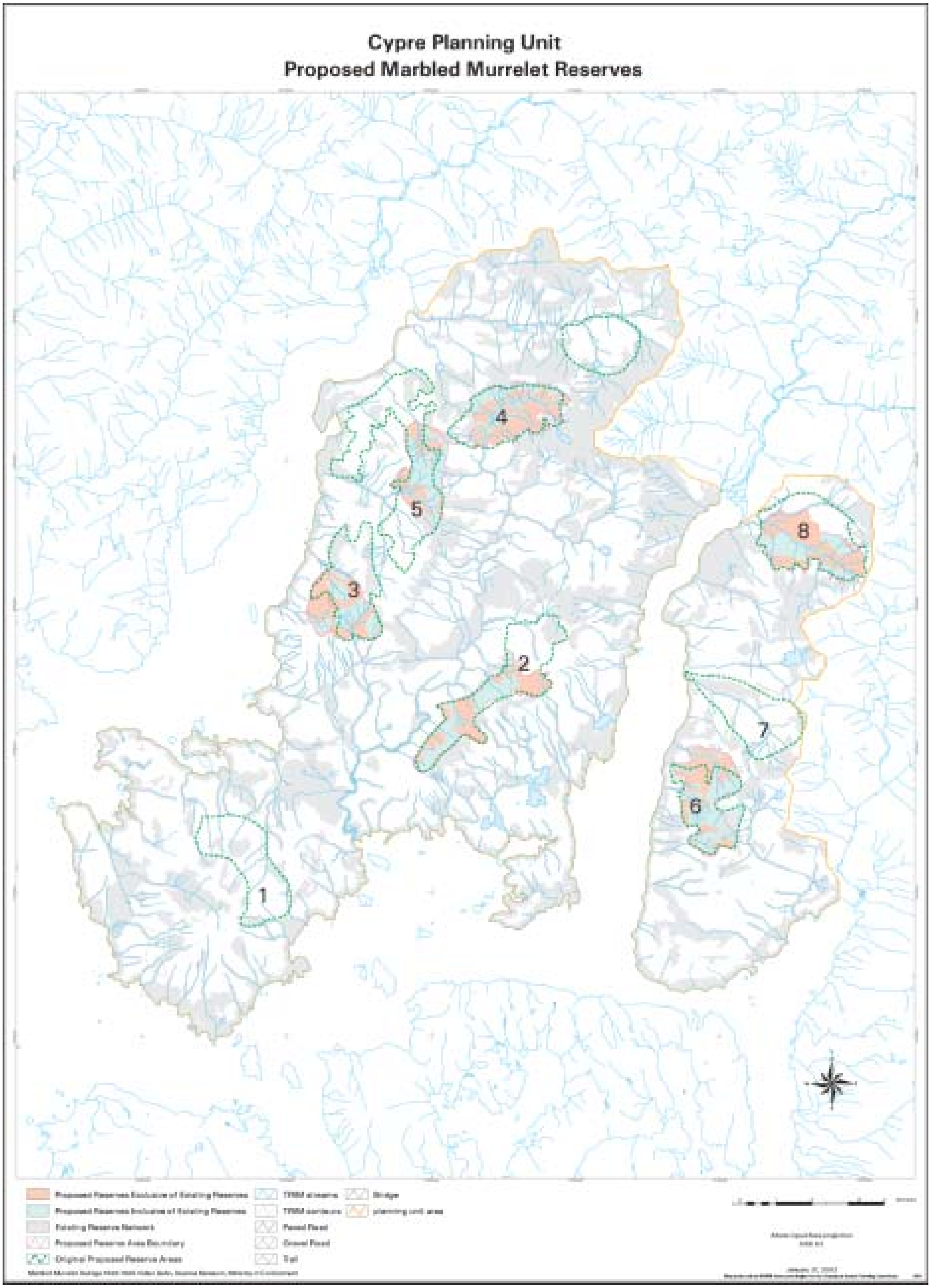

Figure 8-6. Proposed Marbled Murrelet Reserves in Cypre Planning Unit

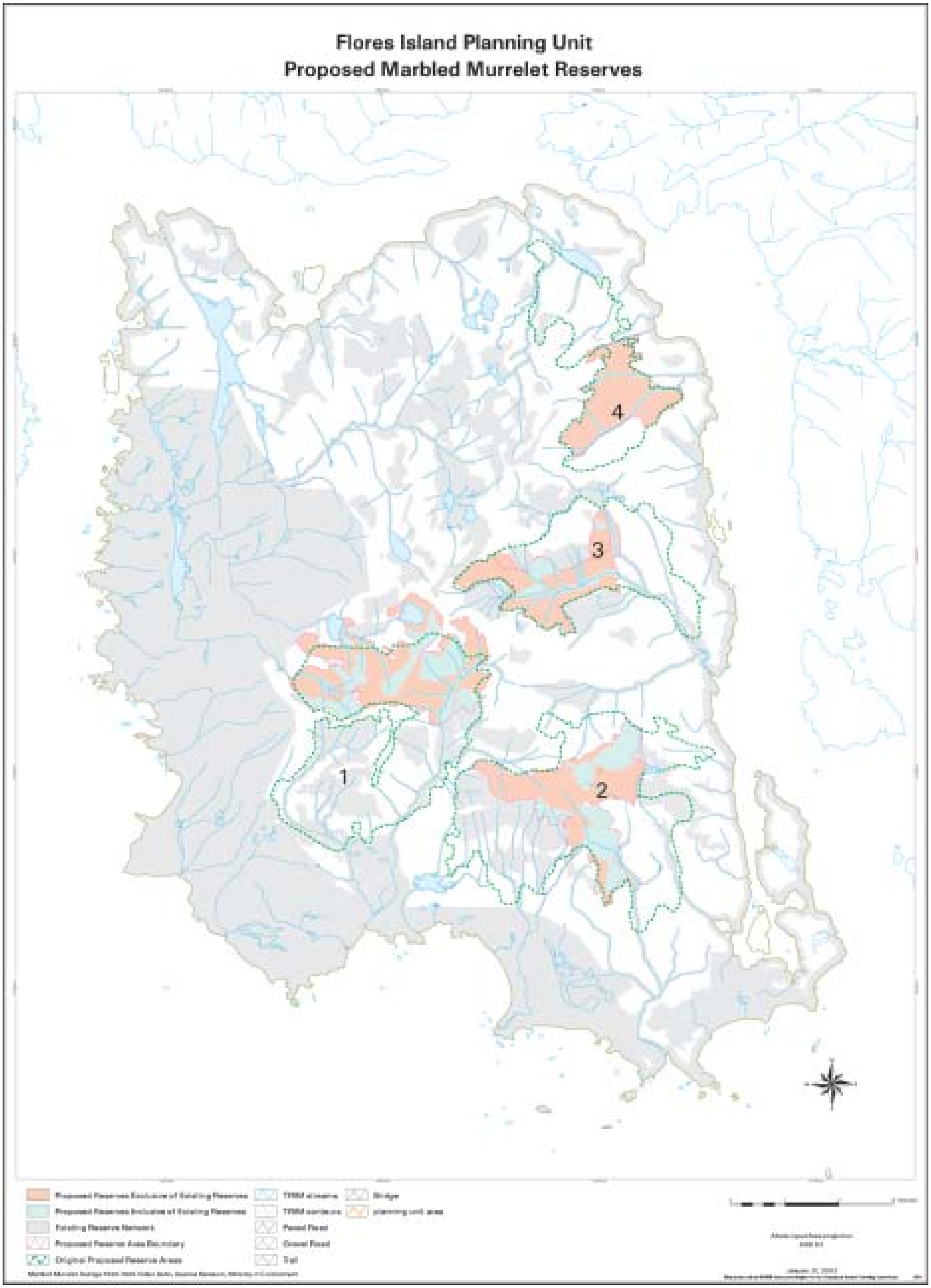

Figure 8-7. Proposed Marbled Murrelet Reserves in Flores Island Planning Unit

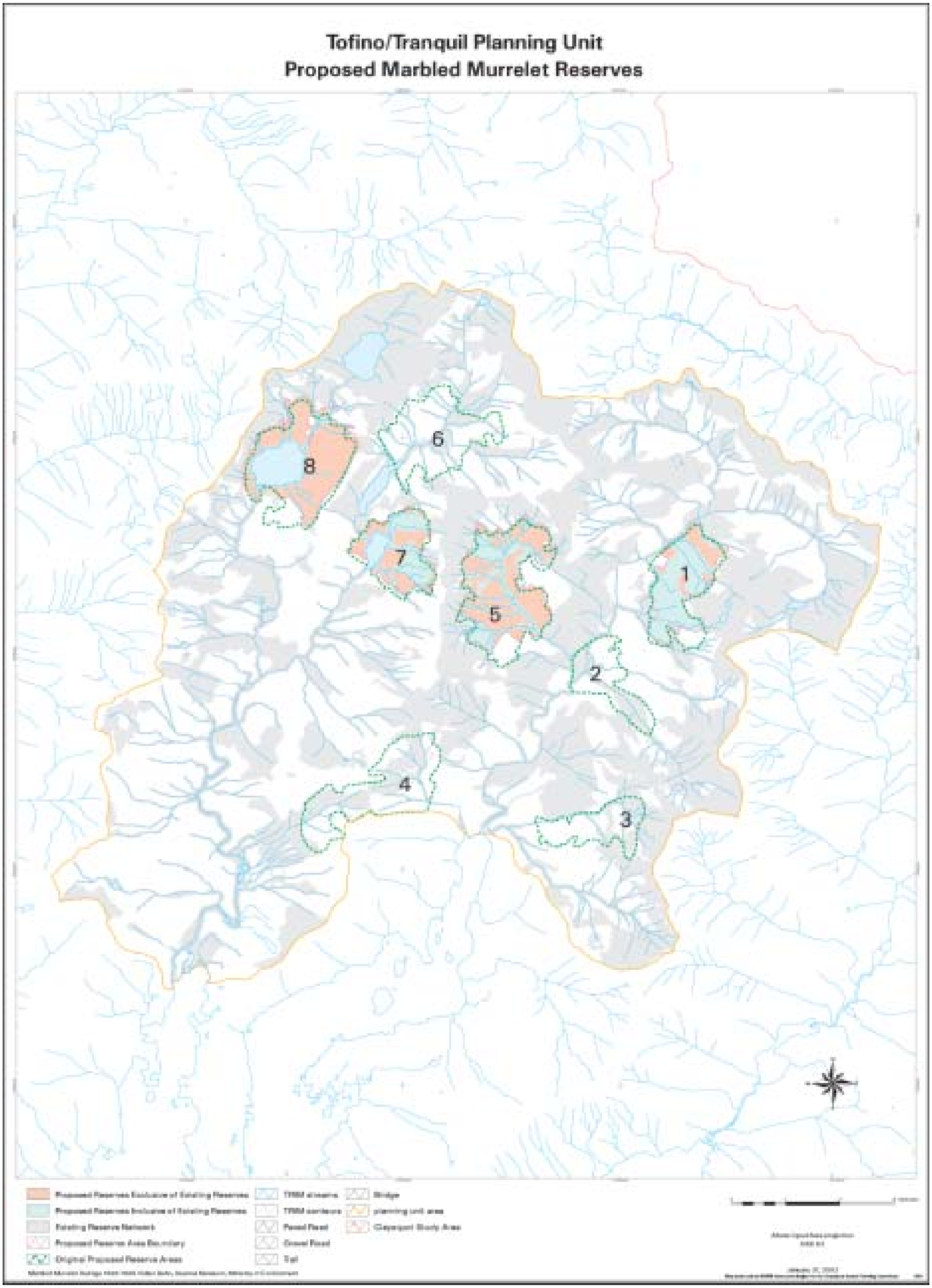

Figure 8-8. Proposed Marbled Murrelet Reserves in Tofino-Tranquil Planning Unit

and 8) forest operability and related factors. To date, the Bedingfield, Cypre, Flores and Tofino-Tranquil Planning Units have been assessed and verified for potential Marbled Murrelet reserves. Details for each planning unit are given in Appendices 8-2 to 8-5, summarized in Table 8-1, and mapped on Figures 8-5 to 8-8.

In **Bedingfield Planning Unit**, three Marbled Murrelet reserves are proposed, totalling 635.7 ha, including 264.2 ha of habitat not in existing reserves (Table 8-1, Appendix 8-2, Figure 8-5). The reserves are in the upper ends of watersheds and in the northern portion of the planning unit. I could not locate a suitable reserve in the lower portion because the habitat was either unsuitable for murrelets or too fragmented. The McGregor Range area (area #5) was assessed as the best area in the four planning units. The original proposal here was much larger than the final proposed reserve, as the suitable area was very extensive.

In **Cypre Planning Unit**, six Marbled Murrelet reserves are proposed, totalling 1907.0 ha, including 927.0 ha not in existing reserves (Table 8-1, Appendix 8-3, Figure 8-6). The reserves are reasonably evenly distributed across the planning unit, but a suitable reserve could not be located in the Catface Peninsula due to fragmentation by logging. To allow dispersion of the reserves and to provide undisturbed interior conditions, nearly the whole of two small "face drainages" on the east side of Bedwell Sound was identified as reserves.

In **Flores Planning Unit**, four Marbled Murrelet reserves are proposed, totalling 1328.8 ha, including 827.5 ha not in existing reserves (Table 8-1, Appendix 8-4, Figure 8-7). Although a large area of Flores Island is protected within a provincial park, this area is mostly low-lying bog and not suitable for murrelets. The proposed reserves are in the upper ends of drainages and are generally less accessible to forest harvesting.

In **Tofino-Tranquil Planning Unit**, four reserves are proposed, totalling 818.2 ha, including 428.3 ha not in existing reserves (Table 8-1, Appendix 8-5, Figure 8-8). I tried to choose reserves in each major drainage of the planning unit. The reserves are in the northern part of the planning unit, because there has been harvesting in the lower portions of the watersheds.

Stand Level Protection of Marbled Murrelet Nest Trees

It is generally thought that micro-site level protection, i.e., protection of individual nest trees is inappropriate for Marbled Murrelets due to the importance of interior forest to nesting success (Manley 1999, Burger 2002). However, protection of individual nest trees can occur after landscape-level management goals have been achieved. Protection of individual trees in which a nesting Marbled Murrelet is found is mandated by the BC Wildlife Act (Section 34) and can occur through the finer-scale silvicultural planning process. A provision to avoid disturbance due to logging or road-building within 200 metres of the nest during the nesting time (from April through mid August) should provide a measure of protection for the nest. As there is some evidence for re-nesting in the same trees (Manley 1999), a Wildlife Tree Patch with minimum radius of 200 m should be established surrounding a tree with a known nest.

Conclusions

The specific Marbled Murrelet reserves in Bedingfield, Cypre, Flores Island and Tofino-Tranquil Planning Units ensure that 17-26% of the Important habitat is reserved in areas >200 ha. The inclusion of the larger Marbled Murrelet reserves into the network ensures that the risk of decreased nest success near forest edges, leading to population decline, should be minimal. The Marbled Murrelet reserves, combined with the smaller existing reserves that have additional value to murrelets (until they are fragmented by logging), protect approximately half (52-54%) of the Important habitat identified in these planning units. This provides insurance at this landscape level that the overall risk to this threatened species is low, even if forest harvesting removes nests or patches of nesting habitat not in reserves. Having a combination of large and small reserves ensures that both the quality and quantity of reserves in the planning units are adequate at the Watershed/Sub-Regional planning level.

If, through adaptive management research, it can be shown that Marbled Murrelet populations do not decline when their habitat is fragmented, the inclusion of the larger reserves allows for a future change in reserve design. However, if, as current research indicates, murrelet populations decline as their habitat is reduced and fragmented, the larger reserve areas will provide source habitats where successfully nesting murrelets can provide young to recolonize other areas. Monitoring of the effectiveness of our strategy could occur through the use of radar to measure murrelet numbers in watersheds with reserves and proposed logging. The study should encompass several watersheds and cover at least two years of pre-harvest and two years of post-harvest sampling. If this monitoring shows that the population is declining despite the inclusion of reserves, then additional reserves need to be included in each planning unit, or another strategy will be required.

The multi-scaled research approach to ecosystem planning for conservation of Marbled Murrelets in Clayoquot Sound results in a reserve network that should sustain Marbled Murrelets. This science-based approach and the inventory techniques used to gather the data have application to ecosystem management of Marbled Murrelets throughout the species' range.

Acknowledgements

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Variable retention South-Island Forest District. Large reserves of suitable habitat are important to Marbled Murrelets to provide undisturbed "source" areas for successful breeding. Fragmented areas, even with small and dispersed cutting patterns may act as "sinks" for nesting murrelets. (photo by Trudy Chatwin)

Mossy platforms were evaluated in the potential reserves in Bedingfield, Cypre, Flores, and Tofino/Tranquil Planning Units through low-level helicopter flights. The flights assessed platforms and also verified the habitat suitability ratings. (photo by Trudy Chatwin)

High quality Important Excellent habitat in the McGregor Range, Bedingfield Planning Unit. This was the best and most extensive Marbled Murrelet habitat observed in the 4 planning units assessed. (photo by Trudy Chatwin)

Forest habitat in Area 1, Cypre Planning Unit. Note the spire-topped western red-cedar and the lack of platforms. This potential Marbled Murrelet reserve was ranked Low on the helicopter evaluation. (photo by Trudy Chatwin)

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Appendix 8-1: Factors considered when examining Potential Marbled Murrelet Reserves

1. Overlap with Existing Reserve Network
A large overlap (>30%) of Important habitat with Existing Reserve Network was one of the first criteria for initially choosing potential Marbled Murrelet reserves, and was also used to confirm whether an area should be incorporated into the reserve network. Attempts were made to reserve areas with high amounts of existing reserve to reduce impacts to timber supply.

2. Size of potential reserve
Does the potential reserve meet interior forest nesting habitat criteria? Is it large enough to protect a sizeable number of nests, given that Marbled Murrelets nest at a low density? The 1999 Identified Wildlife Management Strategy (Anonymous 1999) recommends >200 ha patches of suitable habitat be set aside for Marbled Murrelets. These large patches are important for murrelets as they protect interior forest stands and reduce the amount of unnatural edges that nesting Murrelets are subject to. Bahn and Newsom (1999) suggested that annual variability of murrelets at stations could be due to Marbled Murrelets switching activity centres between years. Therefore it would be prudent to reserve larger habitats across the geographic range of Murrelets. Mean nest stand size in the Pacific Northwest is 205 ha and highest activity of murrelets was found in stands greater than 250 ha (Hamer and Nelson 1995). Ralph et al. (1995) recommended protection of stands of 500-1000 acres (312-625 ha.). The conservation assessment by Burger (2002) also suggests that reserves smaller than 100 has will be subject to higher predation rates by edge-loving species. Smaller reserves were considered if there was no other option in that portion of the planning unit.

3) Assessment of potential nest platforms
Abundance of trees with potential nest platforms was considered to be critical to this assessment. Marbled Murrelet nests are usually located on large diameter limbs that have moss substrate and a high degree of overhead foliage cover. This structure provides a nesting platform for murrelets, which do not build a nest. Moss provides a warmer, more protective substrate for an egg than a bare branch. Large primary limbs, the junction of primary and secondary limbs, mistletoe deformities, and multiple leaders often provide suitable nest platforms. Studies by Manley (1999) on the Sunshine Coast and our studies in Clayoquot Sound (this volume) showed that Marbled Murrelets select nest sites with abundant mossy platforms and most often nest in stands with large diameter trees. Abundance of platforms varied within potential reserves. For example, ridge areas tended to have sparse platforms while valley bottoms had more trees with platforms. Maps were marked with comments as they were evaluated and then an overall platform evaluation of high, medium, or low was given to the area.

4) Forest fragmentation
Marbled Murrelets are adapted to reduce predation through cryptic plumage, hidden nest sites, dispersed nests, and flights to and from the nest in periods of low visibility. Fragmentation of forests is a major concern due to the increases in edge along recently logged cutblocks and roads, and concurrent decline in forest interior habitat. Corvids are the most frequent predators of Marbled Murrelets, and Steller's Jays (*Cyanocitta stelleri*), Northwestern Crows (*Corvus caurinus*), and Common Ravens (*Corvus corax*) are more abundant in edge habitat than forest interiors (Manley et al. 1999, Masselink 2001, Burger 2002, Rodway and Regehr this volume). Nest trees in Oregon, Washington and California were a mean distance of 92 m from any opening (Hamer and Nelson 1995). Degree of fragmentation and cut-block or road edges was an important consideration to the present evaluation. An attempt was made to locate reserves away from road edges or to restrict roads to the bottom edges of reserves only.

5) Spatial distribution of reserves
There are operational and biological spatial considerations. Is the potential reserve at the back of a valley where it would be more costly to extract timber? Headwater areas often have good potential for undisturbed, unfragmented habitats and often have good platform development (perhaps due to being protected from wind, which in turn favours moss development on branches). Is the potential reserve in a part of the planning unit that does not have a contiguous section of reserved Marbled Murrelet habitat? Conservation biology principles point to the benefits of a well-distributed system of reserved habitats throughout the Landscape Unit. Is the potential reserve near a lake? Lakes are used by Marbled Murrelets in winter and early spring for staging and possibly foraging (A. Burger, pers. comm., I. Manley pers. comm.). The presence of a lake adds to the value of a potential reserve. Is the potential reserve a separate "mini-drainage"? Reserved "mini-drainages" and small "face-drainages" will have no disturbance and fragmentation effects.

6) Amount of Important Excellent habitat
The nest density study conducted in the Ursus Valley (Conroy et al., this volume) found nests only in habitat rated as Important Excellent by the model of Bahn and Newsom (this volume). Many micro-habitat features important to nesting murrelets were also more abundant in Important Excellent habitat than in other suitability classes. Therefore an area with a high proportion of Important Excellent habitat would be ranked high.

7) Tree species
Although there was not a specific ranking for tree species composition of the potential Marbled Murrelet reserves, consideration was given to how a particular dominant tree species may effect nest platform development. Nests on Vancouver Island have been found in Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), amabilis fir (*Abies amabilis*), western red-cedar (*Thuja plicata*), and Douglas-fir (*Pseudotsuga menziesii*) (Burger 2002). The structures of the various tree species provide varying degrees of platform development. Sitka spruce has the most abundant horizontal, mossy platforms and a high percentage of nests have been found in this species. Spire-topped western red-cedar does not usually have many protected platform sites. However, nests have been found where cedars fork into candelabras, if the fork is covered by overhead branches. Amabilis fir has abundant platforms, but often the branches angle downwards.

8) Forest operability and related factors
When possible, attempts were made to choose Marbled Murrelet reserves in areas that were in the backs of more inaccessible valleys, on steeper slopes or otherwise in less operable forest.

Appendix 8-2. Evaluation of Potential Marbled Murrelet Reserves: BEDINGFIELD PLANNING UNIT
Total area: 10,601 ha
Area of Important habitat: 3714 ha
Area of Important habitat in Existing Reserve Network: 1663 ha (45% of Important habitat)
Spatial configuration of Important Habitat in Existing Reserves is not in contiguous forest blocks with interior habitat.
Evaluation of Potential Marbled Murrelet Reserves

Potential MAMU Area	Area (ha)	Amount of Important Excellent Habitat	Tree species (In order of abundance)	Configuration	Platform assessment	Fragmentation	Overlap with Existing Reserves	Other	Overall Rank	Inclusion as Reserve
1. East of unnamed lake between Bedingfield Bay and Millar Channel along Balbo Creek	ca. 250	Low	Cw, Hw, and minor Df	Near lake and would provide habitat in lower portion of unit	Low, only in draws	Fragmented	Moderate	If area had better platform development it would be good to provide habitat representation in this area	Low	No
2. Atleo River Valley	ca.180	High	Ss	Narrow strip along river	High	Surrounded by harvested area	Only along river – Low	This area had excellent platform development but does not meet interior forest conditions	Mod	No
3. Shark Creek, East of Millar Channel	ca.250`	Mod. (about $^1/_2$)	Much Cw spike-topped	Nice patch at west-side of unit	Pockets on N. facing slope Low – Mod	Has road	Only along narrow corridors of creek – Low	This area has road and is of high interest to Iisaak	Low	No
4. Main tributary of Atleo River, flowing from North	192	Mod. (about $^1/_2$)	Ba, Hw, Cw	Steep area at top of creek. In centre of planning unit	Good in gullies	Lower boundary is cut	High	Area looks to be inaccessible to forestry as it is at top of ridge	Moderate	Yes
5. McGregor Range	227	High (most of it)	Ss, Hw, Ba	Back of valley, including valley bottom and slopes	Excellent, best area in assessment	None	About. $^1/_2$	This area at the back of valley and upper tributaries was the best area, seen in study	Excellent	Yes
6. West of Herbert Inlet, South of Moyeha Bay	217	Mod. (about $^1/_2$)	Hw, Ba, Df and Ss	Side of Inlet on E. side of unit	Good, lots of moss	Cut at S. edge	About. $^1/_2$	Looks to be mostly reserved on lower edge of slope	Good	Yes
7. Small slope on Miller Channel	83	About $^1/_3$	–	Small drainage off Miller Channel in SW part of planning unit	–	Cutblocks	None	In planning for well-distributed reserves, this area is possibly best in this section of planning unit.	Low	No

Proposed Marbled Murrelet Reserves in Bedingfield (#4, 5, and 6) total 636 ha of which 265 ha is not part of Existing Reserve Network

Appendix 8-3. Evaluation of Potential Marbled Murrelet Reserves: CYPRE PLANNING UNIT
Total area: 24,508 ha
Area of Important habitat: 7540 ha
Area of Important habitat in Existing Reserve Network: 2986 ha (40% of Important habitat)
Spatial configuration of Important Habitat in Existing Reserves is not in contiguous forest blocks with interior habitat.
Evaluation of Potential Marbled Murrelet Reserves

Potential MAMU Area	Approx. area (ha)	Amount of Important Excellent Habitat	Tree specie (In order of abundance)	Configuration	Platform assessment	Fragmentation	Overlap with Existing Reserves	Other	Overall Rank	Inclusion as Reserve
1. North and East facing slopes of Catface Mt.	70	About $^1/_2$	Cw, Ba, and Hw	Area of slope on Catface Peninsula.	Low	High	Only along Creek	Approved cutblocks, Nest found by SFU crew	Low	No
2. Bedingfield Range- East facing slopes of Mt. Saavedra	327	About $^2/_3$	Hw, Cw, and Ba	Linear side/top of slope area, Very steep	Moderate, Good access	Lower boundary logged, but area is intact	Most of area is in reserve	Area looks to be inoperable	Moderate to Good	Yes
3. Herbert Inlet- East of Binns Island	226	About $^1/_2$	Hw, Ba, Cw, and Ss	Top end of creek drainages on west side of unit	Good, good access	Logging below at lower elev.	High, about $^2/_3$	At back end of slope, area was reduced from original proposal so that one side of creek is reserved	Good	Yes
4. East of Herbert Inlet in Bedingfield Range	323	About $^3/_4$	Ba	Top end of small drainage. Lots of slide tracks	Common in Ba	None	Mod, about $^1/_2$	Area looks to be inoperable	Good	Yes
5. East of Herbert Inlet	281	About $^1/_2$	–	One side of back end of creek drainage	–	Fragmented by blowdown	Mod, about 1/2	Area was reduced from original proposal to include only back end of drainage. Very steep area	Moderate to Good	Yes
6. East of Bedwell Sound	351	About $^1/_2$	Ba and Hw	Very steep back end of side of inlet	Mod, most on Ba	None	Most, about $^2/_3$	This area is similar to 7. Top ends of watersheds.	Good	Yes
7. Small drainage east of Bedwell Sound	237	About $^1/_2$	Hw, Ba and Ss	Small watershed – Excellent	Good to Excellent	None	Mod, about $^1/_2$	High inoperability at front end of watershed. This area was not chosen as Area 7 was.	Good	No
8. East of Bedwell Sound near mouth of Bedwell River	333	About $^1/_2$	Cw, Hw, Ba, and Cy	Small watershed -Excellent	Good in valley bottom	None	Mod, about $^1/_2$	Important to protect intact watersheds in a fragmented unit like this.	Good	Yes
9. North face of Catface	192	About $^1/_3$	–	Upper slopes, but only area in Catface Penn	–	Fragmented	Low, about $^1/_3$	As there were no MAMU reserve areas in lower portion of planning unit this area was considered.	Low	No

Proposed Marbled Murrelet Reserves in Cypre (#2, 3, 4, 5, 6, and 8) total 1907.0 ha of which 927 ha is not part of Existing Reserve Network.

Appendix 8-4. Evaluation of Potential Marbled Murrelet Reserves: FLORES PLANNING UNIT

Total of 15,307 ha

Area of Important habitat: 5084

Area of Important habitat in Existing Reserve Network: 1879 ha (37% of Important habitat)

Unfortunately, most of the reserve network on Flores Island is on the west side of Flores in bog forest in the Provincial Park. This is unsuitable for Marbled Murrelets. The hydro-riparian reserves on Flores are too narrow for protection of interior forest habitat.

Evaluation of Potential Marbled Murrelet Reserves

Potential MAMU Area	Approx. area (ha)	Amount of Important Excellent Habitat	Tree species (In order of abundance)	Configuration	Platform assessment	Fragmentation	Overlap with Existing Reserves	Other	Overall Rank	Inclusion as Reserve
1. Original Cow Ck. on SE side of Mt. Flores	Orig. ca. 400	Mod-About $^1/_2$	Cw, Hw, and Ba	Drainage off side hill	Good in areas of drainage, not good in boggy area	None	About $^1/_3$	Some areas very good in this area. Area considered operable	Good	No
1. Revised Alto Lake upper Cow	475	Mod-About $^1/_2$	Cw, Hw, and Ba	Upper slope area facing West	–	None	About $^1/_3$	Area is considered inoperable and has Important Excellent Habitat	Good	Yes
2. South Flores	373	Good-About $^1/_3$	Cw, Hw, and Ba	Upper ends of drainages	Good	None	About $^1/_2$	Some slopes below in reserve are low in terms of platform development. This area was considered not easily operable	Mod-Good	Yes
3. Creek 6.	260	Mod-About $^1/_2$	Ba, Ss, Cw, and Hw	Valley except lower part	Good on valley bottom	None	Linear along drainage, about $^1/_3$	Good watershed. Our reserve tried to stay at back end of drainage and on side of creek with most platforms. High activity of MAMU	Mod-Good	Yes
4. Northwest side of Flores	207	High-Most of area	Cw, Hw, and Ss	Top slopes at N.E. end of Flores	Good on Ba and Ss	None	Only on linear drainages	Examined a much larger area, but re-defined this smaller area for this portion of planning unit. Reserve at top of slope	Good	Yes

Proposed Marbled Murrelet Reserves on Flores Island (#1, 2, 3 and 4) total 1328 ha of which 827 ha is not part of Existing Reserve Network

Appendix 8-5. Evaluation of Potential Marbled Murrelet Reserves: TOFINO-TRANQUIL PLANNING UNIT

Total of 11,630 ha

Area of Important habitat: 3886 ha

Area of Important habitat in Existing Reserve Network: 1680 ha (43% of Important habitat)

Spatial configuration of Important habitat in Existing Reserves is not in contiguous forest blocks with interior habitat with the exception of #1.

Evaluation of Potential Marbled Murrelet Reserves

Potential MAMU Area	Approx. area (ha)	Amount of Important Excellent Habitat	Tree species (In order of abundance)	Configuration	Platform assessment	Fragmentation	Overlap with Existing Reserves	Other	Overall Rank	Inclusion as Reserve
1. East side of Tofino Creek at back end of drainage	171	Mod- About $^1/_3$	Cw, Hw, Ba and Yc	Side slopes of Tofino Creek	Poor on ridges, Good in gullies	Across from cutblock	High, nearly all reserve	Area at back of drainage, nearly all reserved	Moderate, Other areas better	Yes, because mostly reserved
2. East side of Tofino Creek, south of above area	ca. 150	About $^1/_2$ of area	Cw, Hw, and Ba	Side slope off Tofino Cr.	Poor mostly, Good in gullies	Some cutblocks nearby	About $^1/_2$	Gully has best habitat, other areas not so good	Moderate	No
3. South side of Onad Creek	ca. 120	About $^1/_2$ of area	Cw, Hw, Ba, and Cy	Back end and one side of creek in south of unit	Low	Logged on one side	About $^1/_2$	–	Low	No
4. Elsul Creek	300	About $^1/_3$	Cw, Hw, Ba, and Cy	Back of drainage in south of unit	Low to Mod on Ba	Above logging and logging road	About $^1/_2$	Very steep	Low – Moderate	No
5. Hanging Valley on west side of Tofino Creek	284	About $^2/_3$	Ba, Cw, Hw	Excellent – Back end of intact valley	Excellent on valley bottom, Mod. On ridges	None	About $^1/_3$	This valley has the best habitat in the Tofino Creek drainage	Good to Excellent	Yes
6. Upper Tranquil Creek above Pitka Lake	280	About $^1/_2$	Ba, Hw	Back of valley behind lake in East fork of Tranquil area	Moderate on sidehills, Good on flats	None	About $^1/_2$	Area not quite as Good as habitat surrounding Hell's Deep Lake or Sinco Lake. Therefore, due to geographic representation I deleted this area	Good	No
7. Hell's Deep Lake	142	About $^1/_2$	Hw, Ba	Area surrounding Hell's Deep Lake. East fork of Tranquil area	East side of lake is Good to Excellent, some patches of Poor	None	About $^1/_2$	Area representative of east valley of Tranquil	Good	Yes
8. Sinco Lake	221	About $^2/_3$	Hw, Cw, Ba, Cy	Contiguous area surrounding Sinco Lake in west valley of Tranquil	Good	None	About $^1/_3$	Area is representative of west valley of Tranquil Creek. Road to bottom of lake.	Good	Yes

Proposed Marbled Murrelet Reserves in Tofino-Tranquil (#1, 5, 7, and 8) total 818 ha of which 428 ha is not part of Existing Reserve Network

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