MARBLED MURRELET CONSERVATION ASSESSMENT 2003, PART B: MARBLED MURRELET RECOVERY TEAM ADVISORY DOCUMENT ON CONSERVATION AND MANAGEMENT

by the Canadian Marbled Murrelet Recovery Team

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FOREWORD

The following document is Part B of a three part Conservation Assessment of the Marbled Murrelet in British Columbia. Part B was written by the Recovery Team members over the last two years our views to date regarding Marbled Murrelet conservation planning for the future. Much has been learned about the species in recent years and new data and analyses continue to emerge. There will continue to be new hypotheses to test and many uncertainties remain but the team agrees that we must move forward with the present information and act to initiate adaptive management and conservation programs. We recommend that the conservation and management implications of recent scientific information be reviewed and updated regularly. We anticipate that this advisory document will be the first of a working document series that will be part of that iterative process.

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INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*) is listed as Threatened by COSEWIC (Committee on Status of Endangered Wildlife in Canada). Loss of nesting habitat in forests, and threats posed by oil spills and gill nets are the main threats (Hull 1999, Burger 2002). The species' threatened status was confirmed by COSEWIC in 2000, primarily on the basis of low reproductive rate and continued evidence of declining nesting habitat. Provincially, the Marbled Murrelet is on the Red-list (species legally designated or being considered for legal designation as Endangered or Threatened), and is one of the Identified Wildlife species within Forest Practices Code Act. The Identified Wildlife Management Strategy (IWMS; Anon. 1999) mandates the creation of Wildlife Habitat Areas (WHAs) for Marbled Murrelets, through the provisions in the IWMS and Landscape Unit Planning Guide under the Forest Practices Code.

This document forms Part B of the 2001-2002 Conservation Assessment of the Marbled Murrelet, being undertaken under the direction of the Canadian Marbled Murrelet Recovery Team (MMRT), and funded by the BC Ministry of Water, Land and Air Protection (MWLAP), Ministry of Forests (MOF), and Environment Canada (Canadian Wildlife Service). The Conservation Assessment will form the basis for a revised national Marbled Murrelet Recovery Strategy (Kaiser et al. 1994) and Action Plan, facilitate revisions of the provincial IWMS within the BC Forest Practices Code and Forest and Range Practices Act (2002), and provide a summary of relevant information to people involved in the conservation and management of Marbled Murrelets.

Building upon a recent review of the species' status in Canada (Hull 1999) and a compilation of research and management reports (Hooper 2001), the Conservation Assessment is a multi-stage process involving these steps:

- a review of the general biology, populations, habitat associations, and conservation of the murrelet, relevant to BC (Part A; Burger 2002);
- a statement of conservation and management objectives focused on the needs of the murrelet (Part B, by the Marbled Murrelet Recovery Team; this document);
- a risk-analysis of management options (Part C; Steventon et al. in press);
- analysis of economic and social impacts (MOF and Ministry of Sustainable Resource Management [MSRM]);
- revision of the Marbled Murrelet Recovery Plan (Marbled Murrelet Recovery Team);
- review of the IWMS requirements applicable to Marbled Murrelets (MWLAP and MOF);
- review of the requirements applicable to Marbled Murrelets under the incoming Species at Risk Act (Environment Canada - CWS).

Factors limiting Marbled Murrelet populations in BC are not well understood. Demographic models indicate that population size is most sensitive to adult survival, followed by survival of immature birds, and fecundity or nesting success (reviewed in Burger 2002). Murrelets spend most of their lives at sea and they are affected by marine processes (e.g., food availability and perhaps the long-term effects of climate change). There are presently few data to identify critical marine problems for murrelets, but this might change with increased research of the birds at sea. The prevailing consensus is that the greatest threats are from loss of nesting habitat in old-growth

forests (Ralph et al. 1995, Hull 1999, Burger 2002). The recommendations made in this document therefore focus on conservation and management of nesting habitat.

GENERAL PRINCIPLES OF CONSERVATION AND MANAGEMENT

The Marbled Murrelet Recovery Team, with input from informed people in government, industry, universities and consultants, has agreed on the following guiding principles in formulating this advisory document and recommending conservation and management options to governments.

1. The initial goal will be to down-list the species from Threatened to Special Concern, using COSEWIC criteria.
The rationale for the current COSEWIC listing is the perceived rate of decline of nesting habitat, which is believed to be causing a similar decline in the provincial population. To down-list the species the immediate goal is to ensure that the population and suitable nesting habitat does not decline by more than 30% from current population levels during the three generations (30 years) after 2002 (i.e. by 2032).

2. The long-term goal will be to maintain the provincial population at a level which is sufficient to de-list the species using COSEWIC criteria.
A key objective is to provide sufficient Marbled Murrelet nesting habitat at the end of this 30 year period, which if maintained in the long term, would likely allow the provincial population to stabilize, within the accepted range of population fluctuations. If this habitat target is achieved, the habitat is maintained, and the population stabilizes, the species may be de-listed. For de-listing the population must also be shown to be at low risk of loss of viability due to the cumulative effects of all impacts on the species.

3. The present range of Marbled Murrelets in British Columbia should be maintained.
A basic principle in wildlife management for the provincial and federal agencies responsible is to maintain the geographic range of a species. The historic breeding range of Marbled Murrelets appeared to cover most of the coast of BC, although abundance varied widely across this range. Murrelets are still found through most of this range and management objectives should include efforts to maintain this distribution. The extirpation of a local population should be considered a serious loss (Soulé 1986, Caughley 1994). If possible, efforts should be made to restore the Marbled Murrelet to parts of its historical range from which most of the nesting habitat has disappeared (e.g., parts of eastern Vancouver Island and the southern mainland). Management should ensure sufficient habitat to maintain a viable population of Marbled Murrelets in each conservation region, distributed widely across the region in those areas capable of supporting the species. Maintaining a widespread range of the BC population is also likely to reduce any negative effects that may result from global climate change.

4. Marbled Murrelets should remain a relatively abundant bird in British Columbia.
The Marbled Murrelet is listed as Threatened by COSEWIC because of perceived declines in the population. Numerical abundance does not guarantee long-term survival of a species which is facing serious declines (Caughley 1994, Pulliam and Dunning 1994). The intention of this

principle is to maintain the species as one of the widespread and numerically common seabird species in BC.

5. Conservation goals should be aimed at acceptable, not minimal standards.
The goal of the advisory document, management recommendations, and operational tactics is to prevent unacceptable population decline (>30% over the next 30 years), and to maintain the geographic range of the species in BC. This will require maintenance of populations and habitat that are more than the minimum needed to prevent extirpation. This is also an application of the precautionary principle (Kriebel et al. 2001), which is particularly relevant to situations where the population size, population trends, habitat use and population dynamics are poorly known, as in many areas of the murrelet's range in BC.

6. Manage Marbled Murrelets according to coast-wide and regional population and habitat criteria
The Recovery Team identified six conservation regions which approximately match both the variation in Marbled Murrelet habitat use and forest districts (see below for details). The Recovery Team recognizes that there are regional differences in the way that murrelets use inland habitats for nesting, and differences among regions in the availability of suitable nesting habitat. Where possible we recommend province-wide standards and habitat criteria, but we also provide regionally specific habitat criteria where applicable.

7. Uncertainties should be addressed by applying an adaptive management approach.
The Recovery Team lacks reliable knowledge of many aspects of Marbled Murrelet biology and responses to land use. This prevents us from confidently prescribing nesting habitat targets and characteristics that will sustain the species in BC, and it makes our projections of future populations less certain than we would like. Because logging and other human impacts on habitats will continue, however, we cannot simply wait until better information becomes available through research and inventories. Adaptive management will therefore be an important tool for learning about how to improve habitat management as government conservation policies are implemented. To take full advantage of the adaptive management process, it must be implemented in a structured, systematic way with attention to scientific principles of project design and analysis (Holling 1978, Walters 1986, Nyberg 1998). Adaptive management should be applied with caution, taking care not to preclude future opportunities for maintaining suitable habitat for murrelets.

STRATEGIC PLAN TO MEET COSEWIC CRITERIA

General Strategic Approach

The strategic approach taken by the Marbled Murrelet Recovery Team in formulating guidelines for conservation and management includes the following steps:

1) Reviewing the COSEWIC criteria by which the Marbled Murrelet is listed as Threatened and letting these criteria guide the strategic plan and recovery goals;
2) Identifying practical conservation regions within BC for the management of the species (Table 1 and Figure 1);

3) Estimating the present populations of Marbled Murrelets within these regions, using the best available information (Table 2);
4) Proposing minimum acceptable populations and habitat areas within each conservation region to meet the COSEWIC guidelines, i.e., minimizing the decline of the overall BC population to less than 30% of the 2002 population over the next 30 years (Table 2);
5) Providing information from radar/GIS studies to guide the calculation of the area of inland nesting habitat needed within each conservation region to meet or exceed the 30-year minimum acceptable population levels (Appendix 1);
6) Providing a summary of habitat parameters useful for the selection of suitable nesting habitat within each conservation region (Table 3 and associated text);
7) Proposing that the application of these management guidelines be made through revision of the IWMS procedures and species account, which will include the details of the amounts and characteristics of nesting habitat within each region;
8) Recommending an adaptive management approach to implement recovery actions, to deal with the uncertainties in regional population estimates, habitat use, habitat availability, and socio-economic realities. Management options should also ensure that future recovery needs are not precluded by current actions.

Listing Criteria and Recovery Goals

Marbled Murrelets are listed as Threatened in Canada on the basis of COSEWIC Criterion A (COSEWIC Organization and Procedures Manual, Appendix VI, Table 2). Criterion A deals solely with Declining Total Populations, and defines a Threatened Species as one with a population decline of at least 30% in 10 years or 3 generations (i.e., 30 years - a generation is estimated to be 10 years for Marbled Murrelets; Burger 2002). A decline of 50% or more in these periods puts a species in the Endangered category. Population decline can be either:

(1) population reduction observed, estimated, inferred, or suspected in the past; or
(2) population decline projected or suspected in the future.

This can be based on

a) direct observation;
b) an index of abundance appropriate for the taxon;
c) a decline in area of occupancy, extent of occurrence and/or quality of habitat;
d) actual or potential levels of exploitation;
e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.

Marbled Murrelets remain listed as Threatened largely on evidence of the past and continuing decline of nesting habitat in coastal old-growth forests (i.e., category c above).

The MMRT has set two goals for the recovery of Marbled Murrelets:
1) The first goal is to down-list the species from Threatened to Special Concern, by creating conditions that will limit the decline of the BC population and its nesting habitat to less than 30% over three generations (30 years), during the period 2002 to 2032. The MMRT recognises that the population in 2002 is likely reduced from historical levels, but the available data on past population size, distribution, and population trends before 2002 are too incomplete to use past populations for setting future minimum acceptable populations. The MMRT believes that dealing

with future declines is more realistic than trying to estimate and manage for past declines across the entire province.

2) The second goal is to ensure that, by maintaining sufficient suitable nesting habitat (see definition below), and by reducing other threats, the species will have a low risk of reduced viability after 2032. This goal will allow the species to be considered for down-listing to Special Concern and eventually de-listed. One of the principles accepted by the MMRT is that the Marbled Murrelet should remain a relatively common seabird in BC, and that the COSEWIC minimum population criteria should not be applied. In other words, Marbled Murrelet recovery actions should be aimed at ensuring that there is less than a 30% population loss over the next 30 years and that human-induced population decline ceases to occur after 2032 or later in regions with lower rates of habitat loss.

Throughout this document we refer to maintenance of nesting habitat rather than protection of habitat, recognising that not all habitat available to murrelets in the long-term will be within legally protected areas. Maintained suitable habitat is therefore defined as suitable nesting habitat within legally protected areas (e.g., parks and ecological reserves), reserve areas (e.g., riparian reserves), and other areas that will not be logged (e.g., inaccessible or constrained areas). Since forests require 140-250 years of succession to provide suitable nesting attributes (e.g., complex canopy structure, thick platforms, mossy mats), maintenance of suitable habitat is not compatible with current timber-supply rotations. Where circumstances warrant it (e.g., there is insufficient suitable old growth to meet regional recommendations) future suitable habitat can be recruited by allowing appropriate areas of second-growth to mature into old-growth forests.

Population Objectives

The management of Marbled Murrelets in BC is unusual in many respects. Unlike most other threatened species in Canada, the murrelet is relatively common. Recovery plans for most other threatened or endangered species, and for the Marbled Murrelet in Washington, Oregon and California (USFWS 1997), seek to maintain or increase present populations. This is unlikely to happen for the BC population of Marbled Murrelet, because harvesting BC's old-growth forests will continue. A more realistic recovery goal is to seek a stable, acceptable population, which will almost certainly be smaller than the present population. For most of BC, therefore, the dilemma is to decide how much of the nesting habitat (and hence the local population) to protect. What loss of population is deemed acceptable? The basic decisions will be to determine how low we will allow the present population to fall before stabilizing. In some areas, where populations are most depleted (e.g., east Vancouver Island and southern mainland coast), management objectives should protect a larger portion of existing suitable habitat than in other parts of the BC range (e.g., west Vancouver Island, central and northern mainland), and should also aim to restore habitat in severely depleted areas to provide for a viable sub-population in the long term.

Caughley (1994) made a distinction between two conservation paradigms: the "small-population paradigm" which focuses on factors which are important when populations are small and facing extinction; and the "declining population paradigm" which focuses on factors affecting populations experiencing serious declines. Both paradigms have relevance to conservation of Marbled Murrelets in BC, but to differing sub-populations within the province. In this context,

Caughley (1994) stressed that we should be equally concerned with the extinction of local populations as with the extinction of the entire species.

The **small population paradigm** deals with a wide range of demographic, environmental and genetic risks associated with small populations. These include risks associated with population fluctuations, environmental variability (including catastrophes), reduced heterozygosity, genetic drift, inbreeding depression, and other problems generally associated with the impacts of random events, loss of genetic diversity and the expression of deleterious recessive alleles (Meffe and Carrol 1994, Pulliam and Dunning 1994, Caughley 1994, Mangel and Tier 1994). These processes are unlikely to apply to most populations in BC, except in rare isolated populations in parts of southeast Vancouver Island and the southern mainland. Conservation strategies in these isolated areas should be concerned with re-building healthy sub-populations by maintaining most of the remaining birds in the short-term, and restoring the species in the long-term to areas where it has been extirpated. Genetic factors are unlikely to be important in BC at present due to the high mobility of Marbled Murrelets and lack of evidence of geographic variability in the genetic composition of the BC population.

The **declining population paradigm** has more widespread application to Marbled Murrelets in most areas of BC. Loss and fragmentation of nesting habitat are clearly the major concerns, although gill-nets, oil spills, and changes in marine food webs might also contribute in some areas. The paradigm focuses on ways of detecting, diagnosing and halting a population decline (Caughley 1994). Caughley stressed the need for scientific hypothesis testing to establish the causes of decline, because correlations between population declines and some factor such as habitat loss do not necessarily mean that this factor was the cause of the decline. Caughley also stressed the value of monitoring treated populations to ensure the success of the conservation prescription. There is a strong case for adaptive management, including large-scale habitat manipulation (Walters and Holling 1990). Large-scale logging operations are likely to continue, and in selected areas where murrelets are still relatively abundant these operations should be used as opportunities to study the effects of habitat loss, fragmentation, patch size and forest edges on Marbled Murrelets. The goal would be to use this information to refine future harvest prescriptions to improve conditions for Marbled Murrelets in managed forests.

Conservation Regions for Marbled Murrelets in BC

Table 1 and Figure 1 show the six conservation regions. The boundaries of these regions are a compromise between the boundaries of existing forest districts, wildlife management regions, Land and Resource Management Plan (LRMP) regions, and ecosections. We use the term conservation region to differentiate between these and forestry and wildlife management regions. The inland boundaries of these regions might be adjusted as further information becomes available on the distribution of murrelets.

Based on changes in areas of habitat (Demarchi and Button 2001a,b; Burger 2002), Marbled Murrelet populations or suitable nesting habitats are perceived to have declined significantly prior to 2002 on eastern Vancouver Island and the Southern Mainland Coast, somewhat less on

the West and North of Vancouver Island and Haida Gwaii, and least in the Central and Northern Mainland regions.

Each conservation region has a somewhat different history, population status and conservation priorities (see Part A for further details; Burger 2002). Some important factors are summarised here and estimated populations are given in Table 2.

West and North Vancouver Island – Populations on the west coast are relatively well censused with radar and at-sea surveys, but those on the north and northeast are poorly known. There is evidence of population decline and substantial reductions in old-growth forest, but populations are still large and form about one third of the provincial total (Table 2). Several large areas of old growth are protected in provincial and national parks but additional areas are required to meet the regional objectives, especially in the northern parts of the island. There are considerable data and habitat algorithms available for selecting suitable habitat, but some additional habitat work might be needed in the northern part of the island. Priorities are to determine the extent of additional maintained habitat needed to meet regional objectives, refine the application of habitat algorithms, and test whether the available data are applicable on the northern part of the island.

East Vancouver Island – The population size and distribution is poorly known and requires inventory. Most of the old growth has been lost, much of it many decades ago and often with permanent conversion to farm and urban areas, and the population is likely a small fraction of its historical size. There are few data on habitat use in these drier forests. Historically, there might have been less suitable habitat than in more moist regions because of frequent stand initiation due to fires, and less epiphyte development due to a drier climate. Short-term priorities include radar studies to improve population estimates, identifying, mapping and maintaining existing suitable habitat. A long-term priority is to re-build the population to exceed the 2002 numbers, by restoring suitable habitat using appropriate older second-growth.

Southern Mainland Coast – The population size and distribution is reasonably well known and several studies have provided similar population estimates (5000-7000 birds). Much of the old-growth has been removed, especially in low elevation areas. In the drier subzones in this region there might have been less suitable habitat historically than in moister forests, because of frequent stand initiation due to fires, and less epiphyte development due to a drier climate. Habitat use has been well studied and regional habitat algorithms are available. Short-term priorities include identifying and maintaining remaining old growth patches to meet the regional objectives, and radar surveys to determine the populations in the southern portions of this region. In the long term, protection of suitable second-growth stands would help restore sub-populations in areas where there is little remaining old growth and populations are well below the likely historical levels.

Central Mainland Coast – The population size and distribution is moderately well known from two radar studies, but most of the watersheds have not been censused and estimates of the regional population have a high degree of uncertainty. Large areas of suitable habitat are probably included within areas set aside as part of the Central Coast Land and Resource Management Planning process. Commercial forestry and some other industrial activities are deferred in these areas until June 2003, when a decision on future development will be made by

government. The distribution and area of suitable murrelet habitat in these deferred areas are currently being mapped. Habitat associations have received little study and there are no regional habitat algorithms. Priorities include extending radar censusing to improve the regional population estimate, habitat studies leading to management algorithms, mapping and calculating existing protected or maintained habitat, and identifying core areas with inadequate maintained habitat.

Northern Mainland Coast – This is generally the least studied region, although radar studies and modelling of density, distribution, and habitat associations have begun. Priorities are similar to those for the Central Mainland, and are at least in part now being addressed through the North Coast Land and Resource Management Planning process. The Marbled Murrelet has been identified as a key species in the Environmental Risk Component of the North Coast LRMP, and suitable habitat is being mapped.

Queen Charlotte Islands/Haida Gwaii - There have been numerous studies on land and at sea, but data on the population size and distribution remain patchy, especially for the west coasts of Moresby and Graham islands. Several studies have provided nest habitat data. Habitat algorithms are well advanced but still require field confirmation. Approximately 1800 km^2 is protected on South Moresby in Gwaii Haanas National Park Reserve, including some areas of old-growth forest. A 3500 km^2 National Marine Conservation Area is proposed contiguous to Gwaii Haanas National Park Reserve and will help protect significant seabird feeding areas. Relatively little has been maintained or protected on Graham Island. Priorities include improving the population estimates using radar surveys, determining the extent of existing protected habitat and identifying additional habitat needs to meet the regional objectives. The distribution and area of suitable murrelet habitat is currently being mapped.

OPERATIONAL OBJECTIVES TO MEET THE STRATEGIC PLAN

Parameters for management and monitoring of populations and nesting habitat

Maintaining adequate habitat suitable for nesting is currently perceived as the greatest conservation need for down-listing Marbled Murrelets. Consequently the primary management goals are to identify and maintain sufficient nesting habitat to maintain or exceed the minimum acceptable populations in each region. These goals will need to be revised if research suggests alternative priorities (e.g., the need to improve adult survival or improve foraging conditions at sea).

Until recently, the existing methods of inventory for Marbled Murrelet (at-sea surveys and inland detections) were too imprecise to determine local populations or monitor their changes. Radar counts offer prospects of more precise measures, but have not been done across most of the province, and might not be applicable in all habitats (e.g., open low coastlines where murrelets use many flight-paths).

Ideally management and monitoring of Marbled Murrelets should include a combination of:

- identifying suitable nesting habitat in each region, by developing and refining habitat algorithms, air photo interpretation and other methods (further details given below);
- mapping and estimating the areas of suitable habitat, taking into account variations of habitat quality;
- tracking past and projected changes in the area and quality of nesting habitat;
- monitoring selected populations using radar at appropriate watersheds.

Where possible these measures should be supplemented by surveys and other research done at sea in adjacent foraging areas, to help explain changes that might occur in local populations.

Recommendations for maintaining areas of suitable nesting habitat

The following are recommendations for establishing maintained habitat areas in old-growth forests, including WHAs established under a revised IWMS, and other areas maintained as suitable nesting habitat. The Marbled Murrelet Recovery Team recognizes that a small proportion of murrelets nest on cliffs, or in deciduous trees (Bradley and Cooke 2001), but the consensus is that management prescriptions should be aimed at nesting habitat likely to be used by the bulk of the BC population.

The Recovery Team proposes three elements for maintaining suitable nesting habitat:

- an overall provincial strategy, aimed initially at maintaining sufficient existing nesting habitat to prevent a decline that exceeds 30% in the provincial murrelet population over the next 30 years;
- specific minimum acceptable murrelet populations and consequently areas of nesting habitat set for each of the six conservation regions; and,
- definitions of suitable habitat and acceptable layouts of maintained habitat patches, some of which apply across the province and others specifically designed for each of the six conservation regions.

1) Estimates of current and minimum acceptable populations

Province-wide the areas of maintained habitat should ensure that the rate of population decline is less than 30% over the period 2002-2032. Until research indicates otherwise, the plan is to prevent the loss of nesting habitat by more than 30% during this 30 year period. Marbled Murrelets within the six conservation regions have varying populations and have experienced varying amounts of habitat loss. The regional population minimums have therefore been adjusted to provide greater protection to regional populations that have experienced the greatest reductions (i.e., East Vancouver Island and the Southern Mainland Coast), and allow greater reductions in the remaining four conservation regions, where the populations are larger and have experienced relatively less decline. The Recovery Team recommends trying to maintain at least 90% of the existing population by 2032 on East Vancouver Island, and 85% (half the maximum allowable provincial rate of decline) on the Southern Mainland Coast. In both of these conservation regions, the long-term goals are to restore the populations to exceed 2002 levels, by maintaining areas of appropriate second-growth which will mature into suitable old-growth nesting habitat after 2032.

Table 2 shows the estimated current population in each conservation region, and the proposed minimum acceptable populations to meet the COSEWIC criteria for down-listing from Threatened. Minimum acceptable populations were rounded to the nearest 100. At this stage it is unrealistic to apply greater precision to these populations.

The 30-year populations given in Table 2 are provided as guidelines for minimum acceptable population levels. These numbers are based on incomplete census data and extrapolations from relatively few studies and therefore have a high degree of uncertainty. As regional censuses and further radar and nest habitat studies provide better data, the regional population estimates and minimum acceptable values should be updated.

2) Estimating the areas of suitable habitat per conservation region

Areas of suitable habitat required to maintain the minimum acceptable populations by 2032 can be estimated in two ways:

1) Multiplying the minimum acceptable population by the density of birds per ha of suitable habitat;
2) Estimating the currently available area of suitable habitat in 2002 and applying the suggested minimum rate of decline to the habitat area.

Both methods are based on the assumption that there is a predictable relationship between the numbers of murrelets and the area of suitable habitat that they occupy. This relationship is suggested by several radar studies, but the precise nature of the bird-habitat regression remains uncertain for most regions, and varies significantly among some parts of BC (reviewed in Burger 2002). There is therefore likely to be some uncertainty in the estimates of area of suitable habitat derived from either method.

Appendix 1 summarizes the analysis of murrelet density estimates from five radar studies made in BC. All five studies found significant relationships between numbers of murrelets and areas of habitat, but with varying degrees of confidence (Burger 2002). Linear regressions gave reasonable fits to the data in most cases, but curvilinear power curves (suggesting fewer murrelets in very large watersheds) gave better fits in some cases. Significant differences were found among the regions in the densities of murrelets per ha of habitat, and densities on the west coast of Vancouver Island were consistently higher than those on the mainland coast (South, Central and North Coasts). A major source of uncertainty in the derivation and application of these density estimates is in the definition and measurement of suitable habitat. Further refinement of landscape-level habitat measures will improve the density estimates and allow their application with greater confidence. The Marbled Murrelet Recovery Team anticipates that revised density estimates will be forthcoming, derived from consistent habitat parameters applied to murrelet counts from all the radar studies. The present density estimates are therefore presented as an aid to estimating the areas of habitat needed in each region, but should be applied with caution.

An additional problem arises if the density values calculated from landscape-level habitat measures are applied to stand-level selection of WHAs and other patches to be maintained as nesting habitat. The landscape-level habitat measures used in the radar studies are invariably broadly defined and forest polygons classified as *most likely* habitat will include some proportion

of *least likely* habitat (see Table 3). Radar counts also underestimate densities because not all murrelets are detected by the radar. These factors lead to an underestimate of density and consequently suggest a larger amount of habitat needed to support a specified population. If such densities are then applied to stand-level patch selection, where a higher proportion of the forest should be *most likely* habitat, then the radar densities might overestimate the area of habitat needed to support the specified population. This source of error can be minimized by using the same definitions of suitable habitat for estimating the density and for applying to patch selection.

It is likely that most polygons of maintained nesting habitat would include combinations of both *most likely* and *moderately likely* suitable habitat. Risk would be lowered if there was a higher proportion of *most likely* habitat. When calculating the amount of habitat required for a specific number of nesting Marbled Murrelets, densities should be applied to match the likely quality of the habitat being considered for maintained habitat. Densities derived from selective, high-ranking habitat measures should be applied if the polygons being considered contain a reasonable proportion which is *most likely* suitable habitat (as defined in Table 3 and in the text below). Lower densities derived from more general habitat measures should be applied if the polygons being considered contain a significant portion of habitat that is *least likely* suitable.

The areas of nesting habitat maintained in each conservation region include areas of suitable habitat currently under some form of protection (e.g. national and provincial parks, ecological reserves, old growth management areas). An inventory of available areas of suitable habitat within each region, including currently protected areas, is urgently needed to allow planning of additional maintained habitat in order to meet the recovery objectives.

3) Maintaining the distribution of populations and habitat within conservation regions

Conservation regions are defined in Table 1 and Figure 1.

The Recovery Team has identified three objectives for maintaining the distribution of murrelets within each conservation region. These are:
a) to match the future distribution of the population and maintained forest habitat across the region with existing conditions as closely as possible;
b) to identify and maintain the most important breeding concentrations within the region;
c) to establish some large core areas of maintained habitat to minimize the risks of future habitat reduction and catastrophic events.

There are several reasons for these objectives. First, the future distribution across BC and within each region should match current conditions as much as possible to maintain genetic diversity, prevent sub-populations from becoming reproductively isolated, and reduce the risk of such isolated sub-populations “winking out” due to unexpected events or climatic variations. Second, areas supporting larger concentrations of murrelets are important for maintaining the size of the BC population. Third, maintenance of several relatively large core areas of suitable nesting habitat within each conservation region should provide some insurance against possible effects of forest fragmentation and catastrophic events, such as wind storms that may destroy smaller patches of nesting habitat. Fourth, these objectives should increase the likelihood of incorporating important foraging and nesting areas, accommodate some shifts in the population

distribution due to changes in the quality of either marine or nesting habitats (e.g., due to climate change or local effects), and reduce the risk of localized catastrophic events, such as wind storms or major oil spills. Finally, this approach will reduce the effects of uncertainty in the information and assumptions used in this document, such as the impact of "hard" unnatural edges on predation at murrelet nests.

To meet these objectives the Recovery Team recommends dividing each conservation region into clusters of Landscape Units. Where possible, Landscape Unit clusters (MSRM 2002) already being used for other forest planning tasks should be used. Where flexibility of land use planning permits, each conservation region should include at least three core clusters of Landscape Units which provide larger proportions of suitable habitat associated with known foraging aggregations in nearby ocean areas. Each of the three core Landscape Unit clusters should support a minimum of 10% of the population within the conservation region. In this context, a large area of suitable habitat is envisaged to cover several thousand hectares, if the local population of murrelets warrants such an area. Some of these larger core areas will be in existing parks (e.g., suitable habitat within Carmanah-Walbran Provincial Park, parks in Clayoquot Sound, Gwaii Haanas National Park Reserve). If the larger, existing protected areas are clustered in only one part of a Conservation Region (e.g., Gwaii Haanas National Park Reserve within the Haida Gwaii/Queen Charlotte Islands region), efforts should be made to identify and maintain larger areas of old-growth in the remaining portions of the Conservation Region to meet the three objectives identified in this section. Large forested areas set aside by Land and Resource Management Planning processes would provide ideal core areas if they included large tracts of suitable habitat.

Where large areas of old-growth forest are not currently available to meet these objectives (Southern Mainland and East Vancouver Island), the Recovery Team recommends that as much suitable habitat as possible be maintained, supplemented by recruiting appropriate second-growth stands for future habitat. High priority should be given to maintaining larger polygons or clusters of polygons likely to support a larger sub-population, and to forest habitat within the likely flight range of known foraging aggregations (most nests in BC were within 50 km radius of foraging areas).

4) Recommended patch areas and exposure to forest edge within Landscape Units

The effects of forest edge on breeding success and risks of predation for Marbled Murrelets depend on the type of edge. Available information (see Conservation Assessment Part A; Burger 2002) suggests that:

- natural edges (e.g., rivers, bogs, avalanche chutes) have no documented negative effects, although some predators of murrelets are associated with natural edges;
- artificial edges bordered by uniform maturing forest (e.g., when regenerating stands approach the base of the old-growth canopy) have little or no negative effects, because the maturing forest should act as a buffer against negative edge effects from predators and adverse microclimate;
- artificial edges bordered by recent clearcuts or young forest (<40 years) not associated with ongoing human activities are known to have negative effects in some situations (e.g., increased densities of some predators, lower nesting success, and micro-habitat deterioration);

- artificial edges bordered by recent clearcuts or young forest (<40 years) associated with human activities providing food for corvids or other nest predators are most likely to pose risks to nesting murrelets.

There is evidence that murrelets can nest successfully in naturally-occurring small patches (<50 ha) on the Sunshine Coast (Bradley 2002, Huettmann et al. in prep.). Geometric models show that the proportion of stand exposed to edge effects increases exponentially with decreasing stand size and also with more convoluted boundaries (Burger 2002). If edges have negative effects on nest success, and assuming negative effects to 50 m from forest edges, the models suggest that edge effects have little impact for patches larger than about 100 ha, assuming all sides of the polygon have "hard" edges. Effects would extend to larger areas in convoluted polygons, but to smaller areas with circular or square polygons. The strongest effects are likely in patches that are less than 40-50 ha and bordered by recent clearcuts, particularly if elongated or with convoluted boundaries. The edge areas affected would be proportionately less in polygons partly bounded by natural edges (rivers, scrub-forest, avalanche chutes etc.).

There is uncertainty on the extent of positive or negative effects of artificial edges less than 40 years old on Marbled Murrelets. To deal with the uncertainty and to provide a precautionary approach against over-fragmentation, some negative effects are assumed to apply within 50 m of recently created artificial edges, such as boundaries between old-growth forests and recent clearcuts or young regenerating forest. There are some biological reasons for considering edge effects as restricted to 50 m of the forest edge:

- predation effects by edge-loving predators, when present, seem strongest within 50 m of artificial forest edges;
- blow-down at artificial edges would mostly occur within 50 m (i.e., approximately one tree length);
- negative effects on microclimate, if present, would be strongest in the first 50-100 m

The Marbled Murrelet Recovery Team recommends treating hard edges (i.e., edges bordering clearcuts, roads, or young regenerating forest reaching less than the base of the old-growth canopy) as less suitable habitat for a distance of 50 m into the old-growth forest from the forest edge. Such forest edges should be considered as less suitable habitat, when bordering old-growth patches of less than 100 ha, and should be minimised in patches of all areas. When establishing protected or maintained habitat patches, consideration should be given to the shape and edge both at the time the patch is assessed and how these might be during the next 30-40 years. For example, if future clearcuts will border the patch in 5-10 years time then the area considered as suitable habitat should be modified to account for the future effects along the affected boundary.

To meet the variation in patch-size use and effects, the Recovery Team recommends retention of a proportional mix of patch sizes across landscape units. For patches bounded by natural edges the size of patch is not important, provided that buffering effects provided by adjacent or nearby forest are not removed. For patches created by forest harvesting, a range of patch size is recommended. A landscape unit consisting predominantly of patches in the small patch range (low 10s of ha) will not provide sufficient protection against errors in assessing the murrelet's requirements. Large patches (in the range of hundreds of ha) are needed to deal with the uncertainty of patch-size effects on murrelets, and to take into account the risk of losing all large

patches. These large patches within managed forests should be designed to fill the range between larger areas established through strategic level planning (i.e., areas of several thousand ha as described in section 4 above) and smaller patches (10s ha or smaller) which are usually more readily established in managed forests. As an interim measure, until the effects of patch size are better understood, the Recovery Team recommends maintaining a mix of large (>200 ha), medium (50-200 ha), and small (<50 ha) patches within managed forests.

5. Definitions of suitable habitat within each conservation region

Table 3 defines the range of critical nesting habitat parameters considered essential as suitable nesting habitat for Marbled Murrelet within each conservation region. The selection of these regional criteria is based on available research information and habitat algorithms specific to particular conservation regions (Hooper 2001, Tripp 2001, Burger 2002). The habitat features are ranked by the likelihood that polygons with these features will contain a large proportion of suitable nesting habitat

Explanations for the criteria selected are given here.

Distance from saltwater – There are few data on the distribution of murrelet nests with increasing distance from the sea, or on the effects that increasing distance inland have on nest success, predation risks to adults, and energetic costs of provisioning. Most nests appear to be within 30 km of the ocean shore and very few nests have been found beyond 50 km inland, and none beyond 80 km (Hamer and Nelson 1995, F. Cooke et al. unpublished data). In Desolation Sound the earlier, more successful birds tended to nest at greater distances from the ocean (Bradley 2002). There is also evidence that the forests bordering oceans provide less suitable nesting habitat along exposed shores, and that there are higher densities of predators along ocean fringes (reviewed in Burger 2002). Forests within 0.5 km of shores are therefore considered less suitable than those further inland, but this restriction need not apply in steep sided fjords, or areas where there is no evidence of higher predator densities or other negative coastal effects, such as fewer suitable platforms, or if available habitat inland is less suitable. On exposed coasts it is important to leave coastal strips as buffers to reduce wind and spray affecting more suitable habitat inland.

Biogeoclimatic subzones - Biogeoclimatic subzones and variants reflect the effects of latitude, elevation and climate on vegetation structure (Pojar et al. 1987). Some differences in quality of habitat for murrelets have been found in different subzone variants (Burger 2002) and subzone variants are useful for landscape-level mapping and modelling in combination with other variables. At the smaller patch or stand scale their effects are likely to be captured by combinations of other variables considered here and subzone variants might not be reliable habitat predictors.

Biogeoclimatic Site Series, Site Index and productivity – Site Series are the stand-level categories in the Biogeoclimatic classification (Banner et al. 1993, Green and Klinka 1994), reflecting soil moisture and nutrients, and thus productivity. Site Series generally have to be determined in the field, although predictive mapping is available in some areas (Terrestrial

Ecosystem Mapping, or Predictive Ecosystem Mapping). Significant differences in habitat quality for Marbled Murrelets occur among Site Series on Vancouver Island, but these are fairly variable and often difficult to apply to murrelet habitat assessment (Burger 2002). Study plots often seem to have more than one Site Series within them and the maps do not always reliably predict the reality on the ground.

Site Series may work better when generalized into ecosystem productivity classes based on predicted Site Index (defined as height of trees at age 50 years in absence of competition, BC Ministry of Forests 1998; Green and Klinka 1994: 197-216). Site Index or productivity classes were more likely than Site Series to reflect meaningful forest structure and provide a mappable parameter in Marbled Murrelet studies (Burger 2002). A tentative ranking of these classes is given in Table 3. Site Index classes might be useful in identifying older second growth which is likely to mature into suitable murrelet habitat in the future, although they have not been specifically tested for that purpose. There appear to be regional variations in the reliability of Site Index classes to predict suitable murrelet nesting habitat; murrelets sometimes nest in patches of lower productivity forest. Site Index estimates are also available from Forest Inventory maps, but accuracy is variable from area to area.

Elevation – The effects of elevation are mediated through habitat effects and elevation could be substituted by biogeoclimatic subzone variants. Murrelets will nest up to about 1500 m above sea level, but the majority of nests have been found below 900 m, including those located by telemetry in four areas of BC (Burger 2002). Review of nest distribution, nest success, predation risk, and habitat characteristics, relative to elevation in BC (Burger 2002) suggests the following (Table 3):

- most optimal habitat is likely to occur in the 0-900 m range in the southern part of the province (perhaps 0-600 m in areas where there is still considerable low-elevation old-growth remaining), 0-600 m in more northern areas and 0-500 m in Haida Gwaii/QCI;
- less suitable conditions are likely above these boundaries going up to the start of the alpine tundra zone at 800 or 900 m in different parts of the province;
- areas within and above the alpine tundra zone (above 800 -1500 m in various parts of the province) should be considered as unsuitable unless there is evidence to the contrary;
- in all cases elevation should not be the sole criterion for establishing suitability, and evidence of nesting, occupancy and/or suitable habitat (e.g., potential nest platforms) is needed for establishing habitat suitability.

Slope – There is lack of agreement on the effects of slope on murrelet nesting and nest habitat quality in BC (reviewed in Burger 2002). Evidence from Desolation Sound, Clayoquot Sound, and Mussel Inlet shows that murrelets do nest on steep slopes (30-70 degrees), and in Desolation Sound murrelets selected steeper slopes and showed higher nesting success with increasing slope. Other studies, however, have shown negative or neutral effects of slope on rates of occupied detections and measures of nest habitat quality (reviewed in Burger 2002). Taking a conservative approach, slope should be treated as a neutral variable.

Stand age – Structures suitable for nest platforms (large limbs usually with thick epiphyte cover) tend to be restricted to old-growth trees. Stands >250 years are most likely to provide such structures but those 140-250 years might also be suitable. Stands classified as <140 years old are

not likely to provide suitable nesting habitat, unless there are suitable old-growth veteran trees or other trees with suitable platforms present.

Tree height class – Across their range, most murrelet nests have been found in very large trees, and those in class 4 or larger (>28.5 m tall) are *most likely* to provide suitable nest platforms. Nests have however been found in smaller trees, particularly in higher elevations and more northerly latitudes and the ranking criteria for each conservation region have therefore been adjusted to reflect the availability and suitability of trees locally. A distinction should be made between polygon height classes and actual tree heights. In some polygons rated as height class 2 some larger, suitable trees exist, but these need to be confirmed before accepting such polygons as suitable habitat. Height classes on forest cover maps generally reflect average conditions in a polygon and might not be accurate for all parts of a polygon.

Canopy closure and vertical complexity - Gaps in the canopy closure and variability in canopy structure have been shown to be important requisites for Marbled Murrelets to nest, and have also been found to be reliable predictors of murrelet occupancy and nest habitat availability (reviewed by Burger 2002). There are, however, no standard measures which give consistent predictions which can be applied to capture these criteria. Canopy cover (projected cover of tree crowns) has been used in some regional algorithms (e.g., McLennan et al. 2000), but is a poorly captured attribute in the forest cover inventory, or is not captured at all in some areas. Vertical canopy complexity is a subjective measure applied during air photo interpretation, incorporating differences in height between the leading species and average tree layer, occurrences of canopy gaps, and tree stocking patterns. Waterhouse et al. (2002) found that this measure of vertical canopy complexity was a more reliable predictor of polygons containing nests in the Sunshine Coast than canopy closure. Bahn and Newsom (2002) included vertical complexity from Vegetation Resource Inventory (VRI) maps in their habitat algorithm.

Canopy closure needs to be applied with caution and if measures of vertical complexity are available they are likely to be more reliable than canopy closure as indicators of suitable habitat. The testing and development of standards for consistently describing canopy complexity and gappiness, and the various sources of these (e.g., tree height and topography), combined with reference photos to be used as regional benchmarks for air photo interpretation and helicopter assessments is a priority.

Topographic variability – Small irregularities in the stand topography can provide variability in the canopy structure, which might enhance the suitability of forest stands for nesting. These might break up the continuity of the forest canopy and perhaps allow greater access to the murrelets. Some examples include small rock outcrops, avalanche chutes, gullies, riparian zones, and small ridges.

Aspect, exposure, and moisture regimes – Aspect and exposure can have strong effects on the suitability of forests for nesting, especially in drier areas where south-facing slopes often have less moss and fewer platforms. Other factors which reduce habitat suitability by inhibiting the formation of mossy platforms or modifying tree structures are exposure to strong winds (e.g., along exposed coastlines, exposed mountain ridges, or mountain outflow gullies) or sea spray.

Other criteria – Density of potential platforms (limbs or deformities >15 cm in diameter, including epiphyte cover) has been widely used in BC, and the U.S. to identify suitable nesting habitat, and this measure is generally positively correlated with measures of occupancy (reviewed in Burger 2002). Regional algorithms and ground-truthing of potential WHAs also use this measure extensively (Tripp 2001, Burger 2002). The measure cannot be derived directly from forest cover or other habitat maps, although it does correlate with some parameters available on such maps.

Selection of suitable habitat for murrelets should, where possible, take both canopy structure and platform density into account. They are essential when ground-truthing or helicopter checking potential WHAs and other areas being considered as maintained habitat.

6. Guidelines for identifying and confirming suitable habitat

Methods for identifying suitable nesting habitat – Identification of suitable nesting habitat should follow a stratified, strategic approach which is consistent across BC and which gives all areas under consideration equal probability of being selected. The level of detail applied below will vary depending on the scale of application (regional strategic planning to operational assessment of individual stands for WHA selection) and the need for certainty.

The recommended sequence is:
1. the use of GIS and/or habitat maps to identify and map habitat polygons under consideration;
2. the use of habitat algorithms and/or recognized habitat indicators (e.g., vertically complex canopy combined with age and size of trees) to assess and rank the suitability of the habitat for nesting murrelets [This can be used directly in strategic land-use assessments, or as a preliminary stratification tool for operational assessments. Accuracy will decrease with spatial scale at which it is used.];
3. air photo interpretation to assess the evidence of suitable habitat using standardized criteria, including vertical complexity, tree height, stand age and other regionally relevant parameters;
4. selection of potential polygons to be protected or maintained as murrelet nesting habitat;
5. confirmation that the selected polygons are suitable habitat (next section).

Although several regional algorithms have been developed for identifying suitable nesting habitat using a range of mappable and GIS data (Tripp 2001), these are not always accurate in identifying suitable habitat or applicable outside the area where they were developed, and should be used with caution. Ideally, the application of algorithms should be supplemented by steps 3-5 when selecting WHAs and other maintained habitat. A process has been initiated to produce guidelines and reference photos for standardised evaluation and ranking of potential habitat using air photo interpretation in BC.

Methods for confirming the use or suitability of identified habitat - Polygons identified as suitable murrelet habitat will usually include some suitable patches, but the bulk of the polygon might in fact be unsuitable and *vice versa*. This may be adequate at a strategic scale, with explicit recognition of the uncertainty, whereas areas to be designated as WHAs, or other protected or maintained areas for nesting Marbled Murrelets should be confirmed as suitable habitat. This can be done using one or more of the following:

- evidence of nesting (nests found, eggshells found);
- evidence of occupancy by murrelets (using the standard protocol; RIC 2001);
- evidence of suitable nesting microhabitat (acceptable evidence of potential platform limbs, adequate epiphyte cover, canopy complexity), established using standard ground plots or transects (RIC 2001);
- evidence of suitable nesting microhabitat (as above) established using low-level helicopter reconnaissance.

Guidelines, reference photos and videos are being prepared for standardized helicopter reconnaissance to assess, rank and document habitat for murrelets in BC.

Monitoring and reporting the sufficiency of land-use plans

To ensure that sufficient nesting habitat for Marbled Murrelets is maintained in each conservation region, the Recovery Team recommends routine reporting on the sufficiency of planning procedures affecting significant areas of Marbled Murrelet habitat within each region. These reports should outline the amounts and quality of Marbled Murrelet habitat to be maintained in the land affected by the planning processes, and explain how these amounts and areas were measured and selected. In addition, the implementation of land-use plans for each murrelet conservation region should be monitored to ensure that the goals of the Recovery Team and COSEWIC are being met. Detailed guidelines for sufficiency reporting and monitoring of nesting habitat available to murrelets could be included in revised IWMS Procedures and Measures for the Marbled Murrelet.

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Table 1. Conservation regions for Marbled Murrelets in BC

Conservation region	Boundaries along the coast (see Map 1 for further details and inland boundaries)
West & North Vancouver Island	Jordan River to Cape Scott and northern Vancouver Island from Cape Scott to Campbell River
East Vancouver Island	Jordan River to Campbell River
Southern Mainland Coast	U.S. border to Bute Inlet
Central Mainland Coast	Bute Inlet to north end of Princess Royal Island
Northern Mainland Coast	Laredo Sound to Alaska border, excluding Princess Royal Island
Haida Gwaii (QCI)	Entire Queen Charlotte Islands/Haida Gwaii archipelago

Table 2. Estimates of the current (2002) and minimum acceptable (2032) populations of Marbled Murrelets in each conservation region. Population estimates (from Burger 2002, Conservation Assessment Part A) are incomplete and are likely underestimated in several regions. The scenario restricts the overall BC population decline to <30% over 30 years, allows slightly higher rates of decline in the four most populated regions, but sets lower rates of decline in the two regions with most depleted populations (E Vancouver Island and the S Mainland). Populations are rounded to the nearest hundred birds. Minimum acceptable populations will need to be adjusted if new censuses indicate differences from the estimated 2002 populations. See text for more details.

Conservation region	Maximum allowable % decline per region	Estimated population (birds)	
		Current (2002)	Minimum acceptable (2032)
A) Optimistic population estimates			
West & North Vancouver Island	31.4	24,500	16,800
East Vancouver Island	10.0	1,000	900
Southern Mainland Coast	14.3	7,000	6,000
Central Mainland Coast	31.4	21,000	14,400
Northern Mainland Coast	31.3	14,700	10,100
Haida Gwaii (QCI)	31.6	9,500	6,500
Total for British Columbia	**29.6**	**77,700**	**54,700**
B) Pessimistic population estimates			
West & North Vancouver Island	31.4	19,400	13,300
East Vancouver Island	0.0	700	700
Southern Mainland Coast	15.0	6,000	5,100
Central Mainland Coast	32.0	10,000	6,800
Northern Mainland Coast	32.7	10,100	6,800
Haida Gwaii (QCI)	31.8	8,500	5,800
Total for British Columbia	**29.6**	**54,700**	**38,500**

Table 3. Guidelines for selecting suitable habitats for nesting Marbled Murrelets in British Columbia. The features are ranked by the likelihood that polygons with these features will contain a large proportion of suitable nesting habitat. '*Most likely*' options indicate the range of habitats considered most likely to provide suitable nesting habitat within each conservation region. '*Moderately likely'* habitats might be considered for WHAs or other maintained areas but require detailed ground truthing. Options classed as '*Least likely*' should be considered for WHAs only if there is strong evidence that the particular site provides suitable nesting habitat, and should be considered low probability habitat at strategic, regional scales. Many of the parameters listed below have qualifiers and caveats for their application and this table should be used in conjunction with the text.

Feature	*Most likely*	*Moderately likely*	*Least likely*
Distance from saltwater (km) – all regions[1]	0.5 - 30	0-0.5 & 30-50	>50
Elevation (m)			
Central & Northern Mainland Coast	0-600	600-900	>900
Haida Gwaii (QCI)	0-500	500-800	>800
All other regions	0-900	900-1500	>1500
Stand age class – all regions	9 (>250 yr)	8 (140-250 yr)	<8 (<140 yr)
Site index productivity classes – all regions	Class I & II	Class III	Class IV
Tree height class – all regions[2]	4-7 (>28.5 m)	3 (19.5-28.4 m)	<3 (<19.5 m)
Canopy closure class – all regions	Classes 4, 5 & 6	Classes 3 & 7	Classes 2 & 8
Vertical canopy complexity – all regions[3]	MU, NU & VNU	U	VU

[1]Areas within 0.5 km of exposed shores tend to have less suitable habitat and higher densities of predators, but this might not apply to steep-sided fjords and inlets.

[2]Nests have been found in polygons ranked height class 1 or 2 but the nests were in larger trees than the polygon average.

[3]Vertical complexity ranked from least to highest (see Waterhouse et al. 2002). VU = very uniform (<11% height difference leading trees and average canopy, no evidence of canopy gaps or recent disturbance). U = uniform (11-20% height difference, few canopy gaps visible, little or no evidence of disturbance. MU = moderately uniform (21-30% height difference, some canopy gaps visible, evidence of past disturbance, stocking may be patchy or irregular. NU = non-uniform (31-40% height difference, canopy gaps often visible due to past disturbance, stocking typically patchy or irregular). VNU = very non-uniform (>40% difference, very irregular canopy, stocking very patchy or irregular).

Figure 1. Marbled Murrelet Conservation Regions in British Columbia. Note that areas in the Stikine and Iskut drainage adjacent to the Alaska pan handle should be included in the Northern Mainland Coast Region if they show evidence of use by Marbled Murrelets.

APPENDIX 1:
DENSITIES OF MARBLED MURRELETS IN FOREST HABITATS

Measures of the density of Marbled Murrelets (birds per area of habitat) are useful for two purposes. First, density can be used to convert population estimates into estimated areas of habitat currently used or required for maintaining the population. Conversely, the number of murrelets likely to be supported by a watershed or patch of forest can be estimated by applying the appropriate density measure to the known area of forest.

This appendix summarizes densities of Marbled Murrelets calculated from five studies done in BC which combined radar counts of murrelets entering watersheds with GIS measures of available habitat within the watersheds. These studies were in:

- northwest Vancouver Island (21 watersheds; Manley 2000, and unpublished data);
- Clayoquot Sound on the west of Vancouver Island (18 watersheds; Burger 2001);
- Sunshine Coast (21 watersheds; Cullen 2002);
- Central Mainland Coast (22 watersheds; Schroeder et al. 1999), and
- Northern Mainland Coast (26 watersheds; Steventon and Holmes 2002).

A more detailed analysis and comparison of these data can be found in the Conservation Assessment Part A (Burger 2002).

Note that radar counts include all birds entering watersheds, and include unknown proportions of breeding and non-breeding birds. The working measure is therefore birds per hectare of habitat, whether applied to populations for estimating the amount of area required, or applied to habitat areas to estimate the number of birds likely to be supported. There is no known method for accurately estimating the number of nests or pairs from radar count data, but a rough rule of thumb is that there would be about one nest for every three birds counted (taking into account non-breeders and having two breeders per nest). Population estimates for each region are also given as birds (including immatures) rather than pairs, which makes them compatible with the density measures used here.

Habitat measures

Measures of available habitat varied across each study, depending on the available GIS information, the type of habitat considered most suitable, and local variations in habitat types. Three measures of habitat were used to estimate densities.

Habitat 1: All mature and old-growth - This category covered the broadest classifications of mature and old-growth forests in each study. For Clayoquot Sound, NW Vancouver Island, the Sunshine Coast, and North Coast this was given as all forest over 140 years old (age class 8 and 9) at all elevations, which in reality was mostly >250 years old (age class 9), especially for the two Vancouver Island studies. For the Central Mainland there was no general measure of mature and old-growth in Schroeder et al. (1999), and the broadest habitat category available was the top three categories of the algorithm based on Broad Ecosystem Unit mapping, considered suitable under current conditions (i.e., regenerating logged forests excluded).

Habitat 2: "Most likely habitat" - The second measure of habitat was more selective and included the habitat found to be most strongly correlated, or most likely to predict suitable murrelet nesting areas. For the two Vancouver Island studies this was low-elevation mature and old-growth below 600 m (Manley 2000, Burger 2001). For the Sunshine Coast this measure was old forest >250 years old with height class >19.5 m in all elevations (Cullen 2002). This was in the top three habitat categories based on correlation coefficient with murrelet numbers, and reflected measures being applied for habitat selection in the Sunshine Coast. For the Central Coast the measure was mature and old-growth, height class 4 (>28.5 m) or higher at all elevations (Schroeder et al. 1999). This measure is based on Forest Cover information, and was preferred to the Broad Ecosystem Unit (BEU) algorithms also used by Schroeder et al. (1999), because these algorithms down-graded slope habitats (now shown to be well used by murrelets), forest cover measures are proving more reliable as indicators of habitat than BEU units, and forest cover measures are most compatible with the measures used in other studies. For the North Coast a Habitat Suitability Index (HSI) was applied to weight the areas of forest in each age and size class (see Steventon and Holmes 2002).

Habitat 3: Highest realistic densities - Finally the habitat measures that yielded the highest densities of murrelets, which were also realistic for modeling (covered relatively large portions of the landscape and found in most watersheds) were considered. For Clayoquot Sound, Northwest Vancouver Island and the Sunshine Coast the categories were the same as Habitat 2 (above). For the Central Coast the top two categories of the algorithm based on Broad Ecosystem Unit mapping, considered suitable under current conditions (Schroeder et al. 1999).

Not surprisingly, Habitats 2 and 3 gave very similar results, but Habitat 2 was probably a more practical and realistic measure of high-quality suitable murrelet habitat.

Effects of outliers

Watersheds which fell outside or on the border of the 5-95% confidence limits for mean density in each study were examined. If there were biological reasons to explain unusually high densities (e.g., strong possibility that many birds were flying to adjacent watersheds and were erroneously included in the surveyed watershed) or unusually low densities (e.g., very large watersheds in which some suitable habitat was too far from foraging grounds, especially those at the heads of long inlets), then the watersheds were omitted from density measures. In Table A-1 densities are given for each region with and without the outliers. In general eliminating the outliers had little effect on the density but, as expected, usually narrowed the confidence limits around the mean.

Density estimates per study and region

For this analysis densities were calculated as the arithmetic mean from the raw data in each study area or region. Analysis of Variance showed that densities from the two areas on West Vancouver Island (Clayoquot Sound and NW Vancouver Island) were strongly similar, and consistently higher than densities from the BC Mainland (South, Central and North Coast). Consequently the mean densities are presented for these larger land units (Table A-1). Density estimates for each study area are also available if required (Burger 2002). Density estimates also varied according to the type of habitat selected for comparison. Densities calculated from general

measures of older forest (all old-growth [age class 9; >250 years] and mature forest [age class 8; 140-250 years]) gave lower densities than analyses using more likely nesting habitat (e.g., age class 9, size class 4+).

Table A-1. Mean densities (with 95% confidence limits) of Marbled Murrelets (birds per ha) calculated from five studies in BC using three different measures of suitable habitat. The results are pooled into the two parts of the province which had differing densities: West Vancouver Island and BC Mainland. See Part A (Burger 2002) for details from each study. Sample size (N) is number of watersheds per study. Results are given with and without the outliers in each area.

	All data included			Outliers excluded		
	N	Mean	95% CL	N	Mean	95% CL
Density 1 (using all age class 8 & 9, all elevations)						
West Vancouver Island	39	0.052	(0.043-0.061)	37	0.049	(0.041-0.057)
BC Mainland	67	0.024	(0.013-0.035)	58	0.019	(0.016-0.023)
All areas pooled	106	0.034	(0.026-0.042)	95	0.031	(0.026-0.036)
Density 2 ("most likely habitat")						
West Vancouver Island	39	0.085	(0.073-0.097)	37	0.082	(0.071-0.093)
BC Mainland	69	0.031	(0.022-0.040)	59	0.028	(0.023-0.033)
All areas pooled	108	0.050	(0.042-0.059)	96	0.049	(0.041-0.056)
Density3 (Highest realistic densities)						
West Vancouver Island	39	0.085	(0.073-0.097)	37	0.082	(0.071-0.093)
BC Mainland	66	0.041	(0.029-0.054)	58	0.034	(0.028-0.040)
All areas pooled	105	0.058	(0.048-0.068)	95	0.055	(0.047-0.063)

Application of density estimates

These estimates of density should be applied with caution. As a general rule the densities should be applied to forest areas using the same measures of habitat used to derive the density estimates. Density 1 values should therefore only be applied to broadly defined habitat including mature and old-growth forests, whereas Density 2 and 3 could be applied to more restrictive categories of habitat which include a greater proportion of high quality nesting habitat. See the main body of this report for further information on the application of density measures.

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