COSEWIC
Assessment and Status Report

on the

Marbled Murrelet
Brachyramphus marmoratus

in Canada

THREATENED
2012

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

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COSEWIC
Assessment Summary

Assessment Summary – May 2012

Common name
Marbled Murrelet

Scientific name
Brachyramphus marmoratus

Status
Threatened

Reason for designation
This small seabird is largely dependent on old growth coastal forests in British Columbia for nesting. Habitat loss has been estimated at over 20% for the past three generations. Future threats including ongoing habitat loss, coupled with increased threats from proposed shipping routes in the core of the species' range, increased fragmentation from a variety of proposed and recently initiated developments, fisheries bycatch and changing at-sea conditions have resulted in projected population losses exceeding 30% over the next three generations.

Occurrence
British Columbia

Status history
Designated Threatened in April 1990. Status re-examined and confirmed in November 2000 and May 2012.

COSEWIC Executive Summary

Marbled Murrelet
Brachyramphus marmoratus

Wildlife Species Description and Significance

The Marbled Murrelet is a small seabird in the Family Alcidae. Marbled Murrelets (hereafter murrelets) forage by diving for small schooling fish in nearshore waters.

Distribution

The murrelet breeds from the Aleutian Islands, through southern Alaska, British Columbia, Washington, Oregon and central California. The bulk of the population breeds in Alaska and B.C. Within B.C., murrelets can be found along most of the coast, but are rare in parts of the Strait of Georgia.

Habitat

The marine foraging habitat is usually nearshore (< 1 km of land) or in sheltered waters. The murrelet is found in a wide range of marine habitats but shows an affinity to shallow seas (generally ocean less than 30 m deep) with sandy or gravel seafloors.

Nesting habitat is usually old-growth forest providing large trees (typically > 30 m tall) with large, mossy boughs and gaps in the canopy allowing access to nest sites. These conditions are usually found in lower elevation forests (< 900 m), on steep or gentle slopes or on valley floors. Based on habitat mapping, there are about 1.98 million ha of suitable habitat in coastal B.C. in the 0-50 km range from the sea. The habitat most likely to be used is 0-30 km inland and totals 1.83 million ha. Estimates of the total loss of old-growth coastal forest (much of it murrelet nesting habitat) since European settlement, due to logging, agriculture or urbanization, range from 35% to 53%. Models using habitat algorithms indicate that the area of suitable nesting habitat has declined by 22% in the 30 years between 1978 and 2008. Habitat losses in portions of Vancouver Island and the south coast regions may have surpassed recommended recovery thresholds.

Biology

Marbled Murrelets, like most seabirds, lay a single egg per clutch. The species has low juvenile recruitment (often less than 0.3 fledged chicks per pair per season), but high adult survival (0.83-0.93 per year). Demographic models predict that populations would be most sensitive to changes in adult survival, but under current conditions with loss of nesting habitat, high nest predation and occasional prey shortages at sea, recruitment of juveniles appears to drive population trends.

Population Sizes and Trends

The total adult population of murrelets in B.C. is roughly 54,450-94,200 (median 74,325).

There are no surveys that allow a good assessment of population trends over the past three generations (30 years). The following surveys provide a mix of direct and indirect population trend estimates, but historical data and spatial coverage are limited and each survey method covers only part of the 30-year period:

- Radar surveys conducted between 1996 and 2010 show a positive non-significant population trend of 2% per year across six Marbled Murrelet Conservation Regions, suggesting a stable population over the study region as a whole. Population trends were similar among regions, although East Coast Vancouver Island was an exception to this pattern, where the trend was more variable and had a higher probability of being negative (P_{neg} = 0.72).
- Repeated at-sea boat surveys indicate declines exceeding 1% per year (for the most comprehensive surveys: 11% per year (1991-2009) at Laskeek Bay, Haida Gwaii; 6% per year (1994-2006) off the West Coast Trail; 6-9% per year (1991-2006) in Barkley Sound), but declines seem to have levelled off since 1999.
- Murrelet numbers correlate strongly with area of nesting habitat, so habitat loss of 22% over 30 years suggests similar reductions in the population.
- Analysis of 26 Christmas Bird Count circles in B.C. reveals significant declines at nine sites, a significant increase at one site and no trends in the remaining sites.
- Analysis of boat surveys and Christmas Bird Counts in the Salish Sea (B.C. Washington border) indicate declines in murrelet numbers between 1978 and 2008 of 71% and 69%, respectively.

Threats and Limiting Factors

Loss of nesting habitat in old-growth forests due to forest harvesting remains the greatest threat to the Marbled Murrelet. Fragmentation of the remaining forest is likely to result in increased exposure to nest predators, which prefer forest edges and changes to microclimatic conditions that could affect mossy pads used for nest sites. Breeding success and population trends are also affected by ocean conditions. Low juvenile recruitment has been reported in years of El Niño or when coastal upwelling fails. As oceans warm, increased competition with southern stocks of mackerel and large Humboldt squid could also be a threat as these piscivores could reduce prey stocks for murrelets. Other present or future threats include: oil spills and chemical contaminants at sea; entanglement in gill-nets; displacement by aquaculture farms; disturbance by boat traffic (especially recreational craft); algal blooms; and developments of “run-of-the-river” hydroelectric schemes and their transmission lines.

Protection, Status, and Ranks

The Marbled Murrelet is listed in the IUCN Red List as “Endangered”. The species has been designated as Threatened by COSEWIC since 1990 and is listed in Schedule 1 of the *Species at Risk Act* (SARA). Provincially, murrelets are Blue-listed and included as an Identified Species under the *B.C. Forest and Range Protection Act*. The new Conservation Framework being used to assess conservation priorities in British Columbia ranks the murrelet in the highest of six categories.

In June 2011, an estimated 681,785 ha of potential nesting habitat (34.4% of the available habitat) 0-50 km inland was protected under a range of legal statutes or land management plans. The proportion in the most-used 0-30 km inland zone was similar (631,814 ha; 34.6% of available habitat). The proportion protected in each conservation region varied (0-50 km zone): Northern Mainland Coast: 30%; Haida Gwaii: 67%; Central Mainland Coast: 30%; Southern Mainland Coast: 26%; West and North Vancouver Island: 34%; East Vancouver Island: 23%.

TECHNICAL SUMMARY

Brachyramphus marmoratus
Marbled Murrelet — Guillemot marbré
Range of occurrence in Canada (province/territory/ocean): British Columbia/Pacific Ocean

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2008) is being used) *Range 6.9-12.8 years based on life-table calculation with 10 years suggested as a working average (Burger 2002)*	10 yrs
Is there an [observed] continuing decline in number of mature individuals? *Spatial and temporal coverage is sparse; most at-sea surveys indicate large declines over the long-term, but data from more recent radar surveys and at-sea counts show no significant trends since the late 1990s.*	Unknown. Population has shown large declines on the long-term and habitat loss continues, particularly in southern parts of the Canadian range. There are indications of stability in the last decade.
Estimated percent of continuing decline in total number of mature individuals within [2 generations]	Unknown
[Inferred] percent [reduction] in total number of mature individuals over the last [3 generations]. *Based on an estimated loss of nesting habitat of 22% over the past 30 years (Long* et al. *2011) or 3 generations and evidence from different spatial scales that murrelet abundance is significantly correlated with area of nesting habitat (Burger and Waterhouse 2009)*.	22%
[Suspected] percent [reduction] in total number of mature individuals over the next [3 generations].	Likely given ongoing habitat loss and other threats
[Inferred] percent [reduction] in total number of mature individuals over any [3 generations] period, over a time period including both the past and the future.	Inferred to exceed 30% based on past rates of habitat loss and future threats.
Are the causes of the decline clearly reversible and understood and ceased? *Logging of nesting habitat continues, but at a lower rate than in the period 1970s to mid-1990s. Negative effects of forest fragmentation have been documented but the demographic impacts are hard to predict. Factors affecting murrelets at sea are poorly understood and future trends are hard to predict, although global warming seems likely to have mostly negative effects for murrelets at sea. The likely impacts of many threats are not quantified (e.g., aquaculture, run-of-river power plants and power lines)*.	No
Are there extreme fluctuations in number of mature individuals? *Both at-sea and radar censuses show annual fluctuations but these are usually less than 20% of mean values*.	No

Extent and Occupancy Information

Estimated extent of occurrence *Based on the B.C. Ministry of Environment habitat suitability model*	284,000 km²

Index of area of occupancy (IAO) (Always report 2x2 grid value; other values may also be listed if they are clearly indicated (e.g., 1x1 grid, biological AO). *Based on a 2 km X 2 km grid applied to suitable nesting habitat*.	112,400 km^2
Is the total population severely fragmented? *There are gaps along the coast where no murrelets breed (especially on east Vancouver Island and the southern mainland) but elsewhere there appears to be fairly continuous occurrence although much of the coast has yet to be adequately surveyed during the breeding season.*	No
Number of "locations*" *Murrelets breed in hundreds of watersheds and forage along much of the B.C. coastline.*	Unknown, but greater than 10
Is there an [inferred] continuing decline in extent of occurrence? *Within B.C., there appear to be extirpations of local breeding populations in parts of east Vancouver Island and the southern mainland around Vancouver*.	Yes
Is there an [inferred] continuing decline in index of area of occupancy? *Nesting habitat continues to decline (see Threats) and birds no longer appear to nest in many areas of east Vancouver Island and the southern Mainland although these are not spatially mapped*.	Yes
Is there an [observed, inferred, or projected] continuing decline in number of populations?	N.A.
Is there an [observed, inferred, or projected] continuing decline in number of locations?	Unknown
Is there an [observed] continuing decline in [area, extent and/or quality] of habitat? *The nesting habitat was estimated to have declined by 22% (Long* et al. *2011; and this text) between 1978 and 2008 (3 generations). Future loss of habitat is likely to be somewhat less due to reduced Annual Allowable Cuts in old seral forests, but it does continue. Habitat quality is likely reduced by fragmentation promoting edge effects (mainly increased predation at nests and possibly deleterious microhabitats at edges)*	Yes
Are there extreme fluctuations in number of populations? *The entire B.C. population is treated as one population*.	No
Are there extreme fluctuations in number of locations*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each population)

Table 10 gives the population within each conservation region. There are no discrete populations within British Columbia	**No. of Mature Individuals**
Range of estimates (assuming 75% of all birds are mature adults)	54,450 – 94,200
Mid-point	74,325

* See definition of location.

Quantitative Analysis

Probability of extinction in the wild is at least [e.g., 20% within 20 years or 5 generations, or 10% within 100 years]. *Population viability predictions based on simulation models using realistic assumptions of demographic values and forest management options (Steventon* et al*. 2006). This simulation suggested <10% probability of extinction within 100-500 years with coastwide population at or above 12,000 breeding pairs (about 36,000 birds). Current population estimate is 72,600-125,600 birds. Increased risk of extinction for local populations below 5000 pairs. See the text for further details and caveats about these results*.	<10% within 100-500 years for the entire B.C. population

Threats (actual or imminent, to populations or habitats) – see Table 13

Known threats:

- Loss of nesting habitat in old-growth forests from logging and roads.
- Negative impacts (mostly increased nest predation) associated with forest fragmentation.
- Entanglement in fishing gear (mainly salmon gill-nets) is an ongoing problem, but likely less of a threat than it was 20 years ago.
- Oil spills—low-volume chronic spills probably kill small numbers of murrelets but there is a risk of a catastrophic spill (e.g., Exxon Valdez), which could kill tens of thousands.
- Contaminants in nearshore waters—not well documented for murrelets but known to be a problem for other piscivores sharing these waters.
- Disturbance from boat traffic (especially recreational craft) is well documented but the range-wide long-term impacts are not known.
- Displacement and disturbance due to aquaculture (finfish and shellfish farms) is known and seems to be a growing problem in localized areas.

Likely future threats:

- Displacement and collision mortality by wind turbines at sea and in coastal areas, and by their transmission lines across nesting habitat.
- Loss of nesting habitat and collision mortality from “run-of-the-river” hydroelectric schemes and their transmission lines.
- Changes to prey stocks resulting from global warming and decadal regime shifts.

Possible threats:

- Reductions in prey stocks due to commercial fishing of schooling fish or euphausiids.
- Release of biotoxins and surfactants from marine algal blooms.
- Increased nest predation from rising populations of corvids associated with human habitation and recreation sites.
- Tidal power-generating plants have been suggested for B.C. and, if built, might displace murrelets in some nearshore shallow seas.

Rescue Effect (immigration from outside Canada)

Status of outside populations *Murrelets breeding in WA, OR & CA declined by 4.3% per year in 2001-2008 (7.9% per year in Zone 1 bordering B.C.). Murrelets in AK declined by 5.4-12.7% per year since the 1990s.*	Significant past and ongoing declines in both bordering states (AK & WA)
Is immigration known or possible?	Yes
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada? *Nesting habitat is declining in B.C. and breeding populations show linear correlations with habitat areas suggesting there is little unused nesting habitat*.	No
Is rescue from outside populations likely? *Some movement of murrelets across the Washington border has been documented and is highly likely across the Alaska border too, but populations in these bordering states are experiencing major declines.*	No

Current Status

COSEWIC: Threatened (2000)

Status and Reasons for Designation

Status: Threatened	**Alpha-numeric code:** A4c
Reasons for designation: This small seabird is largely dependent on old-growth coastal forests in British Columbia for nesting. Habitat loss has been estimated at over 20% for the past three generations. Future threats including ongoing habitat loss, coupled with increased threats from proposed shipping routes in the core of the species' range, increased fragmentation from a variety of proposed and recently initiated developments, fisheries bycatch and changing at-sea conditions have resulted in projected population losses exceeding 30% over the next three generations.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Threatened A4c. Inferred population declines are based on a continuing decline of 30% or more from habitat loss due to forestry activity and combined losses from the degradation of the marine environment, increased threats of oils spills, forest fragmentation, increased industrial development, and bycatch.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not meet criterion. EO is >20,000 km² and IAO is > 2,000 km².
Criterion C (Small and Declining Number of Mature Individuals): Does not meet criterion. Population is >10,000 mature individuals.
Criterion D (Very Small or Restricted Total Population): Does not meet criterion. Population is > 1,000 mature individuals and IAO is > 20 km².
Criterion E (Quantitative Analysis): Does not meet criterion. Simulation suggested a <10% probability of extinction within 100 to 500 years.

PREFACE

This is the third status report on the Marbled Murrelet for COSEWIC, following Rodway (1990) and Hull (1999). Since the last status report there has been a large volume of research completed on the murrelet, summarized by Burger (2002), Lank *et al*. (2003), McShane *et al*. (2004), Piatt *et al*. (2007) and U.S. Fish & Wildlife Service (2009). In particular, there have been major new studies on the population genetics (Piatt *et al.* 2007), demography (Cam *et al*. 2003), population size and trends (Piatt *et al*. 2007), and nest predation linked with forest fragmentation (e.g., Malt and Lank 2009). The at-sea life of the murrelet remains poorly studied but recent studies using stable isotopes (e.g., Norris *et al*. 2007; Gutowsky *et al*. 2009) and at-sea counts and behavioural studies (e.g., Peery *et al*. 2004a; Ronconi 2008), show that marine conditions mediated through prey stocks do affect recruitment and therefore likely impact populations.

The identification and mapping of forest nesting habitat has been greatly improved in the past decade. Although problems and uncertainties remain with habitat algorithms and GIS mapping, we now have a reasonable estimate of the amounts of potential forest habitat remaining and the ways in which murrelets might use such habitat across the British Columbia coast. These methods have allowed refined analyses of the extent (Mather *et al*. 2010) and trends (Long *et al*. 2011) of forest nesting habitats, which are important determinants of population size.

The development of radar as an inventory tool for murrelets in the 1990s and 2000s has led to better estimates of the British Columbia population size, although large and important parts of the range have not been surveyed by any census methods and total population estimates remain crude.

Based on improved population estimates using radar counts, which indicate a larger murrelet population than originally estimated in 1990, the status of the Marbled Murrelet in British Columbia was down-listed in 2010 from Red to Blue. The provincial status of the breeding population was down-listed from S2B (sub-nationally imperilled) to S3B (Vulnerable), but the status of the non-breeding population was changed from S4N (apparently secure) to S3N (vulnerable).

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2012)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Marbled Murrelet, *Brachyramphus marmoratus*; Guillemot marbré (AOU 2009). Order: Charadriiformes; Family Alcidae (auks or alcids).

Morphological Description

Marbled Murrelets are small, stocky seabirds which, like all alcids, forage by diving, using underwater flight (Nelson 1997). Their adaptations for such foraging methods include relatively stubby wings, large breast muscles and dense plumage. Consequently they have high wing-loading (Kaiser 2007) and are not very maneuverable when flying through forest canopies. They require gaps in the canopy to access nest sites and need to nest high in trees to make stall landings and drop-off take-offs. Their alternate (breeding) plumage is mottled dark brown, cinnamon and grey, which provides camouflage on their nest sites; their basic (winter) plumage is dark grey to black upper with ventral breast and belly and distinctive white scapulars and collar on the sides of the neck.

Population Spatial Structure and Variability

The most recent and comprehensive investigation of population genetics on the Marbled Murrelet analysed introns (fragments of DNA that interrupt the coding regions of structural genes and that are not translated into proteins) and nuclear microsatellites (tandemly repeated sequences of small sections of DNA) (Piatt *et al*. 2007). In this study, DNA was collected from 282 murrelets, known or likely to be breeding birds, from 12 sites spaced across the geographic range (from the outer Aleutians to Central California (Figure 1)), including 30 birds from a single site in British Columbia (Desolation Sound). The results showed no evidence for inbreeding or low genetic variation at any of the sampling sites (e.g., there were few significant values of Wright's inbreeding coefficient [F_{IS}] for the 23 loci at any of the 12 sites and none in the British Columbia samples). Estimates of genetic distance (Wright's F_{ST} or Φ_{ST}) for introns and microsatellites (either treated separately or combined) indicated low but significant population genetic structure (mean F_{ST} or Φ_{ST} was 0.022 ± 0.002 [SE]; maximum 0.047 for all loci). This result was consistent with previous analyses, which reported global F_{ST} or Φ_{ST} between 0.05 and 0.09 based on allozymes, mtDNA, introns and/or microsatellites (Friesen *et al*. 1996, 2005; Congdon *et al*. 2000). Allelic richness, observed heterozygosity and F_{IS} did not differ significantly among sites (analyses of variance, all Ps > 0.10; Piatt *et al*. 2007).

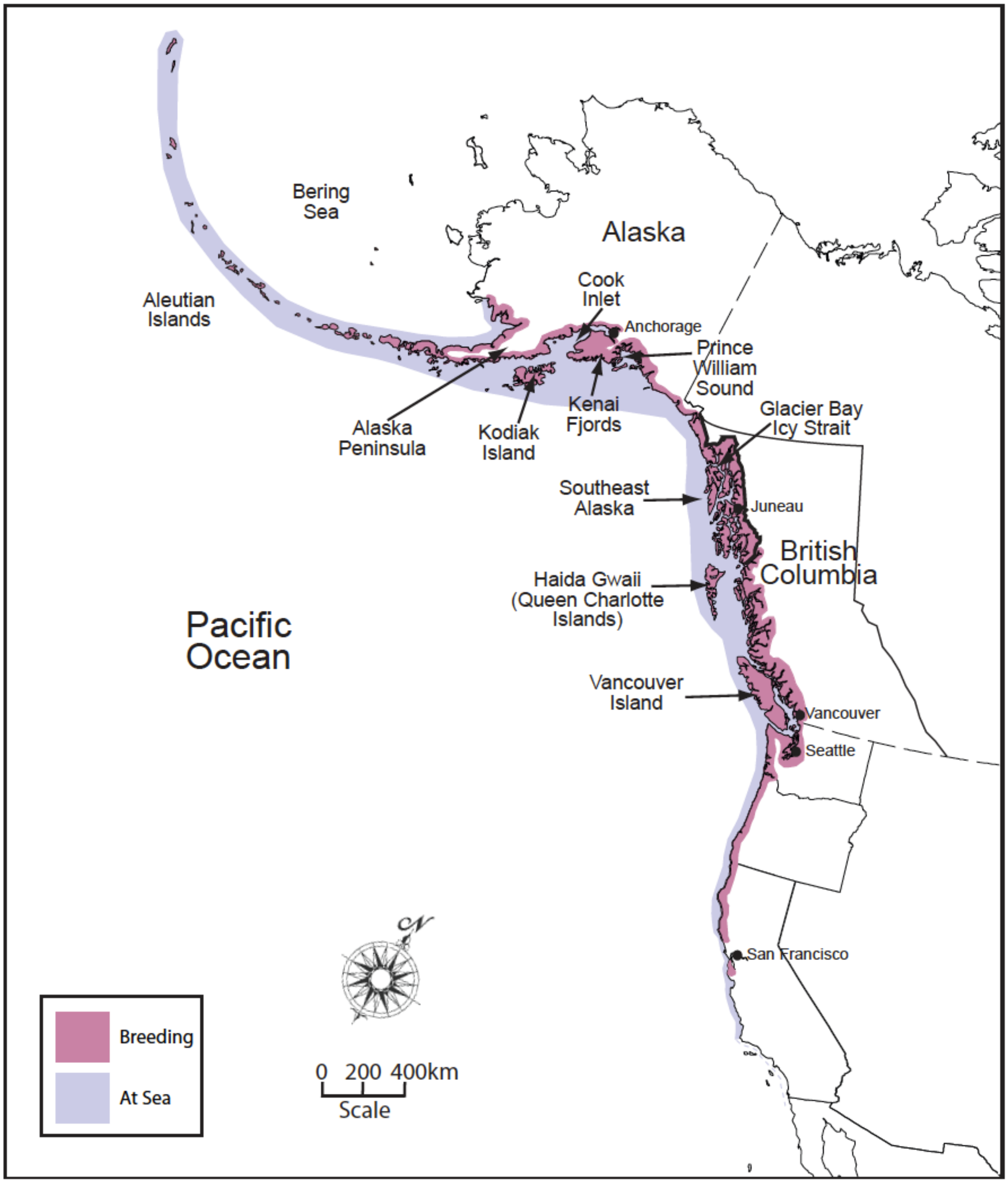

Figure 1. The global range of the Marbled Murrelet showing the marine and inland distributions (from Piatt *et al*. 2007, with permission).

The genetic structure reported in Piatt *et al*. (2007) revealed three likely genetic populations, two of which were associated with distinct geographic sites at each extreme of the range (one in the outer Aleutian and the other in Central California). The remaining birds, from the eastern Aleutian Islands, mainland Alaska, British Columbia, Washington, Oregon and northern California, did not differ genetically and most showed mixed haplotypes. Thus, gene flow appeared to occur among sites within the central region, with a single genetic population from Unalaska (eastern Aleutians) to northern California. Population genetic structure in this species did not appear to arise from historical fragmentation (e.g., Pleistocene glaciation) but was more likely a product of genetic drift and *in situ* local selection, following post-glacial range expansion. A previous study (Pitocchelli *et al*. 1995) failed to find genetic differences in mtDNA between tree- and ground-nesting murrelets in Alaska.

An independent study by Peery *et al*. (2009a) reported no statistically significant pairwise F_{ST} estimates for comparisons within any part of the central range ($F_{ST} < 0.0068$), but confirmed the genetic distinction of the Central California population. This study also revealed that the small and geographically isolated Central California population had suffered greater declines in allelic richness (6.9% decline across loci) than the larger and more continuous central population (4.5%).

The genetic evidence is consistent with the absence of any major population disjunction across the species' central breeding range from Alaska to northern California. There is therefore no evidence of genetic isolation or a genetically distinctive population in British Columbia. Based on the available genetic evidence the birds breeding here are from the geographically widespread and demographically numerous central genetic stock. There has been no investigation of genetic variation among murrelets breeding within British Columbia, and the samples used in Piatt *et al*. (2007) and previous analyses were all from one location—Desolation Sound. Given the high gene flow, no significant genetic differentiation within the province is expected.

Designatable Units

No subspecies or distinct races are recognized in British Columbia, and based on genetic analysis (see above) there is likely considerable gene flow across the B.C. coast and with neighbouring states. Therefore, this report treats the species as a single designatable unit.

Special Significance

British Columbia supports about 26% of the estimated global breeding population of this species (Table 1).

Table 1. Recent estimates of Marbled Murrelet populations of all age groups (rounded numbers).

Region	Estimated no. of murrelets	Likely range of estimate[1]	Source
Alaska	271,000[2]	Not available	Piatt *et al*. (2007)
British Columbia	99,100	72,600-125,600	Bertram *et al*. (2007); See Table 10.
Washington, Oregon and California	17,791	14,631-20,952	Falxa *et al*. (2009)
Total	388,000		

[1]The range for British Columbia is an estimate of the likely minimum and maximum populations from Bertram *et al*. (2007); the range for the U.S. states (except for Alaska) is the 95% confidence interval based on modelling using at-sea densities (Falxa *et al*. 2009).

[2] Estimates for the Alaska population vary considerably, and all are based on extrapolations from surveys that cover only a small portion of this vast area. The estimate given here is based on a recent status review (Piatt *et al*. 2007), and is derived by applying rates of regional decline ranging from -3.7 to -12.2% per annum to an original 1990s estimate of 940,000 birds (95%CI, ca. 655,000 to 1,236,000 birds). Other estimates for Alaska are in the low hundred thousands, possibly around 280,000 birds (Piatt and Naslund 1995) and 655,000-1,062,000 birds (Agler *et al*. 1998).

Like the Spotted Owl (*Strix occidentalis*), the Marbled Murrelet is an umbrella species or indicator of the status of coastal old-growth forests in B.C. Old forests protected as nesting habitat for the murrelet also support many other old-growth-dependent species, especially invertebrates. Because the nesting habitat in B.C. often contains the most valuable timber trees, the protection and management of this habitat has great socio-economic implications.

The Marbled Murrelet is one of the five focal species being used in Ecosystem-Based Management (EBM) land use planning in the North and Central coast regions (Horn *et al*. 2009). In Haida Gwaii, the murrelet was chosen by the Land Use Plan process as a fine filter indicator of biodiversity, in part because it is listed as a Threatened Species due to habitat loss induced by logging (British Columbia Government 2007; Gowgaia Institute 2007). The Marbled Murrelet is one of the key species monitored as an indicator of ecosystem health in Pacific Rim National Park and surrounding areas (Parks Canada Agency 2008a, b).

Aboriginal Traditional Knowledge and Significance to First Nations

Although seabirds feature in the traditional diets of most coastal First Nations on the B.C. coast, the most important birds were the colonial-nesting species whose colonies were regularly visited by First Nations (Wigen 2005; Szpaka *et al*. 2009). By contrast, Marbled Murrelets, whose nests were essentially inaccessible, could only be hunted at sea and their small size and avoidance of boats made them less desirable targets than the larger alcids, gulls, sea-ducks and cormorants. Marbled Murrelets were absent from the archaeological remains from Haida Gwaii examined by Wigen (2005), although other species of seabirds were found in many strata. Similarly, in Haida and Tlingit remains on Forrester Island, southeast Alaska, Marbled Murrelets were the least frequent of the 11 seabird taxa found and comprised only one of the 746 bird remains

(Moss 2007). Marbled Murrelet remains have been found in small numbers in archaeological sites on southern Vancouver Island, and might have been incidental bycatch in nets set under water (R. Wigen, University of Victoria, pers. comm., 2009).

Marbled Murrelets feature in the cultures, wildlife management and conservation plans of several coastal First Nations peoples, both in the marine and forest habitats. During the summer, the Marbled Murrelet is among the most common seabirds encountered in the nearshore waters off the west coast of Vancouver Island. Consequently, the bird is known to many First Nations people in this region. Ten Nuh-chah-nulth Elders were interviewed in 1998-1999 on wildlife at risk in Clayoquot Sound by Dr. Barbara Beasley (in litt. 25 Oct 2009). The Elders were asked about any traditional uses, creation stories or legends, and noticeable changes in populations that they knew about. Marbled Murrelets were among the species photographs shown to the Elders. Although they discussed several other bird species by name, Marbled Murrelets were not specifically mentioned. One Elder mentioned that seabird numbers had declined in the vicinity of Cape Beale, Barkley Sound, where murrelets are usually one of the most common seabirds. This comment corresponds to the declines in Marbled Murrelet numbers in this area reported in several scientific sources (Burger 2002, 2007) and in systematic boat surveys undertaken by Parks Canada since 1993 (see below).

The Marbled Murrelet was included by the Nuu-chah-nulth Nations as one of the focal species in the management of both marine and forest resources in their traditional territories, which cover most of the west coast of Vancouver Island. Their Uu-a-thluk Council of Ha’wiih has compiled a handbook of species at risk (Beasley and Foxcroft 2008; Uu-a-thluk 2009). There is no mention in either document of any specific cultural or economic value of the Marbled Murrelet to the Nuu-chah-nulth Nations. West Coast Aquatic (formerly the West Coast Vancouver Island Aquatic Management Board), representing First Nations in this region, is involved in multiple issues concerning marine and watershed management, resource extraction and recreation. The Board’s website mentions Marbled Murrelets in several places with reference to the importance of the region to this species, importance of some parks and watersheds as nesting habitat and comments on decisions concerning the murrelet made by the British Columbia Forest Practices Board (2010).

Another coastal region of B.C. where the Marbled Murrelet is a common species and is known in traditional knowledge is Haida Gwaii, although, as noted above, this species was rare in the Haida’s pre-European-contact diets. Cultural information gathered by David Ellis in 1991 was reviewed for this report by Barbara J. Wilson Kii’iljus (Cultural Resource Management, Gwaii Haanas National Park Reserve). Information on file includes the Haida name for the murrelet (Ts’alangah or Ts’aallanga) and information that the murrelet was a year-round resident of the islands, changed its plumage during the winter months, and was believed to nest in burrows in the mountains. In the present-day context, Marbled Murrelet nesting habitat is presented in detail in the Haida Gwaii Strategic Land Use Agreement between the Haida Nation and the Province of B.C. (British Columbia Government 2007).

DISTRIBUTION

Global Range

The breeding range of the Marbled Murrelet extends from the outer Aleutian Islands, through southern Alaska to central California (Figure 1; Nelson 1997; Piatt *et al*. 2007). Non-breeding birds are found throughout this range and also range out to sea, occasionally to tens of kms offshore. The bulk of the breeding population occurs in Alaska and B.C. (Table 1).

Canadian Range

Marbled Murrelets can be found along the entire coast of British Columbia. An unknown, but likely small breeding population is also found in British Columbia inland of the Alaska panhandle—these birds forage in Alaskan waters but fly through mountain passes to breed in B.C. (Nelson *et al*. 2009).

Marbled Murrelets are found in the Northeast Pacific (open ocean), Coast and Mountains and Georgia Depression ecoprovinces of B.C. (Campbell *et al*. 1990). Inland nesting occurs primarily within the Coastal Western Hemlock (CWH) biogeographic zone, and to a lesser extent in the drier Coastal Douglas-fir (CDF) and higher elevation Mountain Hemlock (MH) zones.

There is little information on changes in the geographic range in B.C. The species is now a rare breeder on parts of eastern Vancouver Island and the southern mainland where it was reasonably plentiful in the 1800s (details in Burger 2002). Some of this decline has been evident in the past 30 years from counts made in Burrard Inlet (mean counts: 66 birds in 1980-81, 2 in 1994-95 and 0 in 1996-1997) and unquantified declines in Boundary Bay (Burger *et al*. 2007a).

For monitoring and management purposes the Marbled Murrelet Recovery Team (CMMRT 2003) has recognized seven conservation regions in B.C. (Figure 2). The Alaska Border region was added in 2008 when two out of 37 tagged murrelets radio-tagged in Port Snettisham, south of Juneau in Alaska, were discovered nesting in British Columbia (Nelson *et al*. 2009). The numbers of murrelets nesting in this region are thought to be small and to date this region has not been included in any tallies of habitat. Consequently the remainder of this report considers populations and habitat within the remaining six regions.

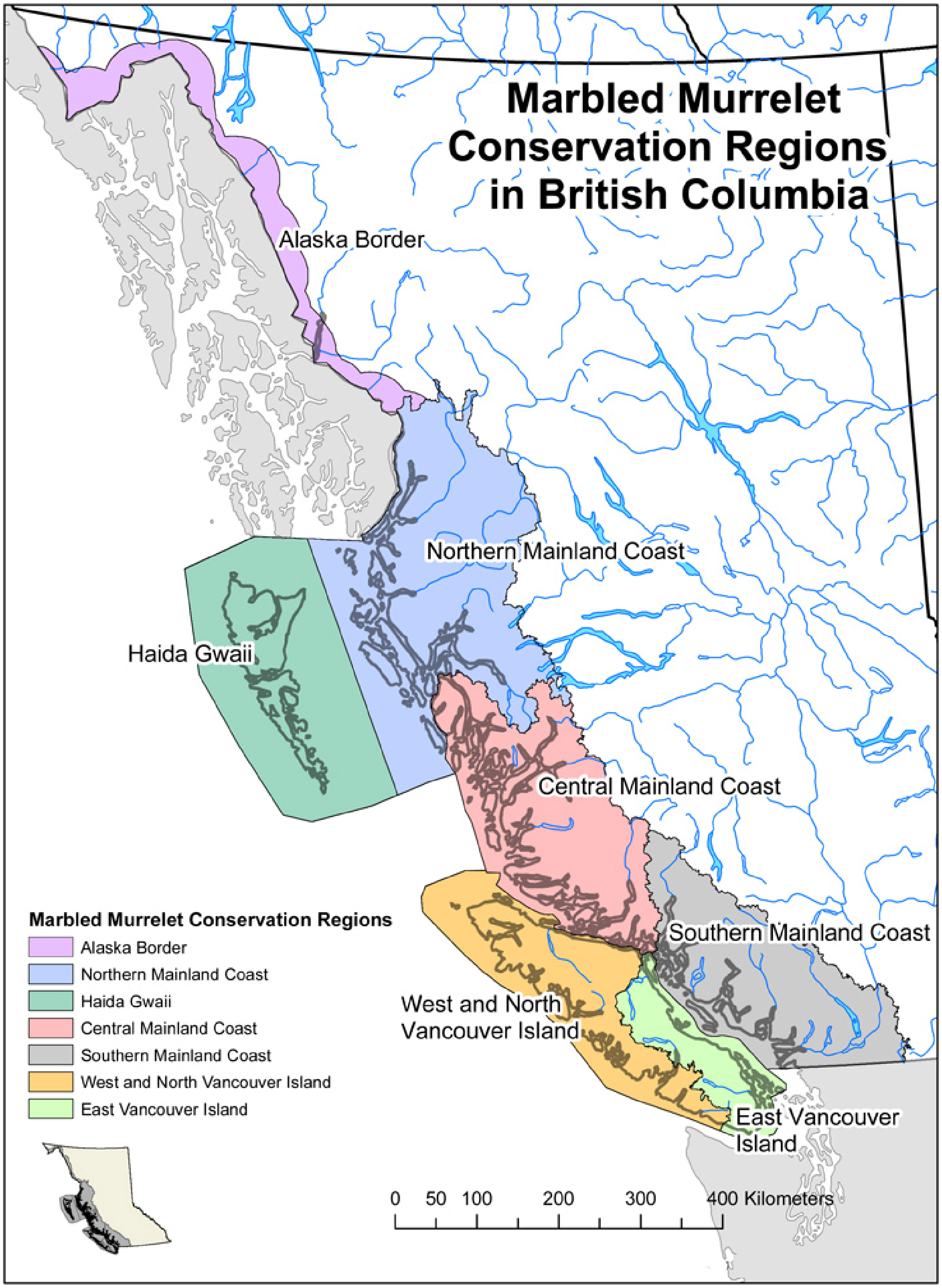

Figure 2. Map of the seven conservation regions recognized by the Marbled Murrelet Recovery Team in British Columbia. Numbers of murrelets breeding in the Alaska Border region are thought to be small (see text) and population and habitat estimates have been made only for the remaining six regions.

The extent of occurrence (EO) for the Marbled Murrelet is estimated at 284,000 km^2 using the B.C. Ministry of Environment habitat suitability model (Mather *et al*. 2010; see Inland Nesting Habitat section), which estimates the area of suitable nesting habitat as of 2002. The index of area of occupancy (IAO) using a 2 km X 2 km grid placed over the area of suitable nesting habitat (Mather *et al*. 2010) is 112,400 km^2.

Search Effort

Distribution and population estimates are derived from boat surveys at sea and radar counts. Boat surveys have been important in identifying concentrations and estimating local breeding populations (Rodway *et al*. 1992; Burger 1995, 2007). Spatial coverage is patchy and many areas, particularly in the Central and Northern Mainland Coast regions, have not been systematically covered by boat surveys. Similarly, there are few at-sea surveys that have been repeatedly undertaken to reveal long-term trends in local populations (Burger *et al*. 2007a). Radar surveys are made from fixed stations at the mouth of watersheds and count birds flying into or out of the drainage at dawn or dusk. These surveys have been identified as the most reliable method for tracking population trends in B.C. (Arcese *et al*. 2005) and in California (Bigger *et al*. 2006), but they have been used only since the mid-1990s. Because neither at-sea nor radar methods provide complete coverage of the murrelet's B.C. range, data from both methods were combined to estimate the total B.C. population (Burger 2007; D. Bertram, Environment Canada, pers. comm., 2010); and population trends were analysed independently for each method (see population trend section below).

HABITAT (1) – MARINE FORAGING HABITAT

Marine Habitat Requirements

Marine habitat features important to Marbled Murrelets were reviewed by Burger (2002) and Piatt *et al*. (2007) and are briefly summarized here. Murrelets tend to remain close to shore: on exposed shores most can be found within 0.5 km of the shore, but in more sheltered waters among islands or in inlets they might occur 1-2 km from shore. They generally forage in waters less than 30 m deep and can probably dive to a maximum depth of 40 m. Murrelets can often be found in predictable aggregations in favoured foraging sites. Characterizing the preferred marine habitats has proved difficult, with few common features among different studies. Tides, sea temperatures and salinity have been found to correlate with habitat use in some studies but not in others, and the results are sometimes contradictory and scale-dependent, e.g., preferences for higher sea temperatures in some situations but for colder water in others. Sub-tidal substrates appear to be important, primarily because Pacific Sand Lance (*Ammodytes hexapterus*), which periodically bury themselves in sand or gravel, are an important prey item. Large-scale modelling of marine habitat (e.g., Yen *et al*. 2004) has not produced reliable predictions of murrelet aggregations (e.g., numbers and distribution of the well-studied populations off southwest Vancouver Island are not reliably predicted by the model; Burger *et al*. 2008; Ronconi 2008). Marine distributions during the breeding season are affected by both marine habitat features affecting prey availability as well as proximity to inland nesting habitat (Meyer *et al*. 2002; Ronconi 2008).

Marine Habitat Trends

Although most research and management efforts in B.C. have been focused on forest nesting habitat, there is growing realization that both historical and current populations are also affected by marine conditions, mediated through prey availability (Peery *et al*. 2004a, 2009b; Norris *et al*. 2007; Ronconi and Burger 2008; Janssen *et al*. 2009; Gutowsky *et al*. 2009). Historically, Marbled Murrelets in the Strait of Georgia appeared to have experienced population declines correlated with reductions in the trophic levels of their prey, possibly as a result of over-fishing of Pacific Herring (*Clupea pallasii*) stocks (Norris *et al*. 2007). Unfortunately, limiting factors in the marine environment remain speculative.

The use of marine habitat by murrelets has been affected by both anthropogenic and natural variations in prey availability over the last 30 years. Some marine habitat has been lost, or used less frequently, because of increased human activities but the extent of these impacts is not known (see Threats). Habitat in inland sheltered seas has been lost due to aquaculture (reviewed by Burger 2002). Murrelets are also known to avoid areas frequently used by boats, especially those used for nearshore recreation (Bellefleur *et al*. 2009). Some of the proposed offshore wind-energy farms (e.g., in Hecate Strait) are in areas used by Marbled Murrelets. Seabirds are likely to avoid marine areas where wind turbines are established (Desholm and Kahlert 2005; Chamberlain *et al*. 2006; Larsen and Guillemette 2007).

Murrelets, like all seabirds, are susceptible to fluctuations in prey availability driven by climatic and oceanic processes at a range of spatial and temporal scales. Murrelets appear to be affected by large-scale climatic/oceanic processes like El Niño Southern Oscillations (ENSO), Pacific Decadal Oscillations (PDO) and some of the associated regime shifts that affect marine productivity and the availability of forage fish over large parts of the eastern North Pacific (Piatt *et al*. 2007). Some of the trends seen in at-sea survey data in B.C. can be explained by the negative effects of El Niños and other warm-water phenomena (see Population Trends). In 2005, anomalous wind and current patterns limited upwelling and caused massive reductions in prey for seabirds from Alaska to California. Murrelets off southwest Vancouver Island responded to reductions in prey in 2005 by spending more time foraging relative to other years, but still experienced very low breeding success (Ronconi and Burger 2008).

HABITAT (2) – INLAND NESTING HABITAT

Nesting Habitat Requirements

Nesting habitat requirements across the murrelet's range have been covered by several reviews (Ralph *et al*. 1995; Burger 2002; Lank *et al*. 2003; McShane *et al*. 2004; Piatt *et al*. 2007). A small proportion of murrelets (<5%) in B.C. nest on the ground—typically on steep, mossy ledges—or in large, old deciduous trees (Bradley and Cooke 2001; Burger 2002). Management and conservation efforts therefore focus on nests typically found in large, old-growth (>200 years old) conifers.

The key elements for nest sites in B.C. are summarized in Table 2. Based on the available evidence, the Canadian Marbled Murrelet Recovery Team (CMMRT 2003) formulated a set of regionally specific guidelines, identifying the suite of habitat features that are Most, Moderately, or Least Likely to include habitat that is suitable for Marbled Murrelets (Table 3). Canopy closure and vertical canopy complexity have proved inconsistent as habitat indicators across all the regions (Waterhouse *et al*. 2008, 2009); in addition, these and site index productivity data are sometimes missing from GIS forest cover data. Consequently, habitat mapping using the CMMRT criteria has focused on the age class and height class of forest polygons, sometimes modified by distance from the sea and elevation limitations.

Table 2. Key microhabitat characteristics for Marbled Murrelet nest sites in British Columbia (for more details see Hamer and Nelson 1995; Nelson 1997; Burger 2002).

Nest site requirements	Key habitat attributes
Sufficient height to allow stall-landings and jump-off departures	Nest trees are typically >30 m tall (range 15–80 m), and nest heights are typically >25 m (range 11–54 m); nest trees are often larger than the stand average.
Openings in the canopy for unobstructed flight access	Small gaps in the canopy are typically found next to nest trees, and vertical complexity of the canopy is higher in stands with nests than in other nearby stands.
Sufficient platform diameter to provide a nest site and landing pad	Nests are typically on large branches or branches with deformities, usually with added moss cover; nest limbs range from 15 to 74 cm in diameter (including epiphytes); nests are typically located within 1 m of the vertical tree trunk.
Soft substrate to provide a nest cup	Moss and other epiphytes provide thick pads at most nest sites, but duff and leaf litter are used in drier areas.
Overhead cover to provide shelter and reduce detection by predators	Most nests are overhung by branches.

Table 3. Features of Marbled Murrelet nesting habitat to consider during selection of habitat patches at the stand and landscape level (from CMMRT 2003, modified for the draft Marbled Murrelet Recovery Strategy, 2009).

Feature	Most likely	Moderately likely	Least likely
Distance from saltwater (km): all regions	0.5–30	0–0.5 and 30–50	>50
Elevation (m)			
Central and Northern Mainland Coast	0–600	600–900	>900
Haida Gwaii	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[1]	Class I and II (site index 20+)	Class III (site index 15-19)	Class IV (site index <15)
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 4–7	Class 3	Classes 2 and 8
Vertical canopy complexity: all regions[3]	MU	NU, U	VU, VNU

[1]Productivity classes as defined in Green and Klinka (1994, p. 197); approximate 50-year site index values also given—application of these indices might vary with different tree species and across regions.

[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 greatest (see Waterhouse *et al*. 2002, 2008). VU = very uniform (<11% height difference between 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).

Several other algorithms have been developed to predict and map murrelet nesting habitat in B.C., with varying success (Tripp 2001; Burger 2002). The “Hobbs” algorithm which includes consideration of dominant tree species in addition to stand age, height class, crown closure, elevation, slope and distance from the sea has been applied in the Central and Northern Mainland regions (Hobbs 2003; Burger *et al*. 2005; Horn *et al*. 2009).

None of the broad-scale algorithms derived for Marbled Murrelet nesting habitat is reliable across the British Columbia range of the species (Tripp 2001; Burger and Waterhouse 2009; Waterhouse *et al*. 2010). Algorithms, such as the B.C. Ministry of Environment mapping algorithm (see below), are considered useful for broad-scale strategic habitat inventory (e.g., Chatwin and Mather 2007; Horn 2009; Mather *et al*. 2010), but for finer-scale management at the watershed or landscape unit level more reliable methods, such as ground-based surveys, air photo interpretation or low-level aerial surveys are needed (Burger *et al*. 2009b; Waterhouse *et al*. 2010).

Availability of Nesting Habitat

Despite improvements in predicting and mapping nesting habitat, reliable measures of such habitat across coastal B.C. remain elusive due to incomplete knowledge of habitat preferences, inability to map habitat requirements e.g., moss, and inaccuracies in mapped forest data. In particular, it is not known whether murrelet densities (nests per ha of habitat) vary among the habitat quality ranks currently used for assessing and mapping nesting habitat, although there are indications that the response to habitat quality is non-linear (Burger and Waterhouse 2009). Consequently, all the habitat estimates summarized here should be used with caution. Depending on the scale used, a proportion of nests will occur in forest stands that are not considered habitat by any of the algorithms, air photo interpretation or aerial survey methods (Burger and Waterhouse 2009).

A simplified version of the CMMRT (2003) guidelines, combining some of the Most Likely and Moderately Likely features (Table 3), has been applied by the B.C. Ministry of Environment (MoE) to estimate and map the extent of Marbled Murrelet nesting habitat across the B.C. range (Mather *et al*. 2010). This algorithm (hereafter referred to as the "MoE BC Model") selects likely suitable habitat as all forest stands of age class 8 or older (>140 years) that also have height class 4 or above (>28.5 m) and follow the regional elevation restrictions for Most Likely (Table 3). The project used air photo interpreted habitat mapping for Haida Gwaii and a slightly different regional algorithm for Clayoquot Sound (see Mather *et al*. 2010 for details). The MoE mapping used 2002 as a reference year for habitat area to allow monitoring of habitat changes over 30 years from 2002-2032 (CMMRT 2003).

The most recent version of the MoE BC Model mapping is summarized in Table 4, broken down by distance from the ocean (Mather *et al*. 2010; updated June 2011). For most applications, murrelet nesting habitat is assumed to include suitable forest up to 50 km from the ocean. Recent analysis of actual nest sites located by telemetry in Desolation Sound, Toba Inlet and Clayoquot Sound indicates that only 1 of 157 nest sites (0.6%) was >30 km from the nearest sea, although a few nests further inland might have been missed by the telemetry searches (Dr. D. Lank, SFU, unpublished data). Only 7.8% of the potential suitable habitat estimated by Mather *et al*. (2010) lies in the 30-50 km inland zone. Most of the strategic planning involving murrelet habitat has used the 0-50 km inland demarcation, with preference given to habitat <30 km inland in some applications (Horn *et al*. 2009). Habitat within 400 m of the ocean is sometimes considered as unsuitable when tallying habitat areas because of reduced use by murrelets and higher predator densities (Burger 2002), but is included as suitable in Tables 4 and 5.

Table 4. Amounts of Marbled Murrelet nesting habitat and currently protected habitat (% protected in parentheses) predicted by applying the MoE BC Model (Mather *et al*. 2010) across the British Columbia range (updated June 2011).

	Habitat within 50 km inland of ocean (ha)	Protected habitat[2] (ha)	Habitat within 30 km inland of ocean (ha)	Protected habitat[2] (ha)	Habitat within 400 m of ocean (ha)	Habitat 30 to 50 km inland (ha)
Spatial range (km from sea)[1]	0-50 km	0-50 km	0-30 km	0-30 km	0-0.4 km	30-50 km
Conservation Region:						
Northern Mainland Coast	435,951	132,396 (30.4%)	365,492	121,284 (33.2%)	38,241	70,460
Haida Gwaii	228,383	152,774 (66.9%)	228,383	152,774 (66.9%)	34,788	0
Central Mainland Coast	568,731	170,454 (30.0%)	549,866	164,444 (29.9%)	90,672	18,864
Southern Mainland Coast	207,733	54,085 (26.0%)	175,053	38,592 (22.0%)	10,943	32,680
West and North Vancouver Island	452,270	152,249 (33.7%)	433,381	143,013 (33.0%)	23,404	18,890
East Vancouver Island	87,777	19,785 (22.5%)	74,653	11,707 (15.7%)	461	13,124
Totals	1,980,846	681,742 (34.4%)	1,826,828	631,814 (34.6%)	198,509	154,018

Notes: Data courtesy Linda Sinclair (B.C. Ministry of Forests, Lands and Natural Resource Operations [MoFLNRO]) and Monica Mather and Trudy Chatwin (B.C. Ministry of Environment [MoE], Nanaimo). For GIS shape file details, metadata and analysis contact these people. Analysis conducted in April 2010; protected areas updated June 2011. The algorithm selected all forest polygons of age class 8 or older (>140 years) that also have height class 4 or above (>28.5 m) and follow the elevation restrictions for Most Likely (Table 3). For Haida Gwaii habitat was assessed from air photo interpretation (A. Cober, MoE, unpubl. data). Alvin Cober, Ecosystems Biologist for the B.C. Ministry of Environment, independently estimated the area of protected murrelet nesting habitat on Haida Gwaii as 167,337 ha (73% of existing habitat), and for Clayoquot Sound a regional algorithm was used. See the text, Chatwin and Mather (2007) and Mather *et al*. (2010) for further details on methods and data limitations.

[1] The habitat zones inland from the sea are shown for various reasons: habitat 0-50 km inland has been used extensively in strategic planning; habitat 0-30 km inland is the most likely used habitat based on nest distribution (see text); habitat 0-400 m and 30-50 km inland is sometimes considered less likely to be used (see text).

[2] Protected habitat includes: provincial and national parks, conservancies, Wildlife Management Areas, protected wildland zones, Legal Biodiversity Mining Tourism Areas, legal Old Growth Management Areas, Ungulate Winter Ranges, and approved Wildlife Habitat Areas (WHAs; core areas only). Core areas were selected because of the non-harvest General Wildlife Measures applicable to these portions of all approved WHAs. The WHAs included are not just those established for Marbled Murrelets but include suitable habitat in WHAs set up for other species too. Murrelet habitat within FRPA/SLRPs was included here too although some of these areas have yet to be completely mapped and the final areas might differ slightly from those used here.

During a study aimed at estimating nesting habitat trends over the past 30 years, Long *et al*. (2011) estimated areas of habitat using three models based on variations of the CMMRT guidelines (Table 5). Model 1 (termed exclusive; i.e. conservative) was based on the “Most Likely” criteria recommended by the Marbled Murrelet Recovery Team (Table 3; CMMRT 2003). Model 2 (intermediate) was based on the same habitat criteria as in the MoE BC Model (Mather *et al*. 2010), i.e., a blend of the Most and Moderately Likely criteria (see text above). The areas estimated from Model 2 differ slightly from those in Mather *et al*. (2010) because of minor differences in source data and because Mather *et al*. (2010) used some regionally specific models and habitat mapping to improve estimates. Finally, Long *et al*.’s (2011) Model 3 (termed inclusive) selected the combined areas predicted by the Most and Moderately Likely habitat. This estimate is almost certainly an overestimate of actual habitat used by murrelets because it includes stands with relatively small trees (<28.5 m) and areas 30-50 km inland that are unlikely to be used by murrelets.

Table 5. Comparison of two recent estimates of the areas of habitat suitable for Marbled Murrelet nesting in British Columbia.

	Area of suitable nesting habitat (ha) from the MoE BC Model (Mather *et al*. 2010)		Area of suitable habitat (ha) from Long *et al*. (2011)		
	April 2010 data[1]		Model 1 - exclusive	Model 2 - intermediate[2]	Model 3 - inclusive
Reference year	**2002[3]**	**2002[3]**	**2008**	**2008**	**2008**
Spatial coverage	0-30 km	0-50 km	0.5-30 km	0-50 km	0-50 km
Conservation Region:					
Northern Mainland Coast	365,492	435,951	243,404	431,566	968,185
Haida Gwaii	228,383	228,383	188,933	267,859	452,934
Central Mainland Coast	549,866	568,731	330,384	526,622	1,105,271
Southern Mainland Coast	175,053	207,733	114,329	200,990	502,973
West and North Vancouver Island	433,381	452,271	384,579	591,019	846,355
East Vancouver Island	74,653	87,777	27,005	91,882	151,043
Totals	**1,826,828**	**1,980,845**	**1,288,634**	**2,109,938**	**4,026,761**

[1] Habitat modelled by Mather *et al*. (2010) and updated June 2011 by the B.C. Ministry of Environment, Nanaimo, B.C. See Table 4.

[2] Model 2 (intermediate) of Long *et al*. (2011) used essentially the same criteria as the 0-50 km model by Mather *et al*. (2010) but the numbers differ slightly because of minor differences in data sources and the application of some regional models in the latter study.

[3] The areas of habitat estimated by the MoE BC Model use 2002 as the reference year to match the habitat baseline established by the Marbled Murrelet Recovery Team but the actual mapping assessments were made from 2009 to 2011 (Mather *et al*. 2010; M. Mather pers. comm. June 2011).

The MoE BC Model and similar simple algorithms are best used for B.C.-wide assessments (such as the COSEWIC review) and for aspatial strategic planning at the regional level, with more refined methods (e.g., air photo interpretation and aerial surveys; Burger 2004) applied for finer-scale mapping and management (Waterhouse *et al*. 2010). The overall working estimate is therefore 1.98 million ha of potential nesting habitat estimated by the MoE BC Model for all of B.C. with the regional areas shown in Table 4 (Mather *et al*. 2010). The distribution of this habitat, overlaid with protected areas, is shown in Figure 3.

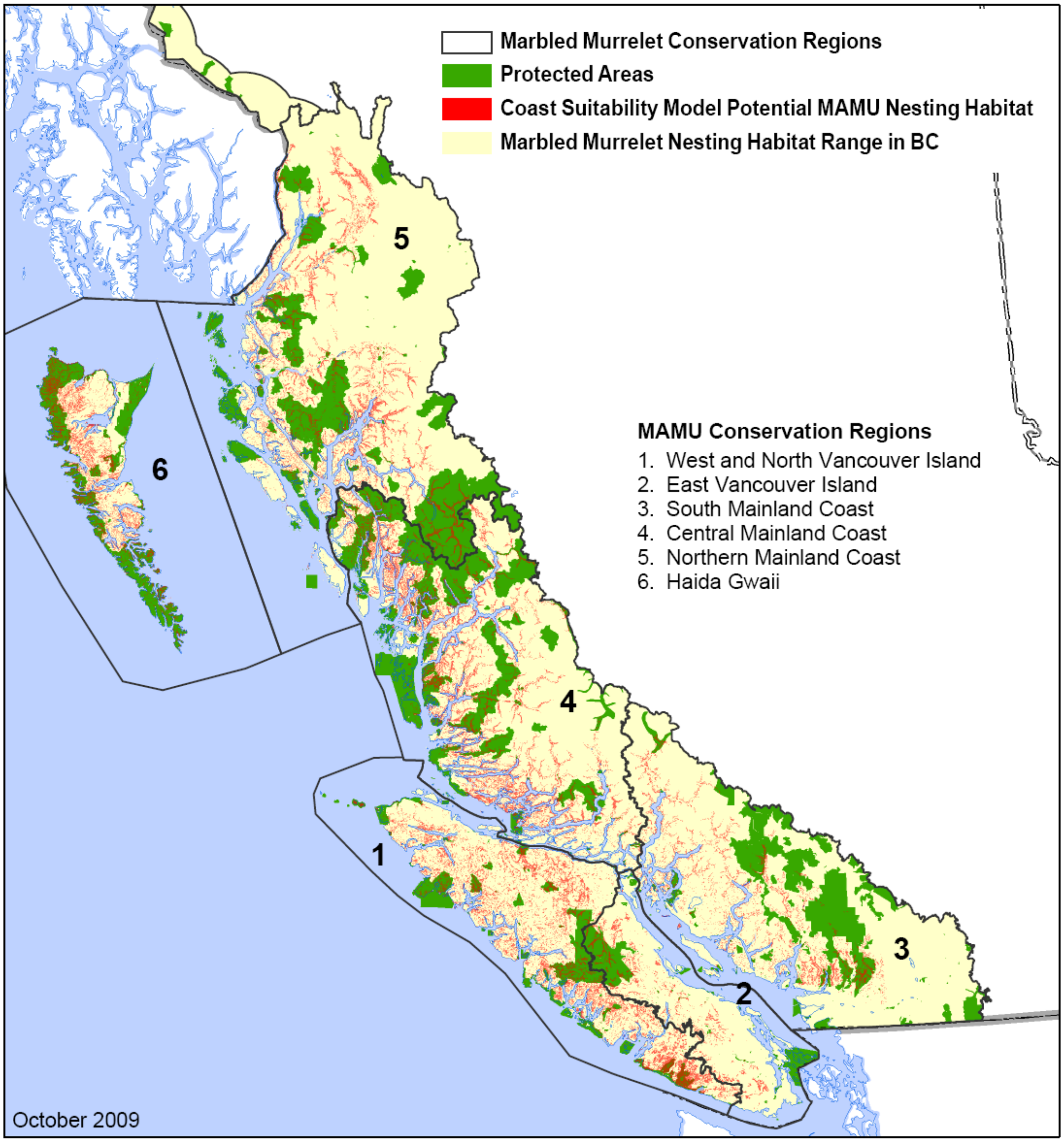

Figure 3. Distribution of the likely suitable nesting habitat of the Marbled Murrelet in British Columbia based on the B.C. Ministry of Environment (MoE) mapping (MoE BC Model; see text for details) with protected areas overlaid. Protected areas included in this map are explained in Table 4. Map by Linda Sinclair and Monica Mather, B.C. Ministry of Environment, Nanaimo, B.C.

Nesting Habitat Trends

Analyses of Landsat imagery by the Sierra Club of Western Canada estimated that 53.1% of British Columbia's "ancient coastal rainforest" had been logged by 1999 (Hull 1999), and this value was broadly similar to an analysis by the then B.C. Ministry of Forests (MacKinnon and Eng 1995). Much of the past logging focused on large, old conifers in coastal lowlands that were likely to have provided nesting habitat for murrelets, although the precise extent of lost habitat will never be known. During the past 10 years there have been three attempts to analyse changes in the area of likely suitable nesting habitat across the species' B.C. range and some notable regional analyses of habitat trends. Comparison among estimates of habitat loss across the B.C. range and within regions is difficult because there is continuing uncertainty and/or little overlap in the definitions or algorithms of likely suitable habitat, the areas and the time period covered by each study, and the sources and accuracy of forest GIS data used for modelling (Mather *et al*. 2010; Waterhouse *et al*. 2010; Long *et al*. 2011).

In 2000, Marvin Eng (B.C. Ministry of Forests; unpubl. data) used coarse-scale Baseline Thematic Mapping (BTM) of B.C. coastal forests to make a rough estimate of habitat change. He estimated that 33% of the pre-industrial habitat (approximately 7.671 million ha) had been lost by 1973. By 2000, the habitat area available in 1973 (5.164 million ha) had been further reduced by 24% (to 3.934 million ha) and was about 51% of the original pre-industrial area. At the time, however, there was little information on suitable murrelet nesting habitat and the large areas resulting from Eng's analysis suggest that he included a significant proportion of unsuitable habitat. Furthermore, the BTM provides only crude estimates of age and height classes in forest polygons, which are key elements in mapping murrelet nesting habitat.

In 2001, Demarchi and Button (2001a,b) estimated habitat loss since European settlement due to urbanization, agriculture and logging by comparing maps of habitat *capability* (estimated pre-European habitat) and *suitability* (distribution and ranking of nesting habitat in 2001). Habitat ranks were developed by Demarchi (2001) in collaboration with government biologists, and applied to coarse-scale 1:250,000 Broad Ecosystem Inventory mapping. Assuming that the top three of the six habitat ranks represent likely nesting habitat, the Demarchi and Button data indicate the loss by 2001 of 34.6% of the original habitat (details in Burger 2002: Figure 4.10 and Table 4.14). Among the forest districts with appreciable habitat, the greatest losses were on Vancouver Island and the southern mainland: Port Alberni (47% reduction), Campbell River (41% reduction), Duncan (77% reduction), Port McNeil (35% reduction), and the Sunshine Coast (70% reduction) districts (Burger 2002).

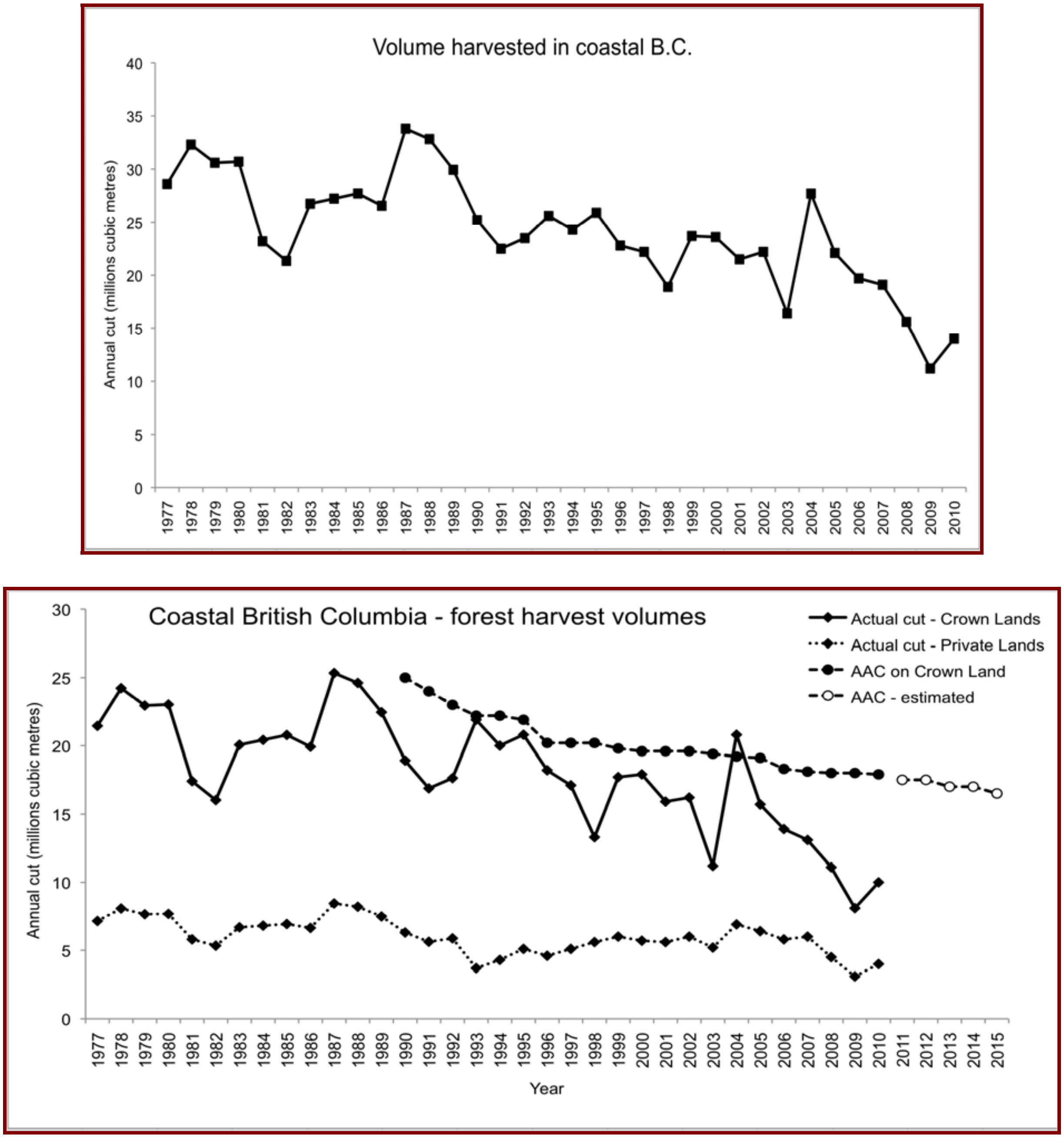

Figure 4. Changes in the volumes of timber harvested in coastal British Columbia. The upper graph shows the change in the estimated total volume harvested, 1977-2010. The lower graph shows the details of the Annual Allowable Cut (AAC) on Crown Lands (values from 2011-2015 shown on the dashed line are estimated predictions) and the actual volumes cut on Crown and private lands. Data from Les Kiss (Coast Forest Products Association, Vancouver, B.C.) and Statistics Canada (Canadian Forestry Statistics). The proportion of these timber volumes that might have been suitable nesting habitat for Marbled Murrelets is not known.

Several studies have analysed regional losses of murrelet nesting habitat. Zharikov *et al*. (2006) estimated that about 80% of the original suitable habitat in the Sunshine Coast Forest District (a large portion of the Southern Mainland Region) had been removed by logging by the mid-1990s. For the Haida Gwaii region, Holt (2004) estimated a 42% reduction in the area of likely suitable habitat (the top three of six habitat ranks in the algorithm used) between 1800 and 2000, with most reduction occurring since 1950. Data from the Gowgaia Institute (2007) indicate recent losses on Haida Gwaii at 93,000 ha from 1978 to 2008 (about 30% reduction over the period).

Long *et al*. (2011) analysed the likely change in nesting habitat area in B.C. between 1978 and 2008 (i.e., over 30 years, or 3 generations). The study provides the most rigorous estimate of habitat change in B.C. This study used three habitat models (1, 2 and 3; termed exclusive [i.e., conservative], intermediate and inclusive, respectively) as described in the previous section. The study used a range of databases to spatially estimate suitable habitat and changes to the area of habitat (see Long *et al*. 2011 for details). To account for spatially undocumented 1978-1985 changes, aspatial estimates of areas logged between 1978 and 1985 were derived from the Ministry of Forests, Lands and Natural Resources Operations annual reports. Recruitment of nesting habitat was estimated as stands with appropriate criteria (tree height, elevation, distance from sea) aged, and either changed from Unsuitable (<140 years old) to Moderately Likely (140-250 years old) or from Moderately Likely to Most Likely (>250 years old).

The Long *et al*. (2011) results are summarized in Table 6. Habitat losses over 30 years were estimated to be 20.2%, 20.6% and 16.3% for Models 1, 2 and 3, respectively. Taking into account the estimated recruitment of mature and old forest habitat, the net loss over 30 years was estimated to be 5.4%,18.5% and 14.4%, respectively. Because the spatial data from 1978 to 1985 were incomplete, Long *et al*. (2011) estimated an additional harvest of 190,000 ha across all regions (of which a proportion occurred in murrelet habitat). When these aspatial losses were added, the overall estimated net loss over 30 years was estimated to be 9%, 22% and 17% for Models 1, 2 and 3, but the authors considered the high rate of recruitment found in Model 1 to be unrealistic (Long *et al*. 2011; J. Long pers. comm., June 2011). They concluded that the net change over 30 years was 22% loss, using the most realistic Intermediate model. The greatest losses occurred in the West and North Vancouver Island and East Vancouver Island regions (Table 6).

Table 6. Change in area (ha) and percentage area of forest nesting habitat over 30 years (1978 to 2008) in each of six conservation regions using three models of nesting habitat (data from Long *et al*. 2011).
Habitat loss includes mature forest logged, burned or otherwise disturbed. Habitat recruitment includes forest which aged during the 30-year period to move into an older age class and met all other criteria (tree height, elevation, distance inland) for nesting habitat (see Long *et al*. 2011 for details).

	Model 1 - exclusive		**Model 2 - intermediate**		**Model 3 - inclusive**	
Measure	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
A) Loss of habitat 1978-2008						
North Coast	18,512	-8.1	52,858	-11.1	85,998	-8.3
Haida Gwaii	35,407	-16.0	45,095	-14.5	66,763	-13.0
Central Coast	64,212	-21.5	112,365	-17.8	164,345	-13.1
South Coast	38,422	-27.6	62,438	-26.0	98,485	-17.4
West & North Vancouver Island	113,316	-25.6	225,685	-27.9	304,271	-26.7
East Vancouver Island	5,416	-16.8	33,918	-27.1	48,657	-24.5
Total	275,287	-20.2	532,359	-20.6[1]	768,519	-16.3[1]
B) Recruitment of habitat						
North Coast	33,236		9,334		21,154	
Haida Gwaii	3,157		2,319		7,340	
Central Coast	95,711		8,790		15,988	
South Coast	13,405		23,034		35,180	
West & North Vancouver Island	55,282		8,359		10,740	
East Vancouver Island	276		746		860	
Total	201,067		52,582		91,262	
C) Overall net change						
North Coast	14,724	6.4	-43,524	-9.2	-64,844	-6.3
Haida Gwaii	-32,250	-14.6	-42,776	-13.8	-59,423	-11.6
Central Coast	31,497	10.5	-103,575	-16.4	-148,357	-11.8
South Coast	-25,017	-18.0	-39,404	-16.4	-63,305	-11.2
West & North Vancouver Island	-58,034	-13.1	-217,326	-26.9	-293,531	-25.8
East Vancouver Island	-5,140	-16.0	-33,172	-26.5	-47,797	-24.0
Total	-74,220	-5.4	-479,777	-18.5[2]	-677,257	-14.4[2]

[1] Long *et al*. (2011) adjusted these habitat losses to -24% (Model 2) and -20% (Model 3) taking into account the aspatial estimates of habitat lost between 1978 and 1985.

[2] Long *et al*. (2011) adjusted these net changes to -22% (Model 2) and -17% (Model 3; J. Long, pers. comm., June 2011) taking into account aspatial estimates of habitat lost between 1978 and 1985.

Long *et al*. (2011) compared their results with other studies analysing changes in murrelet habitat. Their coast-wide estimate of 22% net loss from 1978 to 2008 is broadly similar to the 24% loss for 1973 to 2000 reported by Marven Eng (B.C. Ministry of Forests; summarized above). Data from Tomlins and Gray (2006) for the Sunshine Coast forest district (Southern Mainland Region) suggest a net loss of 12.0% from 1985 to 2005, with higher losses expected due to more intense logging before 1985. The 30-year net changes for the Southern Mainland Region reported by Long *et al*. (2011) for Models 2 and 3 (-16.4% and -11.2%; Table 6) therefore appear low, but if their aspatial adjustment is applied the values would be more similar to those of Tomlins and Gray (2006). On Haida Gwaii, data from the Gowgaia Institute (2007) show that 92,776 ha of forest were logged from 1978 to 2008; most of this would have been at least moderately likely habitat (A. Cober, pers. comm., 2009; M. Eng, pers. comm., 2009). Long *et al*. (2011) concluded that their spatial estimates on Haida Gwaii indicate losses of 67,203 ha for the same time period, but these data did not include aspatial losses. Comparing the period 1985 to 2008 (when Long *et al*. had more reliable spatial data), the Gowgaia Institute (2007) estimate (61,302 ha) is similar to that of Long *et al*. (2011; 58,020 ha). The Long *et al*. (2011) study is therefore fairly consistent with other estimates of habitat loss in B.C.

Recent analysis of satellite imagery in the two Vancouver Island conservation regions has used high resolution SPOT satellite images to calculate murrelet habitat losses since 2002 (Mather 2011). The use of satellite imagery to track forest losses is particularly effective as it covers the entire landbase including private land and does not require GIS records of undocumented harvest. Harvested blocks, roads, landslides and windthrow were accurately identified for the years 2004 to 2007 on the satellite images and overlaid in a GIS environment (Guthrie *et al*. 2011**)** with 2002 modelled habitat (Mather *et al*. 2010). The habitat loss from Vancouver Island in 2004-2007 can be seen in the Marbled Murrelet habitat mashup done for the B.C. Ministry of Environment (http://www.littleearth.ca/moe/mamu/). The amount of habitat lost was then extrapolated to 9 years (multiplied by 3) to encompass the time since the 2002 baseline year and the present, 2011 (assuming a constant amount of habitat loss per year) (Table 7).

Table 7. Vancouver Island estimated habitat losses between 2002 and 2011.

Marbled Murrelet conservation regions	2002 habitat (Ha)	Estimated habitat loss between 2002-2011 (Ha)	2011 habitat (Ha)	Habitat loss per year	Loss in 9 years	Recovery team 30-year habitat loss threshold	How soon will we meet threshold?
Eastern Vancouver Island	87,800	13,629	74,171	1.7%	15.5%	10%	Likely exceeded in 2007
West and North Vancouver Island	452,585	44,418	408,167	1.1%	9.8%	31%	2030

The estimated habitat loss in the Eastern Vancouver Island Conservation Region is 15.5%, which exceeds the 30-year recovery threshold (10%) for the region. The threshold was likely exceeded by 2007 in a region where over 65% of the habitat is in private forest lands (Mather 2011).

The habitat losses for the West and North Vancouver Island Conservation Region were estimated at 1.1% per year (for a total of 9.8% in 9 years), which does not exceed the 31% habitat loss threshold for that region, but is still higher than other studies, which have found less than 1% habitat losses per year.

Since the introduction of the Forest Practices Code in the mid-1990s in B.C. (now the *Forest and Range Practices Act*—see below), both the Annual Allowable Cut (AAC) and the actual volume of timber cut on Crown Lands has declined (Figure 4). Private lands are not, however, affected by these management changes. The proportions of these forests that might be suitable nesting habitat for murrelets is not known. Although there is now less habitat loss from logging than before the mid-1990s, net habitat losses from logging, road-building and other developments across coastal B.C. will continue. Continued loss of nesting habitat is of greatest concern on Vancouver Island and the Southern Mainland Coast, which have experienced significant past habitat loss (Burger 2002; Mather 2011). The continued high rate of cutting on private land (Figure 4) is a concern on East Vancouver Island, which has experienced the highest loss of habitat of all the six regions (Burger 2002) and where the retention targets set by the recovery team (<10% loss between 2002 and 2032; CMMRT 2003) are likely already exceeded (Mather 2011).

In summary, crude estimates show loss of nesting habitat since European settlement in the range of 35-50% and more refined estimates show net habitat loss over the past three murrelet generations (30 years) as 22% of 1978 values. Coast-wide, net losses of nesting habitat will likely continue although rates of loss have declined since the mid-1990s. Much habitat has been protected in the northern conservation regions but losses continue on the southern mainland and on Eastern Vancouver Island, in particular, where they appear to exceed the Marbled Murrelet Recovery Team's recommendations.

Effects of Habitat Fragmentation on Populations

In addition to the absolute loss of nesting habitat, the effects of habitat fragmentation need to be taken into account. Research into the effects of forest fragmentation and edge effects on nesting Marbled Murrelets has produced some contradictory results (reviews by Burger 2002; McShane *et al*. 2004; Piatt *et al*. 2007). It remains difficult to establish likely impacts of forest fragmentation due to clearcut logging, roads and other disturbances, let alone quantify these impacts in population models. Murrelet nests are often found close to (< 100 m) forest edges, although the trend is less clear when the edges are human-made, and there is also a bias toward finding nests near edges unless telemetry is used (Burger 2002). Range-wide reviews showed that successful nests were significantly further from forest edges than those that failed (Nelson and Hamer 1995; Manley and Nelson 1999), but analysis of nests located with telemetry in B.C. indicates a more complex relationship (reviewed in Burger 2002). In general, nests located near natural edges (e.g., avalanche chutes, rivers) had higher success than those in the forest interior and the small sample of nests near human-induced edges (e.g., bordering recent clearcuts or roads) showed no trends either way (Bradley 2002). The analysis by Zharikov *et al*. (2006, 2007a), which reported no negative effects of edges or small forest patches on murrelet nesting success in Desolation Sound and Clayoquot Sound has been criticized on the basis that the spatial scale used for the analysis was too coarse to detect the types of trends reported (Burger and Page 2007; for response see Zharikov *et al*. 2007b).

Experimental work using artificial murrelet nests in a range of habitats in B.C. showed that disturbances by avian nest predators (mainly corvids) were significantly more frequent at hard edges (bordering recent clearcuts, 5-11 years after cutting) relative to forest interiors, but less frequent at soft edges (bordering regenerating forest 17-39 years old) (Malt and Lank 2007, 2009). The studies showed no edge effects at natural-edged sites (bordering large rivers or avalanche chutes). The distribution of the major predators (corvids) indicated that predation risk was higher at hard edges than interiors.

Overall, the evidence reviewed above suggests that risks to nesting murrelets appear to be increased when old-growth forests are fragmented by logging and road-building causing a greater proportion of the murrelets to nest in close proximity to hard edges bordering recent clearcuts (i.e., regenerating forests <20 years old) or roads. Malt and Lank (2009) showed that edge effects were not static; predation risk was highest in old forests bordering recent clearcuts but as the clearcuts regenerated into young forest the risk declined and when bordered by uniform structured, maturing forest, predation risk was actually lower than in forest interiors or natural edges.

Edges and fragmentation may also affect the microclimate in the canopies where murrelets nest. Possible deleterious edge effects in old-growth canopies include increased solar radiation and summer air temperatures, increased windthrow, and loss of canopy moss due to winds and drying effects of winds (reviewed in Burger 2002). Most of these effects are likely to extend beyond 100 m of edges in coastal forests of B.C.

Past and Future Effects of Climate Change on Nesting Habitat

The past and expected climatic changes relevant to inland nesting habitats of Marbled Murrelets include: increases in mean air temperatures on the B.C. coast by 0.6^{o}C over the past century; mean annual temperatures across the province expected to rise by 1-4^{o}C by 2100; temperature increases on the coast will be less than those inland; in coastal regions the wet (winter) seasons have become shorter and wetter while the dry (summer) seasons are drier and longer and this trend will continue; in future winter temperatures will rise more than summer temperatures (Gayton 2008; see also British Columbia Ministry of Environment Climate Action Secretariat 2010).

Hamman and Wang (2006) modelled the potential effects of climate change on the distribution of ecosystems and tree species in B.C. The biogeoclimatic zone currently used by most nesting Marbled Murrelets, the Coastal Western Hemlock (CWH) zone, is expected to increase in elevation and area, while the high-elevation Mountain Hemlock (MH) zone, which currently supports few murrelet nests, is expected to decline overall and disappear from many coastal areas. The drier Coastal Douglas-fir (CDF) zone which has a restricted range on southeastern Vancouver Island and the associated islands is expected to increase substantially toward the north and in total area; this biogeoclimatic zone is currently used by few nesting murrelets in B.C. (Burger 2002). Of the tree species now most often used for nest sites in B.C., the Hamman and Wang

(2006) climate-driven models predict increases in the overall area and frequency of Sitka Spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii*), Western Red-cedar (*Thuja plicata)*, Western Hemlock (*Tsuga heterophylla*). Amabilis Fir (*Abies amabilis*) and Yellow Cedar (*Chamaecyparis nootkatensis*) are expected to increase slightly in spatial extent but become less abundant. The less-used Grand Fir (*Abies grandis*) is also expected to become more common. Other studies generally support the Hamman and Wang (2006) predictions although there are a few discrepancies (Gayton 2008). In particular, Hebda (1997) identified the CWH zone as being vulnerable to the effects of climate change.

Marbled Murrelets might be affected by climate-driven changes in the forest canopy ecosystems in which they usually nest. Most nests are situated on thick pads of moss and other epiphytes growing on the tree boughs (Burger 2002; Nelson 2007). Very little is known about the factors affecting the growth and persistence of these epiphyte mats (Lowman and Rinker 2004). Bryophyte growth is a sensitive indicator of moisture and temperature regimes at forest edges (Stewart and Mallik 2006). Epiphyte growth might be stimulated by reduced snowfall and increased rainfall in winter, but the predicted increases in length and severity of the summer dry periods might reduce the formation of epiphyte mats.

Overall, the predicted changes to forest ecosystems and tree species in coastal B.C. do not suggest major deleterious effects resulting for nesting Marbled Murrelets in the next 25-50 years. Direct impacts to nesting habitat due to logging and forest fragmentation appear to be of far greater significance than climate-driven changes in forests over the next few decades. Nevertheless, the paucity of information on how changing climate might affect epiphytes and microclimates of the forest canopies in which murrelets nest is troubling.

BIOLOGY

Details of the species' biology are reviewed by Ralph *et al*. (1995), Nelson (1997), Burger (2002) and Piatt *et al*. (2007).

Life Cycle, Reproduction and Demography

Marbled Murrelets, like most seabirds, lay a single egg per clutch. Incubation, by both parents, takes 28-30 days and chicks, fed by both parents, remain at the nest for 27-40 days. The species has low juvenile recruitment (often less than 0.3 fledged chicks per pair per season), but high adult survival (0.83-0.93 per year). Basic demographic parameters are summarized in Table 8, based on the best data applicable to B.C., but there is considerable uncertainty in many of these estimates (see Burger 2002; McShane *et al*. 2004).

Table 8. Summary of demographic parameters for Marbled Murrelets based on studies in B.C.

Feature	Measure	Source and notes
Sex ratio	Likely 1:1	Review by Burger (2002)
Age of first breeding	Estimated mean 3 years (range 2-5 years)	Review by Burger (2002) based on sparse data.
Proportion of mature birds breeding	Estimated to be 0.05, 0.40, 0.60, and 0.80 for birds aged 2, 3, 4 and 5+ years, respectively. Overall, 75% of all birds were assumed to be mature adults.	Estimates used by E. Cam reported in Burger (2002). Sealy (1975) reported 85% of birds dissected as mature. Estimates from Desolation Sound ranged from 55% to 95% based on behaviour, brood patch and vitellogenesis methods (reviewed by Burger 2002)
Clutch size	1 egg	Sealy (1974). Some females might lay a replacement clutch if breeding fails (McFarlane Tranquilla *et al*. 2003)
Breeding success based on nesting data	Estimates for B.C. range from 0.23 to 0.46 fledglings per nesting attempt.	Reviewed by Burger (2002); no new data for B.C. since then.
Recruitment based on ratio of newly fledged juveniles (hatch-year, HY) to after-hatch-year birds (adults and older immatures, AHY) at sea (HY:AHY ratio)	Desolation Sound: 0.13 based on adjusted HY:AHY ratios, 0.16-0.22 based on adjusted nest success data. Clayoquot Sound: adjusted HY:AHY ratios 0.02-0.08. West Coast Trail: <0.01-0.14.	Burger (2002); Mason *et al*. (2002); Ronconi and Burger (2009). HY:AHY ratios vary greatly among sites and among years.
Annual survival (adults)	For Desolation Sound: 0.929 (95% CI: 0.629-0.990) based on mist-netting; 0.829 (95% CI: 0.716-0.903) based on mixed methods	Cam *et al*. (2003).
Survival (immatures)	Estimated to be 70% (juveniles) or 89% (subadult) of adult survival.	Estimates used by E. Cam reported in Burger (2002).
Generation time	10 years (range 6.9-12.8 years)	Estimated from likely estimates of adult survival and age of first breeding (Burger 2002).
Population growth parameter (Lambda λ)	For Desolation Sound: $\lambda = 0.985$ (95% CI: 0.849-1.142) if survival is 0.929; $\lambda = 0.859$ if survival is 0.829	Cam *et al*. (2003).

Several independent modelling studies suggest that changes in adult survival are more likely to limit populations than fecundity (recruitment) (Beissinger and Nur 1997; Cam *et al*. 2003), but field data from B.C. and elsewhere suggests that recruitment, whether estimated from nest success or from counts of newly fledged juveniles on the water, is almost always too low to yield stable populations (Burger 2002; McShane *et al*. 2004; Piatt *et al*. 2007). Population models based on the best data applicable to B.C. and the three states to the south predict declining populations under most parameter ranges (Beissinger and Nur 1997; McShane *et al*. 2004). In the only rigorous analysis done in B.C., Cam *et al*. (2003) found that models based on the demographic data collected at Desolation Sound suggested a slightly declining population (i.e., mean population growth λ was < 1 in all models) although the range of estimates did include models with stable or slightly increasing populations (i.e., $\lambda > 1$). More recent modelling done by Piatt *et al*. (2007) using data applicable to Alaska and British Columbia showed that stable populations ($\lambda \geq 1$) were achievable only with the most optimistic assumptions of annual adult survival (0.93).

Diet

The preferred prey are epipelagic schooling fish (Burkett 1995; Burger 2002; Piatt *et al*. 2007). In B.C. the most common prey are Pacific Sand Lance of all age classes and immature Pacific Herring. Other schooling fish taken include Northern Anchovy (*Engraulis mordax*), smelt (Hypomesus spp.), immature salmonids, Eulachon (*Thaleichthys pacificus*), and Capelin (*Mallotus villosus*). Euphausiids and small squid are also taken.

Dispersal and Migration

There is very little information on the movements, dispersal or migration of Marbled Murrelets in B.C. Based on seasonal fluctuations in at-sea densities, there is evidence of post-breeding emigration from waters used during the breeding season (Burger 1995). For example, most murrelets breeding in high densities off southwestern Vancouver Island leave this area in mid- to late-July (Carter 1984; Burger 1995; Burger *et al*. 2008). It is not known where they go to moult or overwinter. A few of the murrelets radio-tagged in Clayoquot Sound in this region were found moving northwards after breeding, but most simply disappeared out of the range being monitored (D. Lank, SFU, unpublished data).

Seasonal migration has been confirmed for only one murrelet: an adult banded in Desolation Sound, B.C. was caught wintering in the San Juan Islands, Washington, 220 km to the south, and was then recaptured again during the breeding season in Desolation Sound (Beauchamp *et al*. 1999). Beauchamp *et al.* (1999) reported that other marked murrelets caught in Desolation Sound appeared to remain in that area after breeding, but radio-tagged adults were later tracked to moulting aggregations near Desolation Sound (N. Parker unpubl. data, cited by Burger 2002). Using radio-telemetry Lougheed *et al*. (2002) documented late-summer emigration from the study area in Desolation Sound, giving mean residence times of 5.3 days for newly fledged juveniles and 126 days for birds in adult plumage. Several murrelets captured on the Washington side of the Strait of Juan de Fuca were found nesting on Vancouver Island, although the distance moved by these birds was well within the normal commuting range of breeding murrelets (Dr. M. Raphael, U.S. Forest Service, pers. comm., 2009).

In summary, the sparse data suggest considerable migration of murrelets immediately after the breeding season ends. It is not known whether this constitutes a moult migration, i.e., birds moving to specific marine areas to undergo moult when they are flightless, or whether these are movements to overwintering grounds. It appears that murrelets breeding along exposed coastlines (e.g., west coast of Vancouver Island) might move into more sheltered waters (e.g., Strait of Georgia or Puget Sound) to overwinter. Movements of murrelets across international borders, both to and from Alaska and Washington, almost certainly occur although the extent of these movements is not known.

Interspecific Interactions—Predation

Predation is the most frequently documented cause of failure at Marbled Murrelet nests (Nelson and Hamer 1995; McShane *et al*. 2004). Known predators of adults, chicks or eggs in forest habitat include Peregrine Falcon (*Falco peregrinus*), Sharp-shinned Hawk (*Accipiter striatus*), Northern Goshawks (*Accipiter gentilis*), Common Raven (*Corvus corax*), and Steller's Jay (*Cyanocitta stelleri*) (Burger 2002; McShane *et al*. 2004; Malt and Lank 2007, 2009; Peery and Henry 2010). Suspected avian predators at nests include Great Horned Owls (*Bubo virginianus*), Barred Owls (*Strix varia*), Cooper's Hawks (*Accipiter cooperi*), Northwestern Crows (*C. caurinus*), American Crows (*C. brachyrhynchos*), and Gray Jays (*Perisoreus canadensis*). Predation by arboreal rodents, including squirrels and deer mice (*Peromyscus* spp.), has not been documented, but studies at simulated murrelet nest sites indicate that these mammals are likely common nest predators of eggs and small chicks (Bradley and Marzluff 2003; Malt and Lank 2007, 2009). Overall, avian predation, especially by corvids, is regarded as the greatest risk to nesting murrelets. In B.C., the Steller's Jay appears to be the most common nest predator.

At sea, predation by Bald Eagles (*Haliaeetus leucocephalus*), Peregrine Falcons, Western Gull (*Larus occidentalis*), and Northern Fur Seal (*Callorhinus ursinus*) has been reported (Burger 2002; McShane *et al*. 2004). Sea lions and large fish might also be occasional predators.

Interspecific Interactions—Competition

Little is known about possible competition between Marbled Murrelets and other piscivorous birds, fish or marine mammals. There is considerable overlap in the diets of Marbled Murrelets and other piscivorous birds, especially Common Murres (*Uria aalge*) and Rhinoceros Auklets (*Cerorhinca monocerata*) (Vermeer *et al*. 1987; Burkett 1995; Burger *et al*. 2008) but in general, murrelets in B.C. are not found in high densities near large colonies of other piscivorous seabirds. Murrelets seldom participate in the mixed-species foraging flocks that are common in B.C. waters in summer (reviewed by Burger 2002).

Murrelets might be negatively affected by competition with predatory fish species. During warm water years large schools of Mackerel (*Scomber japonicus*) and Jack Mackerel (*Trachurus symmetricus*) move north into the coastal waters off B.C. Mackerel invasions into Barkley Sound and adjacent seas in the 1990s reduced stocks of juvenile salmonids and juvenile Pacific Herring (B. Hargreaves, pers. comm., 2002), which was thought to contribute to reduced local numbers and breeding activity in Marbled Murrelet during these warm years (Burger 2002). Invasions by other warm-water piscivores, such as the Humboldt Squid (*Dosidicus gigas*), which washed up in large numbers on beaches in Vancouver Island in 2009, might also affect prey stocks taken by Marbled Murrelets.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Two primary methods have been used to estimate populations of Marbled Murrelets in B.C.—(1) at-sea boat surveys (sometimes supplemented with counts made from shore) and (2) counts made with radar (Burger 2002, 2007; Bertram *et al*. 2007). Both methods now follow provincial standards (at-sea: RISC 2001; radar: Manley 2006) but much of the at-sea survey data date back to the 1970s, 1980s and early 1990s and did not follow standard methods (these early data were not used in population trend analyses).

Boat surveys used to make early population estimates (some of the data still used in current population estimates—see Burger 2007) covered approximately 6,680 km (estimated from Burger 1995: Appendix 1 after removing repeated surveys). This distance represents about 25% of the length of B.C.'s approximately 27,000 km coastline, but the actual distance of coast sampled would be considerably less (likely 15-20%) due to overlaps in some survey routes. The boat survey routes sampled repeatedly and used to assess population trends add up to 345 km (Table 9; grid surveys excluded)—about 1.3% of the B.C. coast. On average these repeated boat surveys recorded an aggregate of 1,808 birds (Table 9), about 1.8% of the estimated 99,100 birds in B.C. (see below).

Table 9. Summary of population trends from studies made in British Columbia covering the 30-year period ending in 2009.
See the text for details. All trend data apply to data collected during the breeding season. Data that show statistically significant or near-significant trends are shown in bold type.

Region and area[1]	Data type	Period assessed	Years of data	Survey route (km)[2]	Mean no. of murrelets counted (± SE)	Trend[2]	Source
HG; Laskeek Bay	Vessel surveys	1991-2009	19	53.8	127 ± 20	**Decline (11.3% per year); P = 0.002.**	See Figure 6 and text
WNVI; Clayoquot Sound	Vessel surveys (grid surveys)	1982 vs. 1993-1996	4	586.0 km but in a grid survey	3203 ± 466	Decline (22-44% reductions over 11-14 years); no statistical tests done.	Kelson *et al.* (1995), Kelson and Mather (1999), but see text for details.
WNVI; Flores Transect, Clayoquot Sound	Vessel surveys	1997-2000	4	82.1	307 ± 43	**Decline (21.3% per year); P = 0.011**	Burger *et al*. (2007a)
WNVI; Tofino Transect, Clayoquot Sound	Vessel surveys	1996-2000	4	49.8	179 ± 22	**Decline (31.2% per year); NS (P = 0.055)**	Burger *et al.* (2007a)
WNVI; Broken Group Inner	Vessel surveys	1991-2006	14	9.2	24 ± 3	**Decline (8.3% per year); P<0.001**	Burger *et al*. (2007a)

Region and area[1]	Data type	Period assessed	Years of data	Survey route (km)[2]	Mean no. of murrelets counted (± SE)	Trend[2]	Source
WNVI; Broken Group Outer	Vessel surveys	1995-2006	10	14.6	50 ± 6	Decline (6.0% per year); NS (P = 0.232)	Burger *et al*. (2007a)
	Vessel surveys	1980-2000	10	43.0	217 ± 19	**Decline (5.8% per year); P = 0.045**	Burger *et al*. (2007a)
WNVI; Trevor/Beale/SBR	Vessel surveys	1979-2005	6	17.2	73 ± 22	Decline (9.3% per year); NS (P = 0.126)	Burger *et al*. (2007a)
WNVI; West Coast Trail	Vessel surveys	1994-2006	10	64.6	826 ± 101	**Decline (6.1% per year); P = 0.017**	Burger *et al*. (2007a)
EVI; Sidney – Mandarte Island	Vessel surveys	1974-2009	27	11.0	4.7 ± 0.5	**Decline (0.5% per year); P = 0.046**	P. Arcese; unpubl. data
WNVI; Clayoquot Sound - 15 watersheds	Radar counts	1996-2006	4	–	3417 ± 195	No change 1996-1998 vs. 2006; P > 0.05	Burger *et al*. (2007b)
Six regions across BC	Radar counts	Variable – see Fig. 8	3-12 years (see Fig. 8)	N.A.	–	No change – see Tables 11 & 12	

[1] Marbled Murrelet Conservation Regions (see Figure 2): NC – Northern Mainland Coast; HG – Haida Gwaii; CC – Central Mainland Coast; SC – Southern Mainland Coast; WNVI – West and North Vancouver Island; EVI – East Vancouver Island.
[2] See Burger (1995: Appendix 1) and Burger *et al*. (2007a) for details.
[3] Tests for statistical significance: P values shown where known; P > 0.05 is considered not significant; NT = not tested.

Marine radar-based methods to detect Marbled Murrelets as they fly between the ocean and inland nesting sites in coastal watersheds (Cooper *et al*. 2001) were first used in B.C. between 1996 and 1998 on the West Coast of Vancouver Island in Clayoquot Sound. This method was used to relate bird abundance at radar stations to the estimated amount of old growth nesting forests in associated watersheds (Burger 2001). Additional studies on Vancouver Island expanded to watersheds in Northwest Vancouver Island (1999-2001) and Southwest Vancouver Island (2002-2005) and new surveys of watersheds on the Central Coast (1998), North Coast (2001), South Coast (2000, 2001) and Haida Gwaii (2004-2005). The relationship between the number of birds and the estimated amount of suitable Marbled Murrelet nesting habitat was estimated for five independent studies, which include 101 watersheds inventoried in B.C. (Burger *et al*. 2004). Annual monitoring of six land-based stations on East Vancouver Island was initiated by Timber West Ltd in 2003.

The Canadian Marbled Murrelet Recovery Team in association with UBC (Arcese *et al*. 2005) identified radar monitoring (in contrast to at-sea surveys) as the superior technique for monitoring population trends of Marbled Murrelets in B.C. A statistically robust program was designed to detect population declines of up to 1% per year over a 10-15 year period based upon repeated radar surveys at a subset of the watersheds surveyed in each of the six Marbled Murrelet Conservation Regions (CMMRT 2003). In

2006, the Canadian Wildlife Service and the Wildlife Research Division of Environment Canada initiated a B.C.-wide sampling design. The design involves a total of 62 radar stations with 6-11 stations in each of the six Conservation Regions (Bertram *et al*. 2011 unpublished report, Figure 7). Each region is visited every 2-3 years and during a given year each station has three dawn surveys on non-consecutive days. Sampling effort per region was: 5 years in Haida Gwaii (surveyed in 5 years between 2003 and 2010), 5 years in Northern Mainland Coast (1998-2009), 12 years in West and North Vancouver Island (1996-2009), 3 years on the Central Mainland Coast (1998-2008), 7 years on East Vancouver Island (2003-2010, no data in 2009), and 5 years on the Southern Mainland Coast (2000-2010).

Neither at-sea boat surveys nor radar count methods provide adequate coverage of the entire B.C. range and estimates of the provincial population therefore involve considerable extrapolation and outright guesswork (details provided in Burger 2002, 2007; Bertram *et al*. 2007). The most recent population estimates are taken from Piatt *et al*. 2007, and updated values for the North and Central Coasts by applying correction factors (e.g., accounting for tilt of the radar units) based on more recent surveys (D. Bertram pers. comm., 2011). Work in Clayoquot Sound indicates that at-sea surveys (in this case grid surveys and strip transects) underestimate local populations compared to radar counts covering the adjacent watersheds (Burger 2001).

Extrapolations based on at-sea and shore-based counts involve either tallies of mean or maximum counts across the coastline covered, or applying mean densities (birds per km^2) to the total length of coastline providing likely marine habitat (details in Burger 1995, 2002, 2007). Extrapolations based on radar counts involve calculating the estimated density of murrelets entering watersheds (birds per ha of likely suitable habitat) and multiplying the mean regional density with the estimated area of likely suitable habitat based on habitat suitability algorithms (details in Burger 2002, 2007; Burger *et al*. 2004). In some coastal areas where neither method provides adequate sampling (e.g., East Vancouver Island; parts of the Southern Mainland Coast region) estimates were the best guess based on available sparse data (Burger 2002, 2007).

Abundance

The most recent population estimate, using extrapolations from at-sea surveys and radar counts, gives the range as 72,600 to 125,600 birds of all ages (mid-point 99,100 birds; Table 10). Assuming 75% of birds to be mature adults (see Table 8 for rationale) this represents an estimated 54,450-94,200 adults (median 74,325). Previous estimates (rounded numbers) were: 45,000 to 50,000 breeding birds (Rodway 1990; Rodway *et al*. 1992); 54,700 to 77,700 birds of all ages (Burger 2002); and 54,300 to 92,600 birds of all ages (Burger 2007). The increase in these numbers is a function of improved information on populations, especially with the application of radar counts, and does not reflect an increase in the actual population. The large increases shown in the most recent data for the Northern and Central Mainland Regions (Table 10) are the result of more intensive radar surveys, the application of more sensitive radar units (with tilted antennae), and the consequence of earlier radar surveys used in the Burger (2007) estimate being made in an El Niño year (1998) when breeding activity of murrelets was expected to be reduced (Bertram *et al*. 2007; Ronconi and Burger 2008).

Table 10. Recent estimates of the British Columbia population (birds) of Marbled Murrelet. Both population estimates shown here are based on extrapolations from both at-sea surveys and radar counts because neither method covers the entire range of the species in British Columbia. The numbers given are for birds of all ages; about 75% of these birds could be considered mature adults (see Table 8).

Conservation region	Burger (2007)	Bertram *et al*. (2007) and D. Bertram (unpubl. data)
Northern Mainland Coast	10,100-14,600	18,400-26,000
Haida Gwaii	8,500-25,000	8,500-25,000
Central Mainland Coast	10,000-21,000	20,000-42,000
Southern Mainland Coast	6,000-7,000	6,000-7,000
West & North Vancouver Island	18,700-23,600	18,700-23,600
East Vancouver Island	1000-2000	1000-2000
Total for British Columbia		
All birds	54,300-92,600	72,600-125,600
Mature adults (rounded)	40,700-69,500	54,500-94,200
Mid-point		
All birds	73,450	99,100
Mature adults (rounded)	55,000	74,300

Fluctuations and Trends

Historical changes based on anecdotal information and sketchy data indicate significant declines in the early 1900s in the Strait of Georgia (summarized by Burger 2002). Declines and the disappearance of murrelets off Boundary Bay, south of Vancouver, and Burrard Inlet, near Vancouver, since the 1980s were summarized by Burger (2002, 2007). There is also compelling evidence from a range of studies at different spatial scales (i.e. large conservation regions, watersheds and forest stands) that murrelet populations show a linear relationship with available areas of nesting habitat (reviewed by Burger and Waterhouse 2009). Thus, the estimated loss of nesting habitat of 22% over the past 30 years (Long *et al*. 2011; see above) may represent a comparable decline in the population over this time period.

Trends in abundance during the past 30 years also come from counts made in the breeding season, which are summarized in Table 9, with further explanations below. The sparse information from outside the breeding season is also summarized below.

At-sea surveys

At-sea surveys for Marbled Murrelets, like radar surveys and most other wildlife inventories, are affected by observer skills, environmental conditions (sea state, weather) and inventory tools (boat size, boat speed). There is thus a lot of variation from sampling, exacerbated by the high mobility of these birds and the variations in their prey availability and habitat use (e.g., Ronconi 2008). It was impossible to adequately include the effects of these sampling and environmental covariates in the trend analyses and the focus is therefore on broad patterns in the available data rather than detailed statistical analyses of at-sea data.

At-sea grid counts made in Clayoquot Sound in 1982, 1993, 1994 and 1996 showed reductions in that population of 22% to 40% since 1982 (Kelson *et al*. 1995; Kelson and Mather 1999). These results have been widely quoted as evidence of major declines, and are compatible with more recent data from that region using different census routes and standardized methods (see below). Close examination of the data revealed that changes were restricted to exposed inshore waters and were linked with the effects of high sea temperatures in those waters in the 1990s (Burger 2002).

Burger *et al*. (2007a) analysed trends in eight transect routes surveyed repeatedly from boats during the breeding season (data shown in Figure 5; statistical summary in Table 9; location of surveys is mapped in Burger *et al*. 2007a). Six routes were sampled in the period 1979 to 2006 (but not in every year) and two from 1996-2000. Apart from one study made at Laskeek Bay on Haida Gwaii, the routes were all off southwestern Vancouver Island; there is considerable overlap in the spatial coverage of some of the survey routes in Barkley Sound but the various data sets cannot be combined because of differences in survey methods, boat size and dates of surveys (see Burger *et al*. 2007a for maps and details). The combined at-sea counts summarized in Table 9 cover, on average, about 5000 birds (1800 if we consider only the repeated transect counts), which is a small proportion of the estimated B.C. population (5% and 2%, respectively) and there are very few data from before 1991. There are thus severe limitations on the spatial distribution, temporal span, and numbers of birds counted in the at-sea surveys, but they remain as the only data which provide information on population trends over a three-generation (30 year) span.

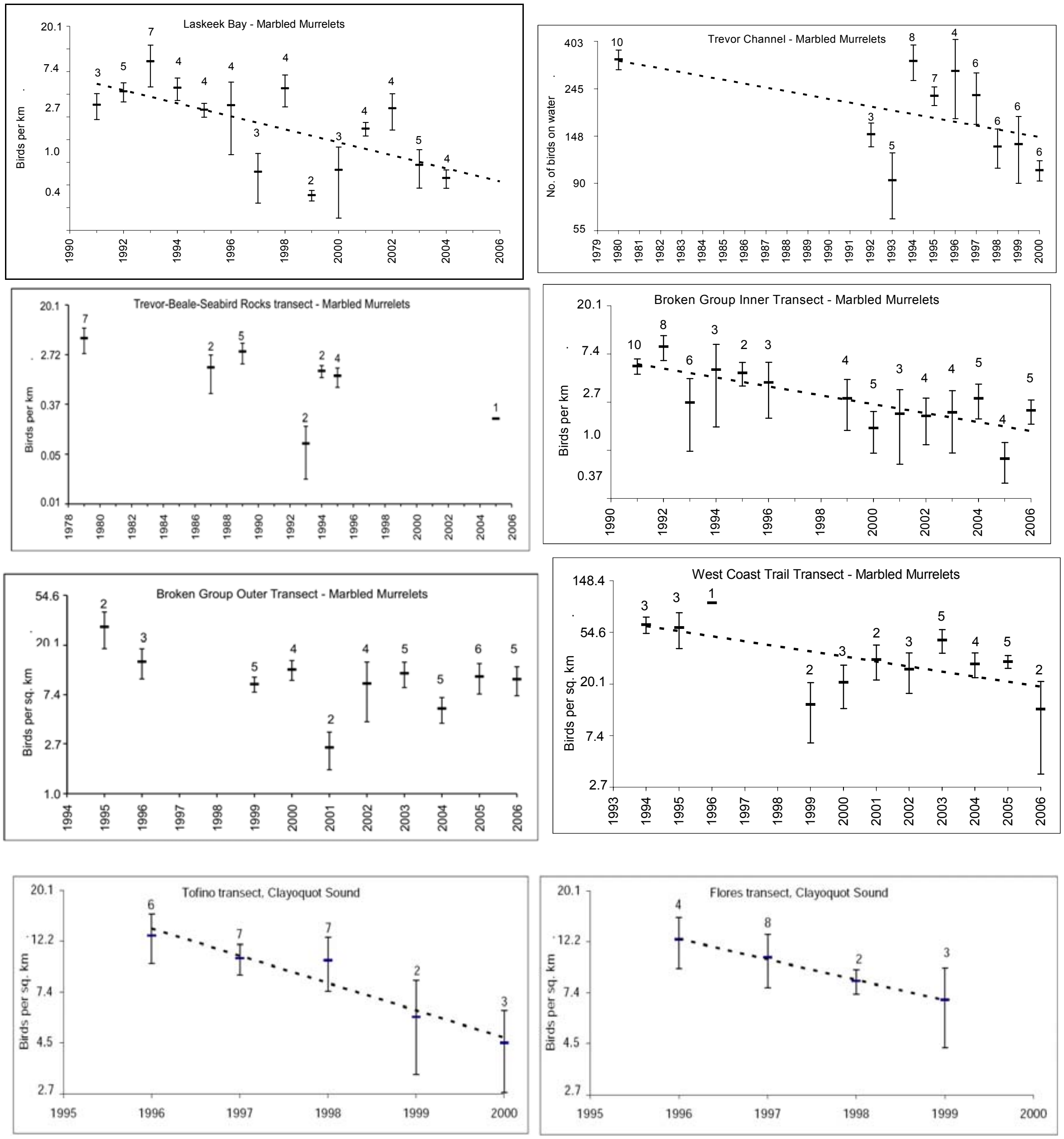

Figure 5. Trends in Marbled Murrelet density from repeated at-sea boat surveys at eight sites in British Columbia (from Burger *et al*. 2007a). Statistical results from these data are summarized in Table 9. Means ± SE are shown with the sample sizes (no. of days surveyed). Trend lines are included for statistically significant trends (Table 9). See Burger *et al*. (2007a) for map of survey sites and details of the trend analysis using log-transformed count data.

All six data sets covering more than 10 years showed declines in densities of murrelets and these trends were statistically significant at four sites (Laskeek Bay, Haida Gwaii; Broken Group Islands inner transect; Trevor Channel, Barkley Sound; and the West Coast Trail coast; Table 9). Annual rates of change in these >10-year-samples ranged between -6.1% and -11.3% (note that the citation of annual rates of change or the use of linear regression does not imply a constant annual change—there is considerable fluctuation in all population data for Marbled Murrelets). All four data sets with adequate sampling from 1999-2006 showed no significant change in densities through these years, indicating that the major declines happened before 1999 (Burger *et al*. 2007a). The two surveys in Clayoquot Sound (Flores and Tofino) showed significant rates of decline (-21.3% and -31.2% per year, respectively) in the years 1996-2000, but cover relatively few years limiting their value to show long-term trends.

Of the eight data sets analysed in Burger *et al*. (2007a) updated data are available only from the Laskeek Bay surveys, adding five years to the time covered. These data show a significant decline in counts of Marbled Murrelets from 1991 to 2009 (Figure 6; linear regression, $F_{1,17}$ = 13.585, P = 0.002). Overall these data indicate an average decline of 11.3% per year since 1991. There was, however, no significant trend in the sub-set of data from 1999 to 2009 ($F_{1,17}$ = 0.002, P = 0. 965). In both the west Vancouver Island (Clayoquot and Barkley Sound) and Laskeek Bay data the trends seem to follow a step function, with major declines before 1999 and no significant change since 1999. There appear to be variations in the Laskeek Bay trends depending on the transects sampled (S. Hazlitt, B.C. Ministry of Environment, pers. comm., 2011), but the detailed co-variate data on these transects are not readily available to allow more refined analysis for this report.

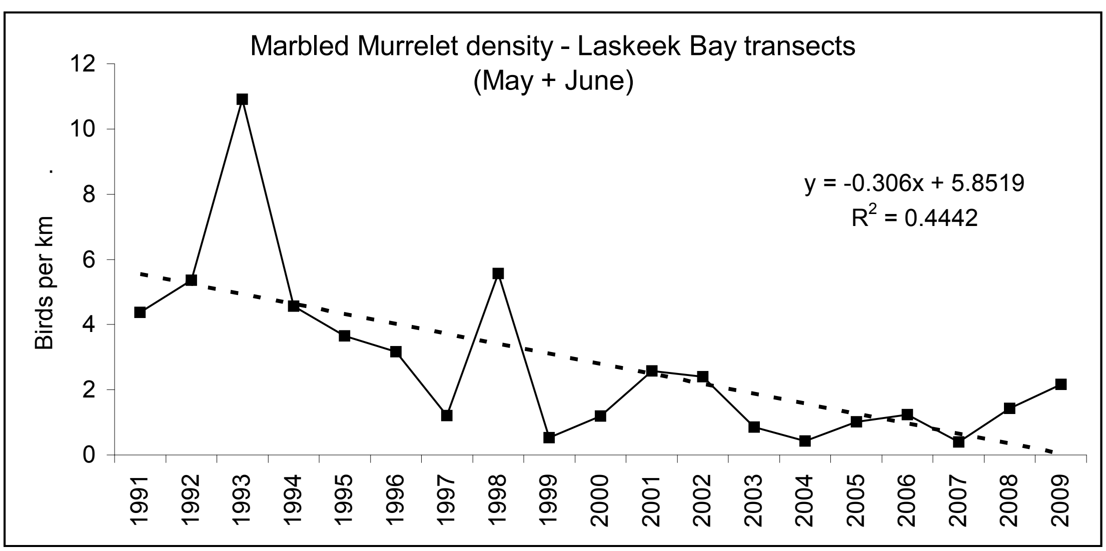

Figure 6. Mean densities of Marbled Murrelets (birds per km of transect) in boat surveys made in Laskeek Bay, Haida Gwaii from 1991 to 2009 in May and June. Data courtesy the Laskeek Bay Conservation Society and Dr. A.J. Gaston (Environment Canada). See Burger *et al*. (2007a) for further details on this survey.

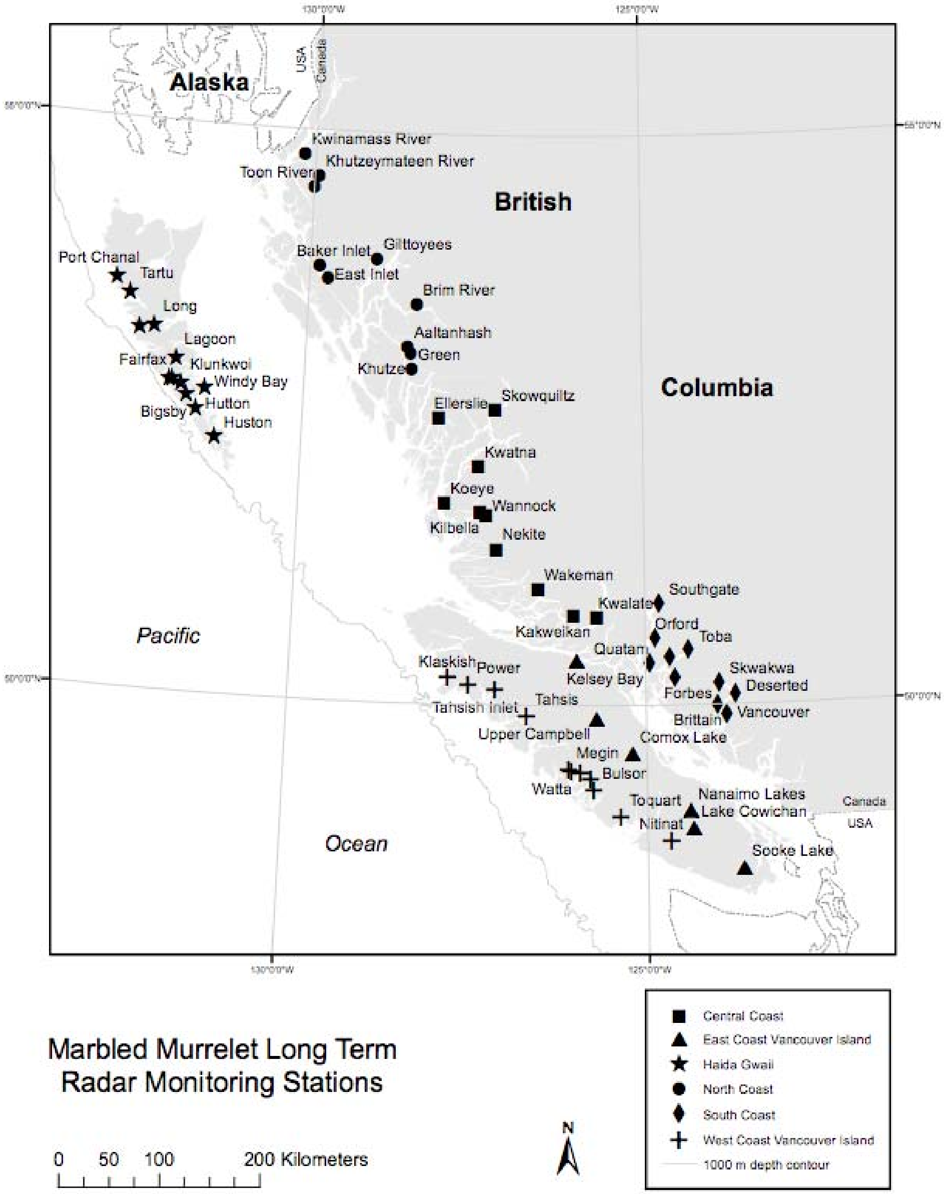

Figure 7. Environment Canada long-term radar monitoring stations (n=62) in the six Marbled Murrelet Conservation Regions defined by the Canadian Recovery Team (CMMRT 2003). Some station names in Haida Gwaii and West Vancouver Island are hidden in this projection.

P. Arcese (unpubl. data, Univ. of British Columbia) collated murrelet counts made on an 11-km transect from Canoe Cove to Mandarte Island, off southern Vancouver Island between 1974 and 2010. Population densities of murrelets in this area are low (mean 5 birds per survey) and the population is likely greatly reduced from pre-1800 levels based on anecdotal evidence (Burger 2002). Data were analysed in three periods: 'Breeding' (Mar-Jul), 'Fall' (Aug-Oct) and 'Winter' (Nov-Feb). Simple regression detected a small but statistically significant decline in breeding season counts (b = -

0.0051, se = 0.0025, P = 0.046, n = 341), no detectable trend in fall counts (b = -0.0028, se = 0.0059, p = 0.634, n = 136), but a comparatively large and statistically significant increase in counts made during winter (b = 0.0260, se = 0.0085, p = 0.003, n = 119). However, trends in all three periods shared a similar oscillating pattern over the 35-year study, which suggests that numbers often rose in association with La Niña events and declined in association with El Niño events. Including the Multivariate ENSO Index as a covariate had no influence on trend estimates for breeding season, reduced slightly the non-significant decline estimated for fall, and reduced very slightly the magnitude of the positive trend detected in winter.

Bower (2009) analysed trends in abundance of seabirds wintering in the Salish Sea (Strait of Juan de Fuca, southern Strait of Georgia and Puget Sound), an area which includes some Canadian waters and is also likely used in winter by murrelets breeding further north in B.C. Data were obtained from a mix of counts from ferries, other boats and the shore. Although there were some differences in methods and sampling effort across years these were not thought to mask major changes in bird abundance (Bower 2009). Comparison of counts in 1978-1980 with those in 2003-2005 showed significant declines in several piscivorous seabirds, including a 71% decline in mean counts of Marbled Murrelets.

Most of the evidence for population declines comes from southern British Columbia. Might this be due to northward shifts in distribution as a function of climate change? We lack the necessary matching data from northern British Columbia to analyse this rigorously, but the severe declines documented in Alaska and at Laskeek Bay, Haida Gwaii, suggest that northward dispersion is unlikely to explain the changing numbers in southern British Columbia.

Radar counts

Temporal trends in radar counts were modelled using a mixed effects approach (Bertram *et al*. 2011 unpublished report). Counts were based on the number of Marbled Murrelets entering watersheds before dawn (n = 877 dawn surveys). Radar counts were ln-transformed, such that $Y_{i|R,t} = \log_e(Count_{i,t} + 1)$, where *i* = Radar Station nested within Region *R*, and *t* = year, and year 1996 was set to a value of 1. The model included fixed effects for year and angle of tilt on the radar unit, scanning radius on the radar unit, day of the year, and observer as random effects (Bertram *et al*. 2011 unpublished report).

The model showed no significant overall population trend for Marbled Murrelets across the six Conservation Regions (Table 11). Marbled Murrelets showed a positive non-significant trend of 2% per year, suggesting a stable population between 1996 and 2010 over the study region as a whole. Population trends were similar among regions (Figure 8). Bootstrap analysis indicated all region-specific trends were non-significant (95% confidence intervals included 0). East Coast Vancouver Island was a potential exception to this pattern, where the trend was more variable and had a higher probability of being negative (P_{neg} = 0.72, Table 12, Figure 8; Bertram *et al*. 2011 unpublished report).

Table 11. Parameter estimates for model depicting temporal trends in the number of Marbled Murrelets counted at radar stations distributed throughout the entire coast of British Columbia.

Counts were based on the number of incoming Marbled Murrelets detected before dawn. Parameters with |t-value| > 1.96 are considered statistically significant (P < 0.05). Trends were based on radar surveys at 62 Stations in six Conservation Regions, with 48 observers and seven radar models, and up to 15 years of data. N = 877.

Variable	Parameter	SE	z-value	P-value
Fixed Effects				
Intercept	-10.041	1.834	-5.47	<0.001
Year	0.022	0.023	0.93	0.351
Tilt	0.046	0.011	4.21	<0.001
Day of Year	0.155	0.020	7.60	<0.001
Day of Year - quadratic	-0.00044	0.00006	-7.55	<0.001
Random Effects				
Variable	SD			
Station/Region	0.517			
Year|Station	0.058			
Region	0.731			
Year|Region	0.0003			
Year as categorical variable	0.222			
Observer	0.326			
Radar Make and Type	0.197			
Residual	0.641			

Table 12. Region-specific trend estimates based on a model depicting temporal trends in the number of Marbled Murrelets counted at radar stations distributed throughout the British Columbia coast.

Counts were based on the number of incoming murrelets detected before dawn. Trends were based on radar surveys at 62 Stations in six Conservation Regions, with 48 observers and seven radar models, and up to 15 years of data. N = 877. Percentiles are based on residual bootstrap analysis of region-specific coefficients. Proportion negative indicates proportion of distribution that had negative trends.

Region	Trend estimate	95% Confidence interval		Proportion negative
Haida Gwaii	0.022	-0.017	0.031	0.27
North Mainland Coast	0.022	-0.015	0.040	0.25
West Vancouver Island	0.022	-0.007	0.042	0.10
Central Mainland Coast	0.022	-0.006	0.057	0.07
East Vancouver Island	0.021	-0.068	0.039	0.72
South Mainland Coast	0.022	-0.019	0.033	0.32

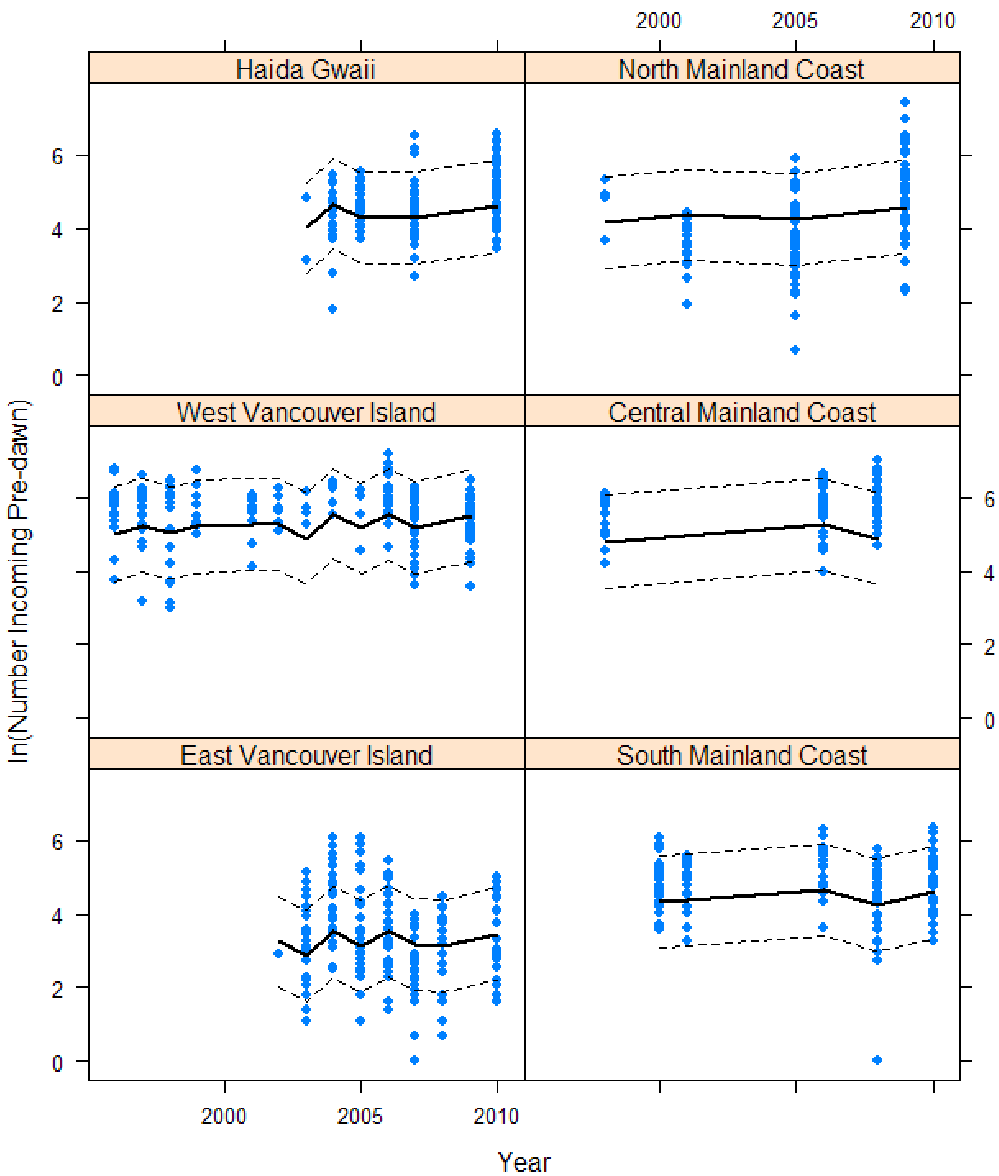

Figure 8. Temporal trends in the number of Marbled Murrelets counted at radar stations distributed through six Conservation Regions in British Columbia, 1996-2010. Thick lines indicate predicted means from best trend model, with 95% confidence intervals that depict the within-Region variation among stations (thin lines). Covariates were set at median values (Tilt = 10.65, DOY = 176).

Inland detections

Detections made during standardized audio-visual (AV) surveys that were for a time a widespread method for assessing stand occupancy and relative activity levels in forest habitat. The only analysis of AV detection data for long-term trends involved annual surveys made at 11 stations in the Carmanah-Walbran watersheds, southeast Vancouver Island, from 1991 through 1999. Analysis of covariance, using local sea temperature as a covariate, revealed a significant decline in occupied detections of about 65% over the nine years (Burger *et al*. 2007a). As this analysis controlled for likely negative effects of warm seas, the effects of recent and ongoing logging in and near these watersheds was suspected in the decline (Burger *et al*. 2007a).

Christmas Bird Counts

Few Christmas Bird Count (CBC) circles in British Columbia encompass important wintering areas for Marbled Murrelets (most CBC circles are centred on urban areas), and there is concern over the reliability of CBC data as indicators of murrelet trends (Piatt 1998; Hayward and Iverson 1998; see Appendix 1). Rodway *et al*. (1992) found no clear trends in counts in B.C. of Marbled Murrelets in CBC data from 1957 through 1988. This analysis used a hierarchical modelling analysis using birds per party-hour as the population index for count circles in four U.S. states and British Columbia in which Marbled Murrelets regularly occurred (Niven *et al*. 2009). The analysis showed an overall decline during the 40-year period averaged at -0.87% per year (95% confidence intervals -3.4% to +1.7%) (Audubon Society 2009).

Bower (2009) compared CBC data made in two periods (1976-1985 vs. 1998-2007) from 11 counts in the southern Strait of Georgia and Puget Sound, including 8 from southern B.C. In the two decades separating these two periods, counts of Marbled Murrelets declined by 68.5%. Other piscivorous seabirds, notably Western Grebe (*Aechmophorus occidentalis*) and Common Murres showed comparable declines. These trends matched those revealed from other methods (boat and shore counts) over the past two decades in this area (Bower 2009; see also the murrelet boat survey trends summarized above).

Christmas Bird Count data from 26 count circles in British Columbia were analysed for this report (Appendix 1). The years sampled ranged from 6 to 40 years; all but two of the sites showing significant changes covered > 20 years before 2008. One site (Bamfield) reported a significant increase in murrelet numbers over the past 22 years. Nine sites showed significant declines and the remaining 16 sites showed no significant trends (details in Appendix 1). Pooling data across sites was difficult because of the large differences in murrelet numbers per site and the variations in the number of years covered (see Appendix 1). It was possible to combine sites from the Salish Sea (Georgia Strait and Strait of Juan de Fuca) to cover the period 1972-2008 (11 sites) and a slightly larger sample to cover the 30-year period 1978-2008 (14 sites). Both of these pooled samples showed great year-to-year variation and long-term declines (Figure A1-1 in Appendix 1) but these trends were not statistically significant.

Trends in Neighbouring States

Populations of Marbled Murrelets breeding in all three states to the south of B.C. (Washington, Oregon and California) have greatly depleted populations that are experiencing ongoing declines (Ralph *et al*. 1995; McShane *et al*. 2004; Raphael 2006). Population models published by McShane *et al*. (2004) predicted declines of 3-5% per year in these populations for the following 20 years. Monitoring data based on intensive at-sea boat surveys covering much of the three-state coastline have confirmed these predictions: the combined populations declined by 2.4% per year (P = 0.04) from 2000-2008 (Falxa *et al*. 2009). These declining trends continued into 2009 but have not been fully analysed (G. Falxa, unpubl. data, Feb. 2010). If the 2000 data were omitted (due to some differences in survey methods), the data show a decline in the three states averaging 4.3% per year (P = 0.003) from 2001 through 2008 (Falxa *et al*. 2009). The monitoring zone bordering B.C. (Zone 1, covering Puget Sound and the southern Strait of Juan de Fuca) showed the highest rate of decline (7.9% per year; P = 0.010).

Alaska supports the largest portion of the murrelet's population (Table 1). Data on population size and trends are sparse across this vast area, but the most comprehensive analysis indicated massive declines in numbers in most of the areas where murrelets have the highest breeding concentrations in Alaska (Piatt *et al*. 2007). Repeated at-sea surveys in selected sites indicate significant declines at five of eight monitoring sites (other sites were not statistically significant), with annual rates of decline between 5.4% and 12.7% since the early 1990s. This review indicated a decline of about 75% in the overall Alaskan population over the 25-year period ending in 2006. Surveys during the past decade indicate that Marbled Murrelet populations might have stabilized or increased in the 2000s in some areas in Alaska, including large populations in Lower Cook Inlet and Katchemak Bay (Kuletz *et al*. 2011a), Kenai Fjords (Arimitsu *et al*. 2011), and Glacier Bay (Kirchoff *et al*. 2010; but see Piatt *et al*. 2011 for problems with differences in sampling techniques affecting these data). The large population in Prince William Sound continued to show major declines of 5.5% per year through the 2000s (Kuletz *et al*. 2011b). Overall, Piatt *et al*. (2011) suggested that, despite some evidence of improved conditions in the 2000s, the Alaskan Marbled Murrelet population has decreased significantly since the 1970s.

Conclusions on Population Trends in B.C.

There are insufficient data to make a definitive statement about the population trends for Marbled Murrelet in Canada over the past 30 years (3 generations). Murrelet populations almost certainly declined during this period but the exact rate of decline remains speculative. The recent analysis of radar counts in six regions covering periods of only 6-14 years, within the 1996-2010 timeframe shows no significant population trends in any region, or for the B.C. coast as a whole. This is consistent with the few at-sea surveys covering this period, which also show no significant trends since the late 1990s. Circumstantial evidence suggests that negative impacts in both marine and terrestrial environments of the murrelet might have ameliorated since the late 1990s. Since that time the northeast Pacific has been less strongly affected by the warm phase of the Pacific Decadal Oscillation, which generally has negative effects on piscivorous seabirds in B.C. (Gjerdrum *et al*. 2003; Hedd *et al*. 2006), although the exact impacts on Marbled Murrelets are not clear. Since the mid-1990s there was also a reduction in the rates of logging in B.C.'s coastal forests (Figure 4) although the impacts of cumulative habitat loss would be expected to continue at a lower rate.

Counts of wintering murrelets are even more sparse and spatially restricted. Evidence summarized above from Bower (2009) and from Christmas Bird Counts (Appendix 1) indicate declines in wintering populations in B.C., but the surveys made by Arcese (unpubl. data) along a 11-km transect off southern Vancouver island show no declines in winter.

Estimated rates of decline in both jurisdictions bordering B.C. greatly exceed 1% per year (see references above: 7.9% per year in Washington Zone 1 bordering B.C. and 4.3% per year across the Washington, Oregon and California range, based on far more intensive at-sea surveys than those in B.C.; between 5.4% and 12.7% per year in Alaska, based on more scattered surveys). It seems unlikely that murrelets in B.C. would be immune from the negative factors driving these declines in neighbouring states. Large-scale marine regimes influencing seabirds in B.C. are shared with neighbouring states (Piatt *et al*. 2007) and, unlike in the U.S., large-scale logging of forest nesting habitat is continuing in B.C.

The estimated loss of nesting habitat is 22% over the past 30 years (Long *et al*. 2011; see above). Given the consistent evidence that numbers of breeding murrelets correlated in a linear manner to available area of breeding habitat (Raphael 2006; Burger and Waterhouse 2009) then the rate of decline in the breeding population would be similar, i.e., about 0.7% per year.

Changes in the marine environment are also likely affecting murrelet populations. There is clear evidence from both historical comparisons (Peery *et al*. 2004a; Becker and Beissinger 2006; Norris *et al*. 2007) and present-day conditions (Becker *et al*. 2007; Gutowsky *et al*. 2009; Peery *et al*. 2009b; Ronconi and Burger 2008) that marine conditions, mediated through prey availability, do affect murrelet recruitment and population trends. Other seabirds, marine mammals and large fish, especially those like murrelets that rely on small schooling fish, have also exhibited large declines in many parts of the northeastern Pacific over the past 30 years associated with climatic change and regime shifts (reviewed in Piatt *et al*. 2007; U.S. Fish and Wildlife Service 2009). Counts of newly fledged juveniles on the water across the murrelet's range tend to be far lower than the levels needed for stable populations and nearly all demographic models using the best available data predict population declines (see reviews by Burger 2002; McShane *et al*. 2004; Piatt *et al*. 2007).

Taking all these data into account, the population has almost certainly declined over the past 30 years, but given the paucity of population trend data before 2000, it is impossible to give a reliable estimate of the proportionate loss of population over this period. The various methods also give somewhat conflicting results. It appears that factors driving these declines have changed so that populations have remained relatively stable over the past 10 or so years.

Rescue Effects

With severely declining populations on both sides of B.C., one cannot expect a cross-border rescue effect to have much long-term benefit to the murrelet population breeding in British Columbia.

POPULATION VIABILITY MODELS

Steventon *et al*. (2006) used a Bayesian belief network to model the persistence of Marbled Murrelets in British Columbia using a wide range of time scales, demographic values and management options. For a single independent (regional) population their simulations showed a diminished probability of persistence below about 5000 pairs (about 15,000 birds), accelerating below 2000 pairs. Persistence was increased when populations were acting as semi-independent subpopulations (due to compensatory dispersal among regions) especially if the deleterious factors, in either the marine or nesting habitats, occurred at different times (i.e., were out of phase with each other). Their results were broadly consistent with their earlier viability simulation modelling with the murrelet (Steventon *et al*. 2003) and more general persistence modelling using life-history parameters from 102 species (Reed *et al*. 2003). Based on these three studies, Steventon *et al*. (2006) concluded that a coast-wide British Columbia population at or above 12,000 breeding pairs distributed among 3-6 semi-independent regional populations (e.g., 1000-4000 pairs per region) appears robust in terms of population viability across spatial scales, temporal scales, uncertainty of demographic parameters, and modelling approach.

How does this predicted stable breeding population translate into numbers of birds? This information is useful because birds and not pairs are censused using both radar and at-sea surveys. Non-breeding murrelets do fly inland and are counted in radar surveys (Peery *et al*. 2004b). In their modelling Steventon *et al*. (2006) applied a range of 0.25 to 0.45 for the proportion of the population made up by breeding females (i.e., no. of pairs), which covers the range of values derived from field estimates (Burger 2002; Cam *et al*. 2003) and assumptions used in other population modelling (Piatt *et al*. 2007). Steventon *et al*. (2006) used an intermediate value (0.33) in their conclusion to assume that 12,000 pairs represented about 36,000 birds. A similar 1:3 (pairs:birds) ratio has been used in other rule-of-thumb conversions (e.g., Burger 2004).

Some words of caution are needed in interpreting the outcome of the Steventon *et al*. (2006) simulation modelling. Many assumptions were made (clearly outlined in the paper) because of the scarcity of hard data on the demographic parameters, population sizes, nesting density, effects of marine parameters, effects of fragmentation and edges on nesting murrelets, rates of nest predation, and other key variables. In order to model persistence over 100-500 year periods Steventon *et al*. (2006) had to assume a mean population growth parameter (r) allowing a stable population (i.e., mean r = 0 or λ = 1), but they modelled a wide range of variance around this mean in order to investigate long-term persistence. The assumption of r = 0 is fairly optimistic, given that mark-recapture studies of the Marbled Murrelet in Desolation Sound (the most intensive study to date and the only study of this kind in B.C.) gave values of r less than 0 (i.e., λ was calculated to be less than 1) except for the most optimistic demographic assumptions (Cam *et al*. 2003).

Furthermore, Steventon *et al*. (2006) assumed that their semi-isolated populations would be impacted by negative factors at sea or inland at different times (i.e., environmental conditions would be somewhat out of phase among the subpopulations). This probably applies to many key factors but some widespread negative influences (e.g., El Niño, warm phases of the Pacific Decadal Oscillation, climate change) are likely to affect all or most of the breeding populations at the same time, reducing long-term population viability. Overall, therefore the persistent population of 12,000 pairs (36,000 birds) must be considered a minimum, optimistic estimate for long term (100-500 year) persistence.

THREATS AND LIMITING FACTORS

Known and potential threats to Marbled Murrelets have been reviewed by Ralph *et al*. (1995), Burger (2002), McShane *et al*. (2004), Piatt *et al*. (2007) and U.S. Fish and Wildlife Service (1999), and are summarized in Table 13.

Table 13. Known, likely, and hypothetical threats to Marbled Murrelet populations in British Columbia. See Appendix 2 for the application of these threats in assessing the status of the Marbled Murrelet.
See also reviews by Burger (2002); McShane *et al*. (2004); Piatt *et al*. (2007) and U.S. Fish and Wildlife Service (2009).

Threat	Type	Comments	Reference
Loss of forest nesting habitat	Known, current	Challenges include relating habitat quality to densities of murrelet and quantifying habitat trends	Burger (2002); Piatt *et al*. (2007); Zharikov *et al*. (2006, 2007); Burger and Waterhouse (2009)
Forest fragmentation	Known, current	More predators in fragmented areas and on edges, windthrow, and change in microclimates.	Burger (2002); Raphael *et al*. (2002); Marzluff *et al*. (2000); Malt and Lank (2007, 2009)
Inland predation	Known, current	Associated with forest fragmentation and human activity	Raphael *et al*. (2002); Malt and Lank (2007, 2009); Peery and Henry (2010)
Wind power generation and power lines	Likely	Mortality through collisions with land- or ocean-based turbines or power lines	Cooper and Beauchesne (2004)

Threat	Type	Comments	Reference
Run-of-river power generation and power lines	Likely, current	Loss of nesting habitat from roads, power corridors and infrastructure; collisions with power lines	Research is being undertaken by power companies but no results have been made public
Oil mortality	Known, current	Risk from both catastrophic and chronic oiling.	Burger (2002); McShane *et al*. (2004); Piatt *et al*. (2007); O'Hara and Morgan (2006).
Entanglement in fishing gear	Known, current	Gill net mortality is known.	Carter and Sealy (1984); Burger (2002); McShane *et al*. (2004); Smith and Morgan (2005); Piatt *et al*. (2007)
Ocean climate variability	Likely	Expected given impacts on other seabird populations in British Columbia	Bertram *et al*. (2005); Hedd *et al*. (2006); Gjerdrum *et al*. (2003); Peery *et al*. (2004a, 2009b); Becker *et al*. (2007); Norris *et al* (2007); Piatt *et al*. (2007)
Aquaculture	Likely	Destruction of foraging habitat and displacement (shown for waterbirds)	Booth and Rueggeberg (1989); Rueggeberg and Booth (1989); Vermeer and Morgan (1989).
Fisheries induced prey depletion	Hypothetical	Competition with present and future fisheries	Becker and Beissinger (2006); Piatt *et al*. (2007)
Boat traffic	Known, current	Disturbance to feeding adults	Speckman *et al*. (2004); Hentze (2006); Bellefleur *et al*. (2009)
Contaminants	Known, current	e.g. Quatsino Sound heavy metals	Vermeer and Thompson (1992); U.S. Fish & Wildlife Service (2009)
Disease, parasites and biotoxins	Hypothetical	Paralytic shellfish poisoning, other algal blooms and diseases can kill seabirds	MacBean (1989); McShane *et al*. (2004); Piatt *et al*. (2007); U.S. Fish & Wildlife Service (2009)

Loss of Nesting Habitat

Loss of nesting habitat in old-growth forests has been identified as the principal threat in B.C. and in the states to the south. There is compelling evidence from a range of studies at different spatial scales that murrelet populations show a linear relationship with available areas of nesting habitat (reviewed by Burger and Waterhouse 2009). Consequently, populations are expected to decline in proportion to the loss of suitable nesting habitat. Recovery recommendations in B.C. are focused on maintaining sufficient areas of suitable old forest to reduce the decline of the murrelet population to less than 30% of the 2002 level over the 30-year period (3 generations) to 2032 (CMMRT 2003).

Increase in Predator Populations

Populations of many predators of murrelets, especially corvids, have increased appreciably in the Pacific Northwest during the past 30 years (Marzluff *et al*. 1994; Peery and Henry 2010). Piatt *et al*. (2007) analysed Christmas Bird Count data from 1970 to 2006 and showed statistically significant increases in southern B.C. in counts of Bald Eagles, Peregrine Falcons, Steller's Jays and Common Ravens, but no significant change in counts of Sharp-shinned Hawks and crows and a significant decline in Northern Goshawks. Several studies have shown increased densities of avian predators, especially corvids associated with human activities (towns, logging camps, garbage dumps etc.) and with forest fragmentation caused by clearcut logging (reviewed by Burger 2002, and Malt and Lank 2007, 2009).

Forest Fragmentation and Nest Predation

In addition to loss of nesting habitat, forest fragmentation and the creation of hard forest edges by clearcut logging are believed to create additional threats to nesting murrelets, primarily through increased risk of predation by corvids (Raphael *et al*. 2002; Malt and Lank 2007, 2009). The increase in populations of corvids and other predators in B.C. (see above) exacerbates the effects of fragmentation. As reviewed above, negative microclimatic changes are also likely to occur as a result of clearcuts and road-building.

Oil Spills and Other Marine Pollution

Previous status reports and recovery plans noted oil spills as a major threat to murrelets (Rodway 1990; Kaiser *et al*. 1994; Hull 1999). Although there has been no documented mortality of murrelets from oiling in B.C. in the past 20 years, threats from oil spills remain important and the level of shipping in coastal B.C. waters is increasing (O'Hara and Morgan 2006; P. O'Hara, Environment Canada, unpubl. data). Because they aggregate in nearshore waters and spend most of their lives on the water, Marbled Murrelets are among the most susceptible birds to oil spills (Carter and Kuletz 1995).

The threats to Marbled Murrelets posed by other chemical contaminants are poorly known, but because this species feeds at a fairly high trophic level, it is likely to be susceptible to contaminants that bio-accumulate. PCBs and PBDE (fire retardant) are currently viewed as the greatest risks in sheltered inland seas (U.S. Fish and Wildlife Service 2009) and are most likely in the Salish Sea region (southern Georgia Strait and Juan de Fuca Strait).

Interactions with Fisheries

Information on interactions between fisheries and Marbled Murrelets in B.C. was summarized by Smith and Morgan (2005) and Piatt *et al*. (2007). Of the more than 15 types of fisheries operating in British Columbia, salmon gill-nets appear to be the greatest threats to Marbled Murrelets. Possible impacts of sports fishing (angling), the purse-seine fishery, and aquaculture remain poorly known. A study in Barkley Sound in the 1980s showed severe impacts of the salmon gill-net fishery on breeding murrelets (Carter and Sealy 1984). The intensity of gill-net fishing appears to have greatly reduced since then but the problem remains and data on bycatch rates are sparse (Smith and Morgan 2005; Piatt *et al*. 2007). Under current fishing levels, Smith and Morgan (2005) estimated that about 550 Marbled Murrelets are entangled in gill-net fisheries per year in B.C. (see also Piatt *et al*. 2007 for further details). Many of these would be adult birds, resulting in a disproportionately large impact on the overall populations (Beissinger and Nur 1997; Boulanger *et al*. 1999). Murrelets appear to be at low risk to being caught in long-line fisheries (either for halibut or rock cod), the salmon troll fishery, the sablefish trap fishery, or the trawl net fishery (Smith and Morgan 2005). A more detailed effort is underway to document fisheries interactions with Marbled Murrelets (D. Bertram and K. Charleton, Environment Canada), but results from this study are not yet available. The U.S. Fish and Wildlife Service (2009) also considered derelict fishing gear as an entanglement risk to murrelets.

Murrelets are vulnerable to changes in prey stocks if the prey species are fished commercially. Currently, the main overlap is with Pacific Herring (reviewed by Piatt *et al*. 2007). Over-fishing of herring and other schooling fish in the Strait of Georgia has been linked to declines in murrelets over the past century (Norris *et al*. 2007). Stocks of herring have recovered in some coastal areas but not others and the effects of current harvests on murrelets is not known (Piatt *et al*. 2007). There is no commercial fishery for the other main prey fish, the Pacific Sand Lance, but sand lance (also known as sand eels) are fished commercially in other parts of the world and if initiated in B.C. a sand lance fishery would most likely have some effect on Marbled Murrelets. Similarly, the current levels of fishing for euphausiids in B.C. seem unlikely to impact murrelets (Piatt *et al*. 2007) but if this fishery increased to meet the demands to feed pen-raised salmon then murrelets might be affected.

Aquaculture

Potential conflicts between seabirds and aquaculture through disturbance and habitat changes were identified in Sechelt-Sunshine Coast, Campbell River-Desolation Sound, Barkley Sound-Alberni Inlet, Clayoquot Sound, Kyuquot Sound, and Queen Charlotte Strait, but in most coastal areas it was difficult to assess the degree of interference (Booth and Rueggeberg 1989; Rueggeberg and Booth 1989). Marbled Murrelets are regularly found in all of these identified areas, either seasonally or year-round. The numbers and size of aquaculture facilities in the British Columbia coast has increased greatly since the 1980s. In sheltered waters off Vancouver Island and the southern mainland the number of shellfish farms has increased by 50%, farm size has increased and the total area of tenures has more than doubled since 1989 (Table 14). Although mussel-feeding ducks appear to benefit from these farms (Žydelis *et al*. 2009) they are more likely to have negative consequences for fish-eating species like the murrelet. Impacts include displacement from foraging habitat plus disturbance by boat traffic from the farms. For example, the shellfish tenure areas in Malaspina, Okeover, Theodosia, and Lancelot Inlets, used by many breeding murrelets, take up about 8% of the water surface area (Žydelis *et al*. 2009).

Table 14. Changes in the number and tenure area of shellfish aquaculture farms in sheltered waters of B.C.
Analysis by H.A. Ford and J. Cragg (University of Victoria) using GIS data provided by the B.C. Ministry of Environment (URL: http://www.env.gov.bc.ca/omfd/fishstats/aqua/shellfish.html)

	Vancouver Island-South Mainland Coast		**Desolation Sound-Campbell River, Sechelt-Sunshine Coast, NW Georgia Strait Area**	
Measure	1989	2008	1989	2008
No. of farms	365	549	301	372
Total tenure area (ha)	1462	3334	n/a	2439
Mean farm area (ha)	5.4	6.5	n/a	6.6

Disturbance by Boats

Several studies showed that Marbled Murrelets are easily disturbed by the passage of boats, especially fast recreational craft. Negative responses to boats include disruption of feeding, flight away from foraging areas, and failure to retain fish being held for nestlings (reviewed by Piatt *et al*. 2007; Hentze 2006; Bellefleur *et al*. 2009). Repeated disturbance by boats is likely to cause murrelets to avoid otherwise suitable foraging habitat, which might have long-term population consequences (Bellefleur *et al*. 2009). With increasing recreational boat traffic in many parts of coastal B.C., this might be a significant problem, especially in the Salish Sea, southwest Vancouver Island, Barkley Sound and Clayoquot Sound.

Energy Developments and Power Lines

There is a large increase in the number of wind turbine farms and independent "run-of-the-river" hydroelectric installations being built or proposed in B.C. (Clean Energy BC 2011). Murrelets, like many other seabirds (Chamberlain *et al*. 2006; Larsen and Guillemette 2007), are likely to avoid wind farms built in coastal waters and might lose foraging habitat. There are currently no offshore wind farms in place or being constructed in B.C. but large farms are proposed for Hecate Strait off Haida Gwaii. The likely impacts of these installations are not known although there are studies underway to assess these risks in Hecate Strait. There are no tidal power generating plants in B.C. waters but the west coast of Vancouver Island has been identified as having "some of the best tidal energy potential in the world" (Clean Energy BC 2011). If built, these plants might impact the nearshore foraging areas of murrelets.

Onshore wind turbines and run-of-the-river hydroelectric schemes are likely to have a negative impact on murrelets if these are built in coastal regions overlapping with nesting habitat. There are currently 35 small hydroelectric facilities operating in coastal areas in B.C. and others in advanced planning (Clean Energy BC 2011). Some of these run-of-the-river projects involve constructions of tens to hundreds of km of roads and transmission lines through areas where murrelets might nest (e.g., East Toba and Montrose Creek hydro project). A large wind farm project (66 turbines) was approved for Knob Hill near Cape Scott on northeast Vancouver Island but has not yet been built (Sea Breeze Power 2011). Negative impacts to murrelets from these wind and hydro power projects could include: risk of collision with turbines and the power lines strung across the murrelets' flight paths; loss of nesting habitat from clearing of roads, power installations and transmission corridors; increased fragmentation of the remaining nesting habitat; and increased populations of corvid predators attracted to human activities and permanently cleared forest land. Some hydroelectric and wind turbine proponents are studying the potential impacts to Marbled Murrelets of their proposals but no results have been released to date.

Climate Change

It is not known how Marbled Murrelets might fare in B.C. under future climate regimes. Given that the species was fairly common further to the south in Oregon and Washington before industrial logging, warmer temperatures *per se* might not be an issue. As reviewed above, there do not appear to be any obvious negative effects linked with the predicted changes of the dominant tree species or distributions of the coastal terrestrial biogeoclimatic zones. Possible negative effects in the forest nesting habitat might include reduced growth of canopy epiphytes providing nest substrates.

Changes in the marine environment are likely to have a more direct impact, but again the net impacts on murrelets remain speculative and might not necessarily be negative (see review by Piatt *et al*. 2007).

Diseases and Biotoxins

Recent blooms of the dinoflagellate *Alexandria* spp. (one species responsible for paralytic shellfish poisoning) and *Pseudo-nitszchia* sp. (producing demoic acid) have caused widespread mortality in nearshore seabirds in the Pacific Northwest in recent years and could cause increased risks to murrelets in a warmer climate (reviewed by McShane *et al*. 2004; U.S. Fish and Wildlife Service 2009). In fall 2009, thousands of seabirds came ashore from northern Washington through central California as a result of a bloom of *Akashiwo sanguinea* (see numerous news reports; e.g., The Oregonian 28 October 2009). This alga, which blooms in warm, low-salinity water, produced foam-like surfactants (detergent-like substances) that cloaked seabirds and reduced their waterproofing causing them to become hypothermic and waterlogged (Jessup *et al*. 2009).

Overall Assessment of Threats

The B.C. Conservation Framework is a quantitative assessment of threats, based on the best available information. This is a modified version of the IUCN/NatureServe Conservation Status Assessments for assessing extinction risk (Master *et al*. 2009). The calculation of threat impacts is relatively insensitive to the levels of uncertainty that usually characterize data on most threatened wildlife. Appendix 2 shows the threats assessment worksheet applied to the Marbled Murrelet (jointly by David Fraser, B.C. Conservation Data Centre and the author, Alan Burger). Although most of the perceived threats to Marbled Murrelets rank as Low, except for loss of nesting habitat within old forests which ranks as Medium, the cumulative overall threat impact is calculated to be High (Appendix 2).

PROTECTION, STATUS, AND RANKS

The following are the status ranks allocated to the Marbled Murrelet by NatureServe (2009) with the provincial status revised in 2010:

- Global Status – G3G4 (12 January 2001);
- Rounded Global Status – G3 (Vulnerable);
- National Status (Canada) – N2 (Imperiled; 11 January 2000).
- Provincial Status (British Columbia) – S3B (vulnerable), S3N (vulnerable) (B = breeding population; N = non-breeding population; status changed from S2B, S4N in April 2010; BC Ministry of Environment, URL: http://www.env.gov.bc.ca/atrisk/changes.htm)
- National Status (United States) – N3N4
- State Status – Alaska (S2S3), California (S1), Oregon (S2), Washington (S3)

The IUCN Red List status for the Marbled Murrelet is EN – Endangered (BirdLife International 2009). The Marbled Murrelet was listed as Threatened by COSEWIC in 1990 and 2000 and added to the federal *Species at Risk Act* (SARA) when that came into force in 2003 (see below). Provincially, the Marbled Murrelet is on the British Columbia Blue List and is included as an "Identified Species" under the Identified Wildlife Management Strategy provisions of the *B.C. Forest and Land Practices Act* (see below).

British Columbia has introduced a new Conservation Framework to more objectively assess conservation priorities for all taxa within the province (British Columbia Ministry of Environment 2008; Bunnell *et al*. 2009). Overall the Marbled Murrelet ends up in the Highest priority category.

Legal Protection and Status

Migratory Birds Convention Act

This federal act affords protection to the bird itself and active nest sites, but not nesting and foraging habitats.

Species at Risk Act (SARA; effective 2003)

The Marbled Murrelet is included in Schedule 1 of SARA. A SARA-compliant Recovery Strategy was drafted by the Marbled Murrelet Recovery Team in 2006, but the strategy and its associated Action Plans had not been implemented by June 2011. The recovery team's recommendations were published earlier (CMMRT 2003).

British Columbia Forest and Range Practices Act (FRPA; effective 2004)

Section 5 requires forest stewardship plans to be consistent with land use objectives set by the B.C. government, but is not routinely applied to managing Marbled Murrelet nesting habitat. Section 7 further defines objectives in terms of the amount of area, distribution of areas and attributes of areas for the survival of species at risk under the FRPA. Marbled Murrelet are included in Section 7 Notices in most coastal forest districts and receive priorities under forest stewardship planning within forest habitat classified as Non-Contributing Land Base (i.e., the less valuable timber lands).

Identified Wildlife Management Strategy (IWMS)

This applies to species requiring special management attention under the FRPA, including Marbled Murrelets. Guidelines for managing the Marbled Murrelet as an identified species have been published (British Columbia Ministry of Environment 2004). Limitations on the allocation of no more than 1% of timber-harvesting land base for IWMS wildlife habitat areas (WHAs) and the slow implementation of WHAs has been repeatedly criticized by the British Columbia Forest Practices Board (2010).

The Old Growth Order

This order (British Columbia Government 2004) establishes provincial old growth objectives and Old Growth Management Areas (OGMAs) to maintain biodiversity values and ecosystem representation. The January 2004 *Marbled Murrelet Letter of Clarification* from the Chief Forester and Assistant Deputy Ministers of other responsible ministries clarifies that OGMAs should meet Marbled Murrelet habitat requirements wherever possible.

British Columbia Wildlife Act

Section 34 provides protection for birds, eggs and occupied nests. Section 5 of the act allows designation of land in a wildlife management area or wildlife sanctuary. Marbled Murrelets are not currently (October 2010) listed under the BC Wildlife Act as an endangered or threatened species.

British Columbia Forest Act

Part 13 of the Forest Act covers cutting permits, road permits, timber sale licences, free use permits, licences to cut, special use permits, operational plans, and management plans.

British Columbia Land Act

The Land Act is the main legislation governing the disposition of provincial Crown (i.e., public) land in British Columbia and is used to implement major land use decisions (see Land Use Planning section below). These processes are responsible for maintaining large areas of likely murrelet nesting habitat especially in Haida Gwaii, and the Northern and Central Mainland conservation regions.

Other federal and provincial legislation

Marbled Murrelets and their habitat are also covered by several other British Columbia laws. Considerable nesting habitat is maintained under the provisions of the *B.C. Parks Act*, the *Protected Area of B.C. Act* and the *Ecological Reserve Act* (all included in the protected areas tally in Table 4). The *British Columbia Private Managed Forest Land Act* (2003) contains provisions to facilitate protection of critical wildlife habitat on private forest land, but does not appear to have been applied to murrelet nesting habitat on private lands (D. Lindsay, TimberWest, pers. comm., April 2010).

At sea, protection against pollution and loss of fish habitat is provided under the Canada and *British Columbia Fisheries Act*. The *Canada National Marine Conservation Areas Act* was passed in 2002 to allow marine protected areas. There are no marine protected areas currently in place that affect Marbled Murrelets, but the Gwaii Haanas National Marine Conservation Area is nearing completion (R. Vennesland, Parks Canada, pers. comm., April 2010). Marbled Murrelets nesting and foraging within Pacific Rim National Park Reserve, Gwaii Haanas National Park Reserve and the Gulf Islands National Park Reserve are protected by the various acts which established these parks.

<u>Conclusions on legal protection and status</u>

Although there are numerous possible protective mechanisms for Marbled Murrelet habitat there has not been a review of policy to determine which mechanisms would best meet recovery objectives for this species.

Non-Legal Status and Ranks

<u>Land use planning</u>

Strategic land use plans are in place or being finalized over much of the range of Marbled Murrelet. The Strategic Land Use Agreement for Haida Gwaii (British Columbia Government 2007) includes 225,000 ha of protected areas and increased to 67% the proportion of nesting habitat protected there (Table 4). Land use decisions for the Central Coast and North Coast announced in 2006 resulted in new and proposed conservancies and parks and the implementation of ecosystem-based management (EBM) for much of these coastal lands (British Columbia Government 2008). The new confirmed and proposed protected areas have contributed to protection covering about 30% of habitat in both regions (Table 4; Mather *et al*. 2010). The Vancouver Island Land Use Plan includes provisions that extend old growth retention targets in the timber harvesting land base in specific areas to meet Marbled Murrelet needs (British Columbia Government 2000).

<u>Sustainable forest management certification</u>

Forest certification programs include provisions for environmental standards (e.g., CAN/CSA Z809 of the Canadian Standards Association; Forest Stewardship Council; Programme for Endorsement of Certification Schemes; and Sustainable Forest Initiative).

Habitat Protection and Ownership

The bulk of Marbled Murrelet nesting habitat (probably >80% of the area) falls within Crown Land managed by the B.C. provincial government, although this varies by conservation region. For example, within the Eastern Vancouver Island Conservation Region, the majority (about 65%) of the habitat is in privately managed forest lands (M. Mather pers. comm., 2012). The B.C. Ministry of Forests, Lands and Natural Resource

Operations (MoFLNRO) has the primary responsibility for the management of these public forests, but the B.C. Ministry of Environment is responsible for managing habitat within provincial parks and for establishing some protected habitat such as Wildlife Habitat Areas (WHAs). Significant tracts of nesting habitat are also on federally administered land, notably Pacific Rim National Park Reserve (southwest Vancouver Island) and Gwaii Haanas National Park Reserve (Haida Gwaii).

Areas of Nesting Habitat Protected

Based on the MoE BC Model (Mather *et al*. 2010) and using data available in June 2011 there are approximately 681,785 ha of habitat protected within the 0-50 km inland zone (34.4% of estimated total habitat; Table 4). The proportion protected within the 0-30 km zone (more likely to be used by murrelets) is similar (631,814 ha or 34.6%; Table 4). These estimates cover all categories of protected areas, including national and provincial parks, ecological reserves, Wildlife Habitat Areas (WHAs), conservancies established under strategic land-use agreements in the north and central coast and Haida Gwaii, Old-growth Management Areas (OGMAs), ungulate winter range, and other protected land (see footnote to Table 4). The proportion of habitat protected within each of the six conservation regions ranges from 16% (0-30 km; East Vancouver Island) to 67% (Haida Gwaii) with the remaining regions in the 22-34% range for both 0-30 and 0-50 km zones (Table 4). The currently protected areas provide half of the recovery team's recommended coastwide total (70% of the potential habitat available in 2002; CMMRT 2003).

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BIOGRAPHICAL SUMMARY OF REPORT WRITER

Alan Burger has a PhD in Zoology from the University of Cape Town. He is a self-employed consultant and Associate Professor (Adjunct) in Biology at the University of Victoria. He has done research on seabirds for over 30 years, focusing on the Marbled Murrelet for the past 20 years. His work on the murrelet covers both marine (foraging) and inland (nesting) habitats and he has published 28 peer-reviewed articles on the species. He has served on the Marbled Murrelet Recovery Team since its inception in 1990 (with a sabbatical break in 1999-2000) and on the Marbled Murrelet Nesting Habitat Recovery Implementation Group since 2004. Burger has drafted many biological reviews, recovery documents, management plans and methodology manuals on the murrelet for governments, the Marbled Murrelet Recovery Team, and other agencies.

COLLECTIONS EXAMINED

No collections were examined for Marbled Murrelets.

Appendix 1. Analysis of Christmas Bird Count data for the Marbled Murrelet in British Columbia

Background

In the absence of a large series of systematic census data, there have been several attempts in the past to use data from the Christmas Bird Counts (CBC) for trend analysis in Marbled Murrelets. Christmas Bird Counts are made by volunteer birders within fixed circles 15 miles (24.2 km) in diameter during a fixed winter period (15 December through 5 January). All individual birds that are encountered are reported and to adjust for observer effort the data are usually analysed as birds per party-hour (Niven *et al*. 2009).

As part of their "State of the Birds" reporting, the Audubon Society analysed the data from count circles in British Columbia and four U.S. states in which the Marbled Murrelet regularly occurred (Niven *et al.* 2009). Over a 40-year period (1966-2005) these data showed an overall declining trend averaged at -0.87% per year (95% confidence intervals -3.4% to +1.7%) (Audubon Society 2009). Two analyses of the Marbled Murrelet CBC data from Alaska produced contradictory conclusions suggesting that CBC data might be poor indicators of population trends in this species (Piatt 1998, Hayward and Iverson 1998).

In British Columbia, Rodway *et al*. (1992) summarized the CBC data for Marbled Murrelet from 22 coastal count areas (1987-1988) and concluded that these data showed no clear trends. Norris *et al*. (2007) used annual sums of CBC data (birds per party hour) from 11 sites in the Georgia Basin as an index of abundance for Marbled Murrelets. They then compared the smoothed data with isotopes in feathers and the estimated proportions of fish in diets derived from these isotopes. Although they reported significant correlations between CBC-derived indices and isotope signatures, Norris *et al*. (2007) made some puzzling site selections to represent the Georgia Basin. Their samples include one site which is not normally considered part of the Georgia Basin (Victoria) and two sites with very few years of data (Lasqueti Island and Nanoose Bay, both sampled since 2002), but left out several sites which had long data series and comparably high murrelet counts (Deep Bay, counted since 1976; Ladner: since 1970; Pender Islands, since 1971). As reported in the main body of this report, Bower (2009) used CBC data from the Salish Sea (Georgia Basin, Strait of Juan de Fuca and Puget Sound) to compare average counts in 1975-1984 with those from 1998-2007.

Methods

A new analysis of the British Columbia CBC data for the Marbled Murrelet was undertaken here. The goal was to detect trends over the past 30-40 years. The count data (number of birds per count and number of birds per party-hour) were downloaded for 26 count circles (Table A1-1) from the Audubon Society database (http://audubon2.org/cbchist/). Counts with fewer than 6 years of data or that had maximum murrelet counts of less than 10 birds were excluded. In a few cases (< 5 count-years overall) there were missing data on survey effort—in these cases the number of party-hours was estimated by averaging the data from preceding and subsequent years.

Because the years of sampling and the densities of birds (represented by birds per party-hour) varied greatly among the sites it was not possible to simply pool the data for trend analysis without creating a biased database. Consequently each site with sufficient data was first analyzed independently (Table A1-1), and then pooled data were tabulated using only those sites which had consistent sampling (few years missed) and similar years of coverage. Nearly all of these long-term data come from the Salish Sea region, and these data were analyzed for two periods (1972-2008, 11 sites; and 1978-2008, 14 sites). Linear regression was used to detect trends—perusal of the raw data showed large fluctuations in counts and the decision was made to use the simplest tool likely to reveal trends.

Results and Discussion

Of the 26 B.C. count sites considered, one showed a significant increase in murrelet numbers (Bamfield), nine showed significant declines (Nanaimo, Nanoose Bay, Pender Harbour, Pender Islands, Sooke, Squamish, Vancouver, Victoria, and White Rock) while the remaining 16 sites showed no significant trends (Table A1-1). For all sites the counts varied tremendously from year to year (in part reflecting boat-based sampling effort which is strongly weather-dependent) making it difficult to detect long-term trends.

The pooled long-term Salish Sea samples showed declining trends (Figure A1-1) but these were not statistically significant for either the 1972-2008 period (11 sites) or the 30-year 1978-2008 period (14 sites) (Table A1-1). The extreme variability of the CBC data are illustrated in these graphs; the peaks in 1975 and 1988 are both due to unusually high counts in a single count area (2125 murrelets in Ladner in 1975 and 1849 murrelets in Sunshine Coast in 1988). It was not possible to reliably measure the rates of decline per year.

Conclusions

Because of the inconsistencies in observer effort, observer identification skills, boat use, and viewing conditions, Christmas Bird Counts cannot be a substitute for systematic professionally undertaken censuses of any marine bird. CBC count circles (15 miles [24.2 km] in diameter and usually centred on a town or city) are generally not favourably placed to count Marbled Murrelets and few count areas overlap with significant wintering populations in British Columbia. Add to this the natural variations in the distributions and movements of a highly mobile species like the Marbled Murrelet and one has to approach the use of CBC data with great caution. Nevertheless, this analysis did show significant declines in numbers of Marbled Murrelets per party-hour in nine of the 26 count sites (four of which had less than eight years of data and were unlikely to reveal trends) but only one site with a significant increase. On balance, therefore, the CBC data, although flawed, suggest declines of Marbled Murrelet wintering in British Columbia over the past 30-40 years.

Table A1-1. Summary of trend analysis for Christmas Bird Count data on Marbled Murrelets in British Columbia from 1969 to 2009. Raw count data from the Audubon Society (http://audubon2.org/cbchist/).

Count area	First year	No. years (post 1969)	Regression			Adjusted R-square	Trend	Slope (if significant trend)
			df for F	F-value	P-value			
Anacortes-Sidney*	1971	30	1, 29	0.018	0.894	0.001	No trend	-
Bamfield	1986	22	1, 20	9.185	0.007	0.280	Increase	+0.1342
Campbell River*	1972	33	1, 31	0.015	0.905	0.032	No trend	-
Comox*	1961	36	1, 34	1.237	0.274	0.007	No trend	-
Deep Bay*	1975	33	1, 31	0.413	0.525	0.019	No trend	-
Duncan*	1970	35	1, 33	1.420	0.242	0.012	No trend	-
Kitimat	1974	31	1, 29	0.182	0.673	0.028	No trend	-
Ladner*	1957	40	1, 38	1.769	0.191	0.019	No trend	-
Lasqueti Island	2002	7	1, 5	0.617	0.468	0.068	No trend	-
Masset	1983	26	1, 24	0.990	0.330	0.004	No trend	-
Nanaimo*	1972	37	1, 35	6.263	0.017	0.128	Decrease	-0.0083
Nanoose Bay	2002	7	1, 5	10.479	0.023	0.612	Decrease	-0.2878
Parksville Qualicum	1991	18	1, 16	0.325	0.577	0.042	No trend	-
Pender Harbour	1991	18	1, 16	7.664	0.014	0.282	Decrease	-0.3156
Pender Islands*	1970	39	1, 37	13.535	0.001	0.248	Decrease	-0.0301
Prince Rupert	1980	27	1, 25	0.664	0.423	0.013	No trend	-
Port Alberni	1992	18	1, 16	0.254	0.621	0.049	No trend	-
Rose Spit	1989	6	1, 4	0.008	0.932	0.247	No trend	-
Sayward	1973	8	1, 6	2.078	0.200	0.133	No trend	-
Skidegate	1982	27	1, 25	1.553	0.224	0.021	No trend	-
Sooke*	1983	21	1, 19	7.398	0.014	0.242	Decrease	-0.0299
Squamish*	1980	28	1, 26	14.272	0.001	0.330	Decrease	-0.0469
Sunshine Coast*	1979	29	1, 27	0.986	0.329	0.005	No trend	-
Vancouver*	1957	38	1, 36	19.956	0.000	0.339	Decrease	-0.0151
Victoria*	1958	40	1, 38	4.614	0.038	0.085	Decrease	-0.0038
White Rock*	1971	37	1, 35	5.575	0.024	0.113	Decrease	-0.0015
Salish Sea sites* (n = 11)	1972-2008	37	1, 35	1.872	0.180	0.024	No trend	-
Salish Sea sites* (n = 14)	1978-2008	30	1, 28	2.872	0.101	0.061	No trend	-

Notes: The year shown indicates the first year for each Christmas count period (e.g., 1970 means the 1970-1971 Christmas Count period).
* The Salish Sea sites summarized in the last two rows are indicated with an asterisk

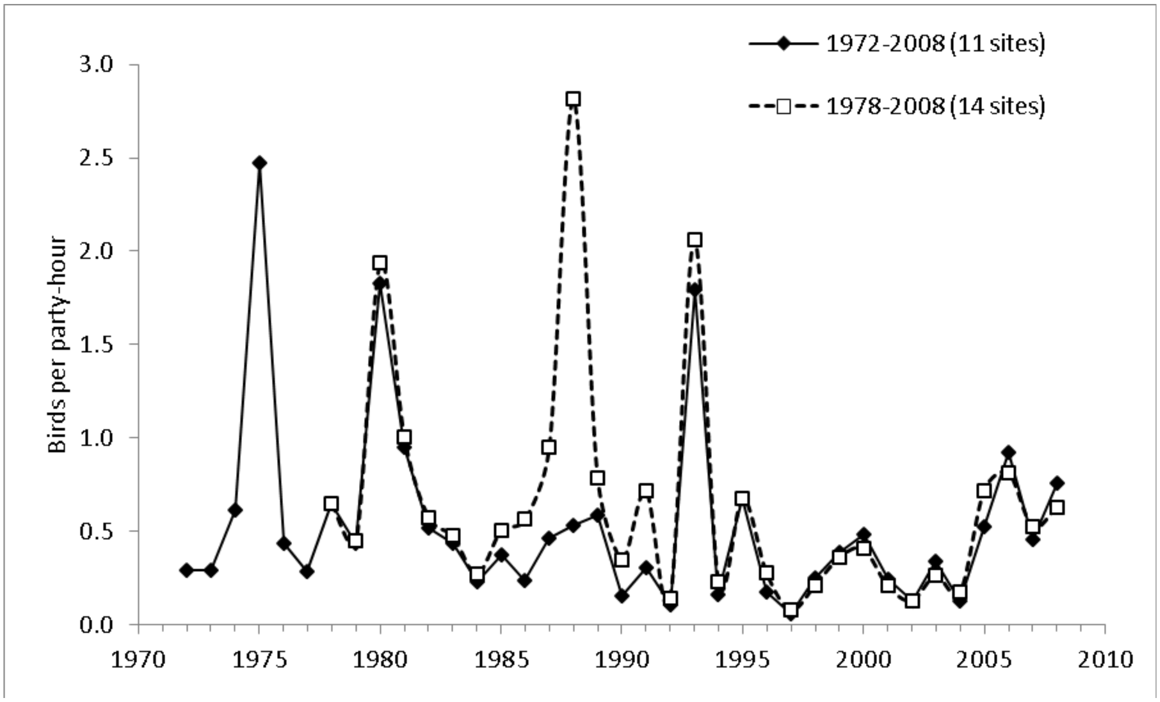

Figure A1-1. Mean counts (birds per party-hour) of Marbled Murrelets in Christmas Bird Counts made at sites in British Columbia within the Salish Sea area (Straits of Georgia and Juan de Fuca) which provided the longest time series (1972-2008; 11 sites) and a slightly larger sample of sites which covered a 30-year period (1978-2008; 14 sites). Neither data set shows a statistically significant trend.

Appendix 2. The modified IUCN/NatureServe Threats Assessment Worksheet applied to the Marbled Murrelet

Notes: Although each of the separate threats was considered Low or Medium, their cumulative impact was rated by the model as High. The Calculated Overall Threat Impact is automatically generated by the internal calculations set by IUCN and NatureServe. David Fraser (BC Conservation Data Centre, Victoria) and Alan Burger (University of Victoria) jointly selected the values entered into this table for the Marbled Murrelet.

THREATS ASSESSMENT WORKSHEET						
Species or Ecosystem Scientific Name	Marbled Murrelet, *Brachyramphus marmoratus*					
Element ID			**Elcode**			
Date (Ctrl + ";" for today's date):						
Assessor(s):	Alan Burger		David Fraser			
References:	see comments, 2012 COSEWIC status report					
Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**			
	Threat Impact		**high range**	**low range**		
	A	Very High	0	0		
	B	High	0	0		
	C	Medium	2	2		
	D	Low	2	2		
	Calculated Overall Threat Impact:		High	High		
	Assigned Overall Threat Impact:		**B = High**			
	Impact Adjustment Reasons:		High threat level. Threats could increase in near future, in particular decisions made in the next few years regarding shipping from BC's north coast could raise the threat from oil spills to a higher category in the next assessment.			
	Overall Threat Comments		Completed by Alan E. Burger and David F. Fraser, October 2009. Refer to COSEWIC status review (draft Nov. 2009) for details. Revised by Fraser April 2012, revisions reviewed by Burger and Marty Leonard.			

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential & commercial development		Negligible	Negligible (<1%)	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	
1.1	Housing & urban areas		Negligible	Negligible (<1%)	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	Applies mainly to proposed housing developments on Vancouver Island, but most of that habitat is already second growth and threat covers less than 1% of MAMU habitat in next 10 years.
1.2	Commercial & industrial areas		Negligible	Negligible (<1%)	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	Development along the BC North coast associated with commercial port development may impact very small amounts of MAMU breeding habitat.
1.3	Tourism & recreation areas						
2	Agriculture & aquaculture	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						
2.4	Marine & freshwater aquaculture	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Marine aquaculture (both shellfish and finfish) displaces birds from nearshore foraging habitat.
3	Energy production & mining		Not a Threat (in the assessed timeframe)	Small (1-10%)	Serious (31-70%)	Low (Possibly in the long term, >10 yrs)	
3.1	Oil & gas drilling		Not a Threat (in the assessed timeframe)	Small (1-10%)	Serious (31-70%)	Low (Possibly in the long term, >10 yrs)	Not now but in the future if offshore exploration and extraction permitted.
3.2	Mining & quarrying						
3.3	Renewable energy	D	Low	Restricted (11-30%)	Moderate (11-30%)	Moderate (Possibly in the short term, < 10 yrs)	Run of river and wind power transmission corridors could be an issue depending on the number that become operational
4	Transportation & service corridors		Negligible	Negligible (<1%)	Serious (31-70%)	Moderate (Possibly in the short term, < 10 yrs)	
4.1	Roads & railroads						
4.2	Utility & service lines		Negligible	Negligible (<1%)	Moderate (11-30%)	Moderate (Possibly in the short term, < 10 yrs)	Utility corridors associated with run of river power production, power lines to service oil and gas production, and proposed port facilities.
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use	C	Medium	Restricted (11-30%)	Extreme (71-100%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting	C	Medium	Restricted (11-30%)	Extreme (71-100%)	High (Continuing)	Literature reviewed in this status report. Loss of nesting habitat from clearcut logging and associated roadbuilding is the primary threat to nesting murrelets.
5.4	Fishing & harvesting aquatic resources		Not a Threat (in the assessed timeframe)	Small (1-10%)	Slight (1-10%)	Low (Possibly in the long term, >10 yrs)	Murrelets might be impacted more if commercial fishing of sand lance or euphausiids (for fish food) became widespread.
6	Human intrusions & disturbance	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	
6.1	Recreational activities	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Disturbance from recreational boat traffic (Bellefleur *et al.* 2009)
6.2	War, civil unrest & military exercises						
6.3	Work & other activities	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Disturbance from commercial boat traffic expected to increase if oil and liquefied natural gas shipping from the north coast goes ahead. North coast areas affected have high concentrations of Marbled Murrelets.
7	Natural system modifications						
7.1	Fire & fire suppression						
7.2	Dams & water management/use						dams associated with run of river projects included in 3.3
7.3	Other ecosystem modifications						
8	Invasive & other problematic species & genes		Not a Threat (in the assessed timeframe)	Large - Small (1-70%)	Slight (1-10%)	Low (Possibly in the long term, >10 yrs)	
8.1	Invasive non-native/alien species						
8.2	Problematic native species		Not a Threat (in the assessed timeframe)	Large - Small (1-70%)	Slight (1-10%)	Low (Possibly in the long term, >10 yrs)	Toxic algal blooms can kill seabirds (U.S. Fish & Wildlife Service 2009)
8.3	Introduced genetic material						
9	Pollution	C	Medium	Restricted (11-30%)	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	
9.1	Household sewage & urban waste water						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.2	Industrial & military effluents	C	Medium	Restricted (11-30%)	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	Oil spills a threat, this could increase if offshore oil extraction proceeds it could increase quickly. PCB and other pollutant effects unknown may be significant. The threat from oil spills could increase significantly if proposed oil and liquefied natural gas shipments go ahead, however, the majority of this impact will not be in the next ten years. High mortality associated with oil spills for those individuals that come into contact with oil.
9.3	Agricultural & forestry effluents						
9.4	Garbage & solid waste						
9.5	Air-borne pollutants						
9.6	Excess energy						
10	Geological events						
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						
10.3	Avalanches/landslides						
11	Climate change & severe weather		Not a Threat (in the assessed timeframe)	Restricted (11-30%)	Moderate (11-30%)	Low (Possibly in the long term, >10 yrs)	
11.1	Habitat shifting & alteration		Not a Threat (in the assessed timeframe)	Restricted (11-30%)	Moderate (11-30%)	Low (Possibly in the long term, >10 yrs)	Possible negative impacts on prey availability with warmer oceans.
11.2	Droughts						
11.3	Temperature extremes						
11.4	Storms & flooding						

Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008).