

Chapter 29

Marine Distribution, Abundance, and Habitats of Marbled Murrelets in British Columbia

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Abstract: About 45,000-50,000 Marbled Murrelets (*Brachyramphus marmoratus*) breed in British Columbia, with some birds found in most parts of the inshore coastline. A review of at-sea surveys at 84 sites revealed major concentrations in summer in six areas. Murrelets tend to leave these breeding areas in winter. Many murrelets overwinter in the Strait of Georgia and Puget Sound, but the wintering distribution is poorly known. Aggregations in summer were associated with nearshore waters (<1 km from shore in exposed sites, but <3 km in sheltered waters), and tidal rapids and narrows. Murrelets avoided deep fjord water. Several surveys showed considerable daily and seasonal variation in densities, sometimes linked with variable prey availability or local water temperatures. Anecdotal evidence suggests significant population declines in the Strait of Georgia, associated with heavy onshore logging in the early 1900s. Surveys made between 1979 and 1993 in Barkley and Clayoquot sounds suggest 20-60 percent declines in densities. These changes are correlated with intensive onshore logging, although El Niño effects are probably also involved.

British Columbia is second only to Alaska in the population size of Marbled Murrelets and also in complexity of marine habitats used by these birds. There have been many marine studies of this species in British Columbia, beginning with the pioneering work of Sealy in the Queen Charlotte Islands (Sealy 1973b, 1974, 1975a,c), and the work of Carter and Sealy in southwestern Vancouver Island (Carter 1984, Carter and Sealy 1984, Sealy and Carter 1984). Most studies have been short term (one season or less) and highly localized. Previous province-wide reviews of marine distributions and habitats relied primarily on data from sight record cards, along with a few standardized censuses (Campbell and others 1990, Rodway 1990, Rodway and others 1992). The sight records are not reanalyzed here. This chapter summarizes data on populations, distribution, habitats, and basic biology of the Marbled Murrelet obtained largely from boat surveys.

Abundance and Distribution

Regional and Range-Wide Population Densities

Marbled Murrelets have been recorded from most of the coastal waters of British Columbia (Campbell and others 1990, Rodway 1990, Rodway and others 1992). Current estimates of the provincial population (45,000-50,000 breeding

birds) are extrapolations from relatively few data from 1972 to 1982, mainly counts in high-density areas and transects covering a small portion of coastline (Rodway and others 1992). Between 1985 and 1993 many parts of the British Columbia coast were censused, usually by shoreline transects, although methods and dates varied, making comparisons and extrapolation difficult. Much of the 27,000 km of coastline remains uncensused (fig. 1).

Appendix 1 summarizes censuses for the core of the breeding season (1 May through 31 July). Murrelet densities are given as birds per linear kilometer of transect. It was necessary to convert density estimates from other units in several cases, and this was done in consultation with the original authors, using charts to determine distances travelled. Several authors used strip counts, ranging in width from 300 m (e.g., 150 m on either side of the boat) to 1 km, whereas others reported all birds visible from the boat. Relatively few murrelets are likely to be detected at distances >200 m, even in the sheltered inner waters of British Columbia (Burger, unpubl. data; Kaiser, pers. comm.), and so these differences in technique, while adding to the variability of the data, were not considered to be a major source of error.

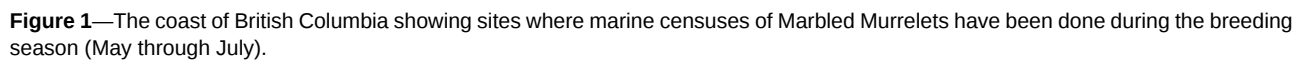
Gaps in Distribution

There are no obvious gaps in the marine distribution in British Columbia, although low densities are associated with several large areas (e.g., eastern Graham Island, eastern Vancouver Island, and many of the large mainland fjords), and this is discussed below. Many areas have not been adequately sampled in the breeding season (much of NW and NE Vancouver Island, the Strait of Georgia, Strait of Juan de Fuca).

Movements and Seasonal Variations in Density

Rodway and others (1992) used an extensive data base of sight record cards in the Royal British Columbia Museum to demonstrate a post-breeding emigration from areas which support large breeding concentrations on the west coast of Vancouver Island and the Queen Charlotte Islands. Habitat shifts were associated with these changes. Apparent densities (mean numbers of birds per sighting record) were higher in spring and summer than in fall and winter in both exposed inshore waters (1-5 km from shore) and nearshore waters (<1 km of shore) of the Strait of Georgia, but the opposite was true for most fjords. This suggests that murrelets leave the exposed outer coast and more exposed areas of large straits in late summer and fall to move into more sheltered waters, including some of the many large fjords on the mainland.

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Shoreline surveys in 1976 and 1977 by Vermeer and others (1983) show similar trends: low densities were found in October and November in most areas in the Queen Charlotte Islands and nearshore waters of the Strait of Georgia (*table 1*). Robertson (1974) reported higher densities of Marbled Murrelets in protected waters off southwest Vancouver Island in summer (11.19 km²) and found low densities in sheltered inlets during winter (range 0.13–1.17/km²). More recently, high densities were found among islands on the northern edge of the Strait of Georgia (Harfenist, pers. comm.) and at some inlets off the strait (Burns, pers. comm.; Prestash, pers. comm.).

Year-round surveys have been made at few sites. Those in Barkley Sound and adjacent waters show that murrelet densities rise in April and decline in late July and August (*fig. 2*). Some of these birds appear to move into Alberni Canal in winter, but the relatively low densities there cannot account for all the Barkley Sound murrelets. In the Strait of Georgia, murrelets were more common between Sidney and Mandarte Island between May and October than in winter, whereas densities were higher in winter in the sheltered fjords of Jervis and Saanich Inlets (*fig. 3*) and also in Puget Sound in Washington (Speich and others 1992; Speich and Wahl, this volume). The winter counts might include birds from exposed western and northern parts of British Columbia.

There is no evidence of a major move into pelagic waters in fall or winter (Burger, unpubl. data; Morgan and others 1991; Vermeer and others 1983, 1989b). Low to moderate densities (0.01 to 1.00 birds per km) were reported from only two areas of open water in winter (in central Hecate Strait, between the Queen Charlotte Islands and Banks Island, and over La Perouse Bank off SW Vancouver Island) (Morgan and others 1991).

Overall, it seems that selected parts of the Strait of Georgia and Puget Sound are the primary wintering areas of murrelets breeding in British Columbia. Small numbers overwinter in most of the coastal waters and more open ocean. Winter samples are, however, very inadequate and other important wintering areas will undoubtedly be discovered.

Habitats Used

Coarse-Scale Comparisons

Marbled Murrelets in British Columbia tend to aggregate within 500 m of land on exposed shores and within 1–5 km in more sheltered waters (Morgan and others 1991; Sealy and Carter 1984; Vermeer and others 1983, 1987). They are relatively rare in more open pelagic water or in the centers of broad straits; consequently these waters were not considered in the following analysis.

Table 1—Seasonal changes in densities of Marbled Murrelets recorded during boat surveys in 1976 and 1977 (Vermeer and others 1983)

Region Census area	Density (birds per km)		
	Pre-breeding (Mar–Apr)	Breeding (May–Jul)	Fall (Oct–Nov)
Strait of Georgia			
Howe Sound	0.74	–	0.09
Mainland coast	3.38	–	0.43
Jervis Inlet	11.02	–	1.46
Bute Inlet	0.63	–	0.00
Northern strait islands	2.60	–	11.82
Neck Point – Campbell River	0.28	–	0.07
Victoria - Neck Point	0.38	–	0.10
E. Queen Charlotte Islands			
Houston - Stewart Channel	–	2.15	0.10
Skincuttle Inlet	–	7.40	0.50
Juan Perez Sound	–	4.72	0.10
Logan Inlet - Darwin Sound	–	1.78	0.04
Cumshewa Inlet - Selwyn Sound	–	0.33	0.08
Skidegate Inlet	–	0.46	0.03
East Graham Island coast	–	–	0.00
N. and W. Queen Charlotte Islands			
N. Graham Island coast	–	0.00	0.02
Masset Inlet	–	0.00	0.10
Naden Harbour	–	0.00	0.04
W. Graham Island coast	–	3.00	–
W. Graham Island inlets	–	0.09	–
W. Moresby Island coast	–	5.16	–
W. Moresby Island inlets	–	0.15	–

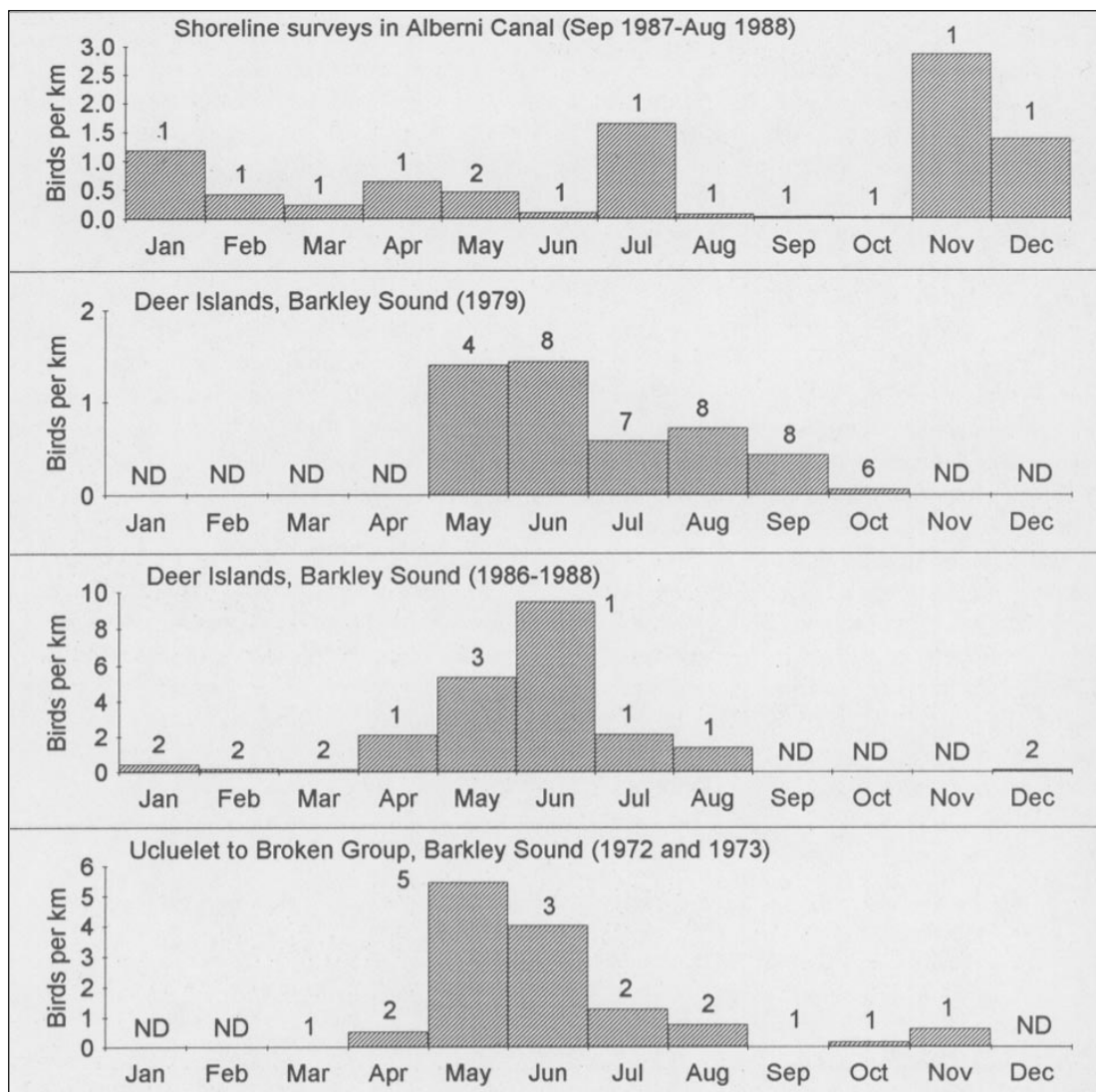


Figure 2—Monthly variations in densities of Marbled Murrelets measured in boat surveys in and near Barkley Sound. Data are from shoreline surveys in the Alberni Canal (Vermeer and Morgan 1992), along fixed routes through the Deer Islands in 1979 (Porter 1981) and 1986-1988 (Burger 1994), and along a fixed route between Ucluelet and the Broken Group islands (Hatler and others 1978). Numbers above columns show numbers of surveys; ND = no data.

Data from the breeding season (generally 1 May through 31 July) in 82 sample areas (some overlapping) show marked variations in density (*fig. 4; appendix 1*). At a very coarse spatial scale (10-100 km), trends include: higher densities on the more sheltered eastern shores of Moresby Island than in the rest of the Queen Charlotte Islands; higher densities off SW Vancouver Island than NW or NE Vancouver Island; and, surprisingly, higher densities along the exposed nearshore coast of western Graham, Moresby, and Vancouver Islands than in the inlets off these coasts. Major concentrations (>5 birds per linear kilometer on average) were found in six regions: the outer west coast of Moresby Island (1976 census); several inlets and bays with many islands on the sheltered coast of Moresby Island

(Long Inlet, Laskeek Bay, Skincuttle Inlet, Poole Inlet and Collison Bay); Okeover Inlet in Desolation Sound on the southern mainland; SE Clayoquot Sound and exposed shores off Long Beach, SW Vancouver Island; several parts of Barkley Sound, SW Vancouver Island; and exposed nearshore water between Barkley Sound and Port San Juan, SW Vancouver Island. This last area supported the highest densities (average >12 birds/km in both 1991 and 1993) for a large stretch of coast (65 km) in British Columbia.

The fjords and sheltered waters of the central mainland coast supported relatively low summer densities overall (average 1.65/km in a 640-km traverse between 15 and 30 May 1990; Kaiser and others 1991), but there were some dense patches (Sheep Passage, and Mussel and Kynoch inlets).

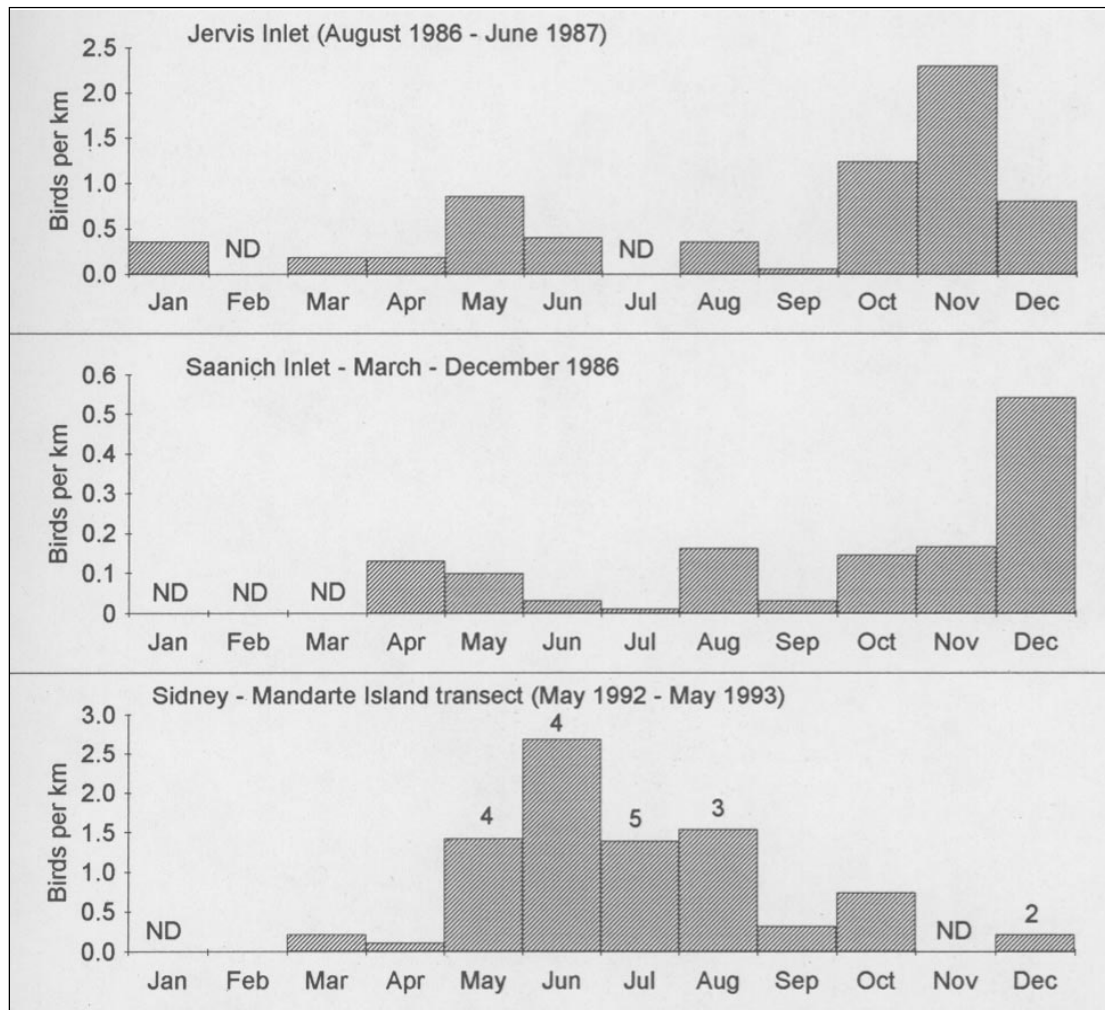


Figure 3—Mean monthly densities of Marbled Murrelets in the Strait of Georgia. Data are from fixed shoreline transects in the fjords of Jervis Inlet (Vermeer 1989), and Saanich Inlet (Morgan 1989), and from a fixed transect among the southern Gulf Islands, between Sidney and Mandarte Island (Clowater, pers. comm.). One survey was done per month, except as otherwise noted. ND = no data.

Stationary counts of Marbled Murrelets at the mouth of Mussel Inlet were high in 1991 (>500 on several days) but lower in 1992 and 1993 (Prestash and others 1992a; Prestash, pers. comm.). These appear to be commuting birds, drawn from an undetermined area, which are channeled through narrow fjords *en route* to feeding areas in more open ocean.

I analyzed coarse-scale habitat use by using the material in *appendix 1*. Habitats were classified as:

- E: exposed ocean (facing the open Pacific or exposed parts of large straits);
- S: sheltered water in large strait or sound;
- I: smaller inlet; or
- F: steep-sided fjord.

Within these categories were subcategories:

- OW: open water (>1 km from shore);
- NW: nearshore water (<1 km from shore);

- IS: among islands offering relatively sheltered water;
- OC: outer coast (for fjords or inlets);
- IC: inner coast (for fjords or inlets).

Each survey was assigned to one or more combinations of categories (see *appendix 1*).

Exceptionally high mean densities in May and June (>5 birds/km) were associated with few habitats: sheltered waters on the east of the Queen Charlotte Islands, SW Vancouver Island, and Desolation Sound; and exposed nearshore waters off SW Vancouver Island (*table 2*). Exceptionally low summer densities (<1 bird/km) were found in sheltered nearshore waters of NW Vancouver Island and fjords of the southern mainland, southern Strait of Georgia and SW Vancouver Island. This analysis is not entirely satisfactory, because some transects covered large areas of diverse habitat, and the habitat classification was not based on detailed field data.

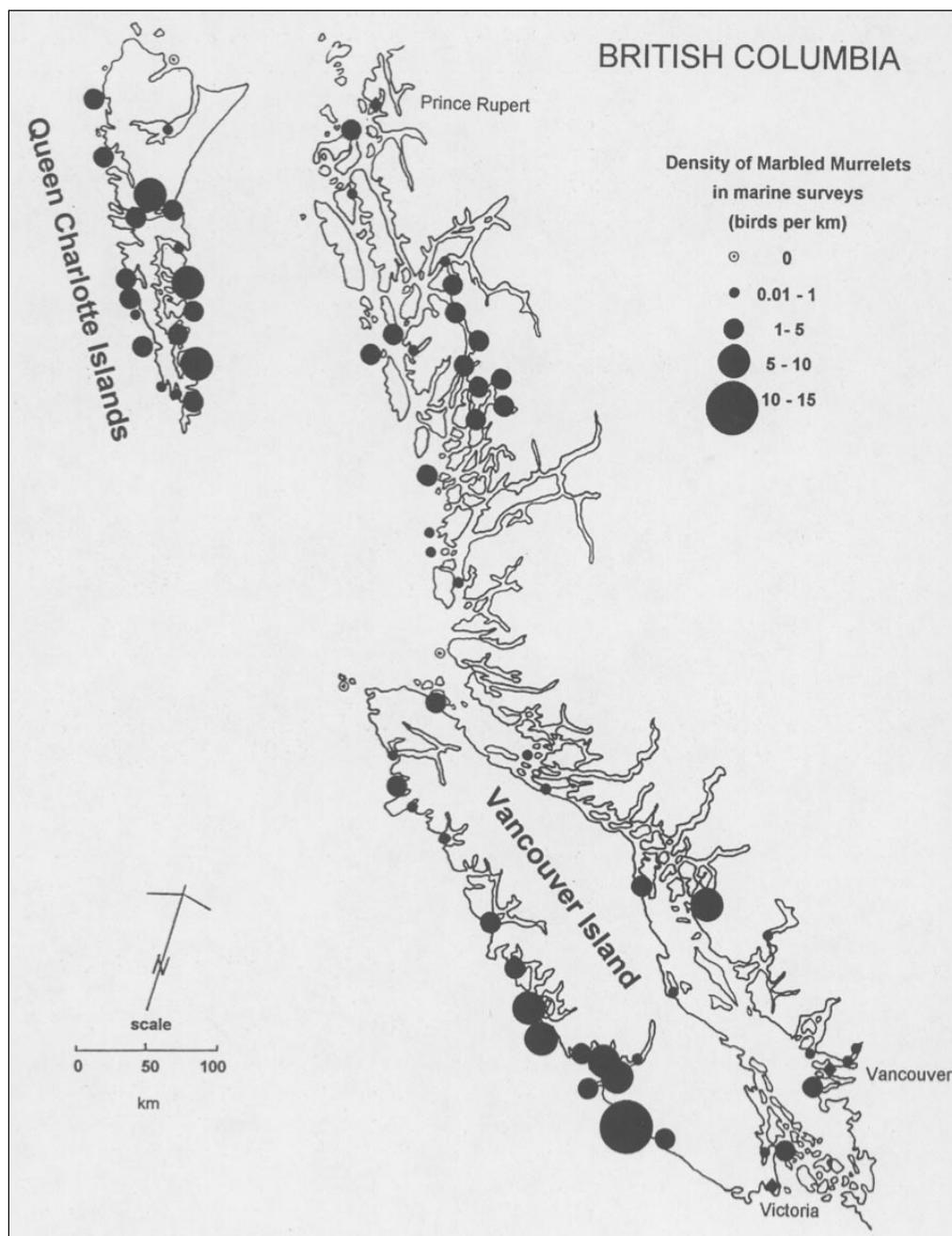


Figure 4—Mean estimates of the densities of Marbled Murrelets during the breeding season (May through July) from marine surveys in British Columbia. The data are shown as birds per km of transect, which was the most compatible measure among the variable studies (see *appendix 1* for details). Most of these data were collected in the 1980s and early 1990s.

Fine-Scale Comparisons

Habitats

Several studies reported murrelet habitat use on a finer spatial scale (0.1-1.0 km). In deep fjords, higher densities were associated with estuaries, shallow bays, and waters off beaches (Morgan 1989, Vermeer 1989, Vermeer and Morgan 1992). This might be linked with the habitat supporting prey species such as sand lance (*Ammodytes hexapterus*), which bury themselves in sand for parts of the day (Field 1988).

Off NW Vancouver Island, murrelets avoided deep open water in fjords, but in shallower, sheltered bays and exposed nearshore seas densities were higher in open water (5.58/km) than in inlets (0.16/km) or channels (0.56/km; Savard and Lemon 1992).

Sealy and Carter (1984) reviewed the distribution of 9955 sightings of murrelets in a grid census of Barkley and Clayoquot Sounds. Murrelet densities were highest in inshore

Table 2—Mean densities of Marbled Murrelets (birds per km) in marine habitats in British Columbia. Data from appendix 1 (see text for selection criteria). Mean $\pm$ s.d. shown, and (in parentheses) range and sample size

Region	Exposed nearshore	Sheltered nearshore and open / islands	Inlets	Fjords
N. and W. Queen Charlotte Islands	2.7 $\pm$ 2.6 (0-5.2; 3)	—	1.1 $\pm$ 1.2 (0-4.0; 12)	—
E. Queen Charlotte Islands	—	5.4 $\pm$ 4.4 (0.9-16.0; 11)	2.6 $\pm$ 0.2 (2.3-2.9; 6)	—
Northern and Central Mainland	1.4 $\pm$ 1.9 (0-4.2; 5)	1.1 $\pm$ 1.6 (0-3.2; 6)	2.1 $\pm$ 1.8 (0.6-4.1; 3)	2.7 $\pm$ 1.7 (0.4-4.9; 8)
Southern Mainland	—	5.11 (-; 1)	—	0.63 (-; 1)
Gulf Islands and S. Strait of Georgia	—	2.08 (-; 1)	—	0.05 (-; 1)
NE. Vancouver Island	—	1.2 $\pm$ 0.6 (0.8-2.2; 5)	—	—
NW. Vancouver Island	3.0 (-; 1)	0.6 $\pm$ 0.6 (0.03-1.3; 4)	—	—
SW. Vancouver Island	8.5 $\pm$ 5.1 (4.1-14.2; 5)	4.5 $\pm$ 1.3 (2.8-6.0; 6)	1.9 $\pm$ 1.4 (0.9-2.9; 2)	0.7 (-; 1)

areas (12.9 birds/km²), relative to more nearshore channel and fjord habitats (6.3 and 0.2 birds/km², respectively). Carter and Sealy (1990) reported lower densities of murrelets in mid-channel, than in shallower, sheltered nearshore waters in Trevor Channel, Barkley Sound. High densities were associated with sheltered, shallow nearshore water and at a sill at the mouth of the channel, where a thermal front was frequently found (Carter 1984).

I summarized data from Carter's (1984) grid and transect surveys in and near Barkley Sound to show the distribution of Marbled Murrelets relative to distance from the shore (*fig. 5*). The distances to shore were estimated from the midpoints of each of 12 sample blocks in Trevor Channel and from the midpoints of each of 16 transect segments in Trevor Channel, Imperial Eagle Channel, and the open sea off Cape Beale (collectively referred to here as the Cape Beale transects). The transect densities were converted from birds/km as given by Carter (1984) to birds/km² by assuming a 250-m transect width on each side of the boat (the same as used in the grid surveys). Murrelets in this area were strongly aggregated within 1 km of the shore, with highest densities 100-600 m offshore (*fig. 5*). Similar results were found in grid surveys in 1992 and 1993 (*fig. 5* inset). Overall, the 1980 data fitted a negative logarithmic curve:

$$\text{density [birds/km}^2\text{]} = 2.438 d^{-1.356}$$

$$(r^2 = 0.735, n = 28, P < 0.001)$$

where d is distance from shore in kilometers. This curve is plotted in *figure 6* for values of $d \geq 100$ m. The density for $d < 100$ m was assumed to be 7 birds/km² from the data in *figure 5*. This model probably applies only to more exposed shores of western Vancouver Island.

A strikingly different distribution pattern emerges from surveys made in Laskeek Bay, Queen Charlotte Islands, from 1989 through 1993 (see *appendix 1* for references). Two types of transects were sampled repeatedly: shoreline transects within 400 m of the surfline and linear transects in open water and among islands, up to 3 km from land. The open water transects often had similar or higher densities than the nearshore ones, and there was considerable variation within and between seasons (*fig. 7*). The variability in these data emphasizes the need for caution in interpreting distribution and census data based on only one or a few seasons.

In 1992 the positions of all Marbled Murrelets in open water at Laskeek Bay were plotted on a chart to the nearest 200 m and, at this fine scale, show the widespread and variable distribution of murrelets relative to the nearest land (*fig. 6*). The pattern in these sheltered waters is quite different from that of the more exposed outer Barkley Sound area shown by the logarithmic model (*fig. 6*). These data clearly illustrate the problems in estimating total densities for any marine area from extrapolations of one or more shoreline transects. The distribution pattern for open and exposed water is quite

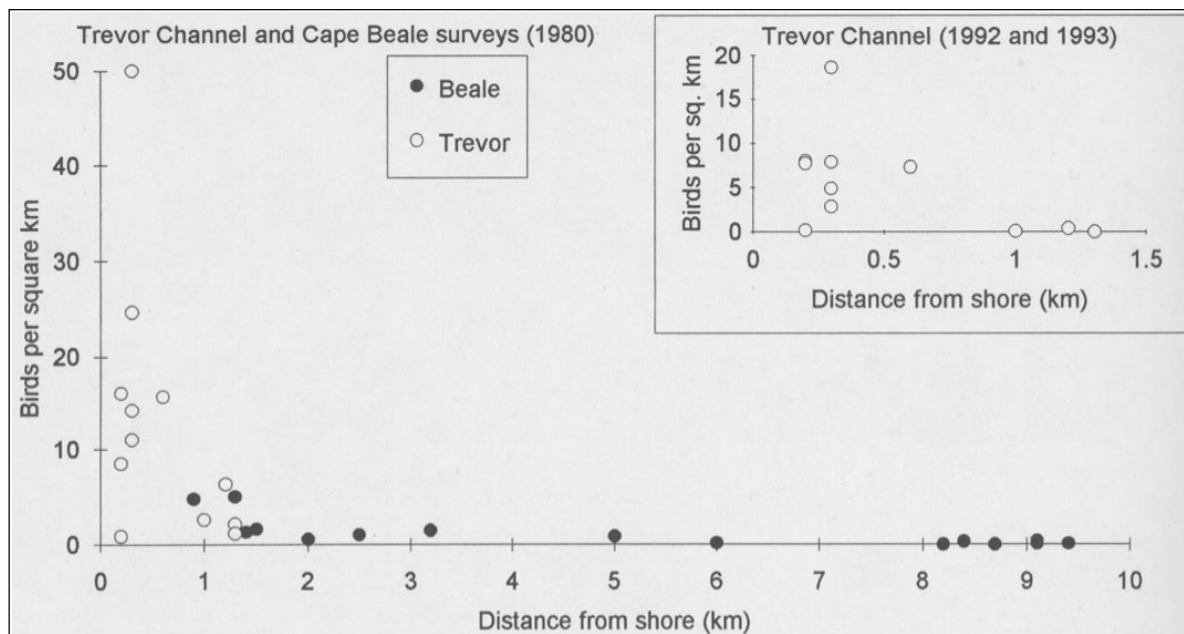


Figure 5—Densities of Marbled Murrelets in and near southern Barkley Sound between 1 May and 31 July in 1980, 1992, and 1993. The main graph shows densities from grid surveys in Trevor Channel and strip transects near Cape Beale in 1980 (Carter 1984). The inset shows densities from grid surveys in Trevor Channel in 1992-1993 (Burger 1994).

different, and the presence of islands and reefs adds further complications (see also Sealy 1975c, Sealy and Carter 1984).

Temporal Patterns

Using repeated grid surveys in Trevor Channel, Barkley Sound, Carter and Sealy (1990) showed that local densities of Marbled Murrelets declined, but clumping increased through the day. Consistent high densities in some quadrats and direct flights by murrelets into these areas at dawn indicated that the birds were returning to predictable feeding sites. Nitinat Lake, a large semi-saline lake adjacent to important forest and marine habitats appears to be used as a staging area for murrelets which leave the forests at dawn and later move to the ocean (Burger 1994).

Effects of Temperature and Salinity

In fjords and channels in Desolation Sound, Kaiser and others (1991) found no correlation between murrelet density and sea surface temperature, and a weak positive correlation with salinity ($r^2 = 0.256$, $n = 20$, $P < 0.05$). Between 6 June and 8 August 1990, the murrelets were often concentrated in areas with strong currents, and densities were negatively but weakly correlated with sea temperature ($r^2 = 0.185$, $n = 15$, $P < 0.05$). Warm water was associated with algal blooms, creating surface turbidity, which might have affected prey densities and the birds' hunting efficiency. The murrelet's primary prey, sand lance, was usually found in clear water. These fish are likely to move to deeper water or become dormant in their burrows in unusually warm water (Field

1988). Murrelet densities declined rapidly in late July as the surface water heated up to near 20° C. Large-scale effects of warm water influxes are described below.

Tidal Patterns and Presence of Rips

The relationship between tides and feeding patterns of Marbled Murrelets in British Columbia is not consistent. Repeated surveys in Barkley Sound (Carter 1984, Carter and Sealy 1990) and Desolation Sound (Kaiser and others 1991) reported no significant changes in murrelet densities with tidal state or tidal flow rate. Aggregations of murrelets at sites with strong tidal flow were reported from Edye Passage and north of Stevens Island, both on the northern mainland (Fuhr, pers. comm.), Hiekish Narrows (central mainland), and Desolation Sound (Kaiser and others 1991), Sechelt Rapids in Jervis Inlet (Vermeer 1989), and Yuculta Rapids between Sonora Island and the mainland (Prestash, pers. comm.). Marbled Murrelets were sparse or absent, however, at strong tidal rips at Malibu Rapids (Jervis Inlet), and Active Pass (Gulf Islands) where many gulls and other birds were feeding (Vermeer 1989, Vermeer and others 1987).

Abundance Related to Feeding and Nesting Habitats

Effects of Prey Availability

There have been no detailed comparisons of murrelet distribution relative to independent measures of prey

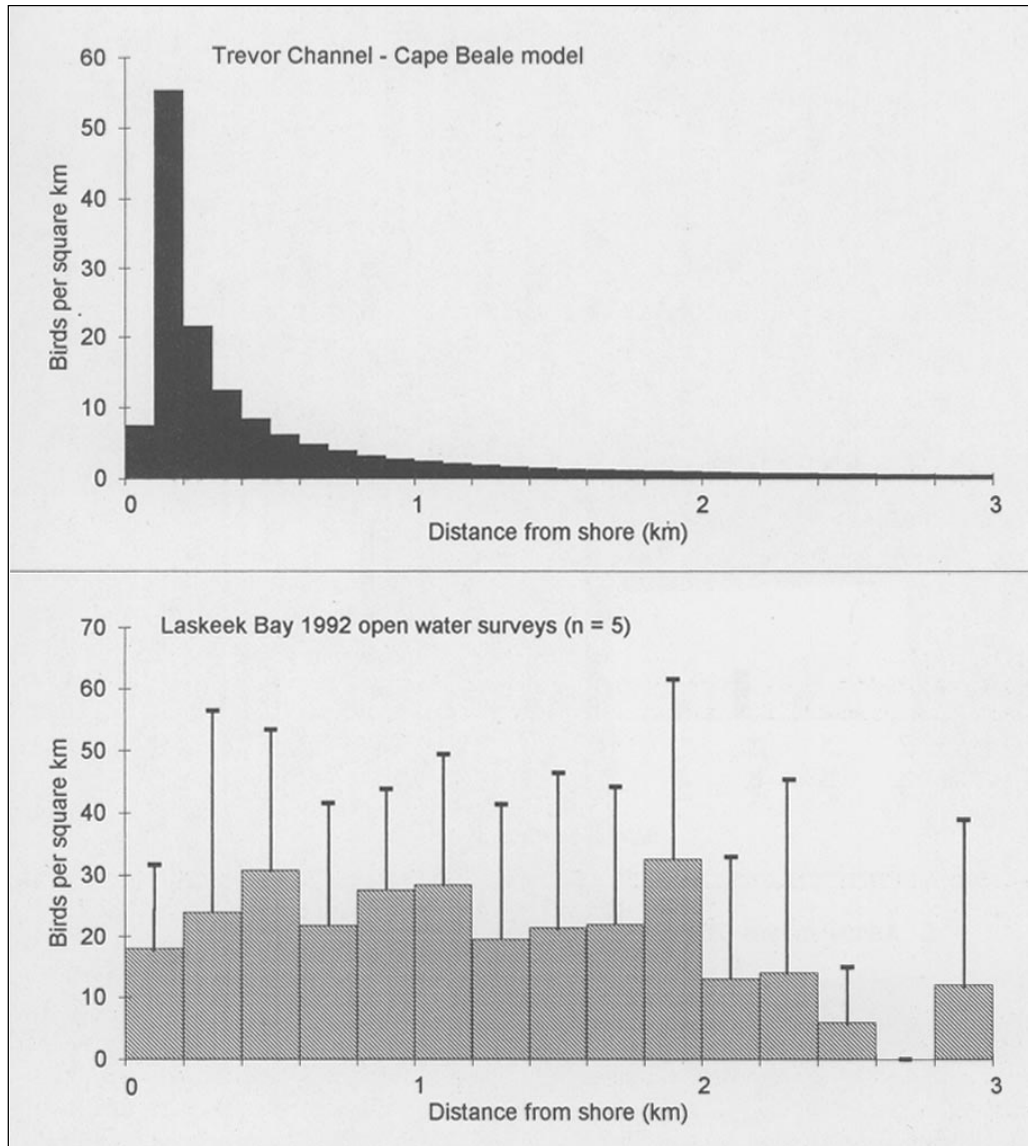


Figure 6—Variations of the density of Marbled Murrelets with distance from shore, in exposed (upper) and sheltered (lower) inshore waters in British Columbia. Upper: densities predicted by the logarithmic model derived from Carter's (1984) counts made in 1980 in Trevor Channel and the Cape Beale area (see fig. 5). Lower: mean densities in 200-m segments of open water surveys made in Laskeek Bay in 1992 (Lawrence, pers. comm.). Error bars show standard deviation.

abundance, such as estimates using echosounders. Carter (1984) explained the influx and aggregations of murrelets in Trevor Channel, Barkley Sound, as a consequence of aggregations of juvenile herring (*Clupea harengus*) and sand lance. Murrelet distribution in this area was highly clumped and was associated with features such as gravel or sand substrates, where sand lance might burrow, or thermal fronts and small channels, where juvenile herring and other prey aggregate (Carter 1984, Carter and Sealy 1990). Carter (1984) found that murrelets in Trevor Channel were more likely to have food in their guts in the morning than in the afternoon or at night, and linked this with the availability of sand lance and juvenile herring in surface waters. Off Langara Island,

where murrelets concentrated on euphausiids and sand lance, the birds appeared to feed throughout the day (Sealy 1975c). Availability of sand lance appeared to affect both the spatial distribution and the seasonal densities of murrelets in Okeover Inlet, Desolation Sound during the breeding season (Kaiser and others 1991, Mahon and others 1992).

The effects of El Niño and other oceanographic events on murrelets in British Columbia are poorly known. Exceptionally warm water persisted off southwestern Vancouver Island from January through August 1992 and again from April through mid-June 1993 (data from H. Freeland, in Burger 1994). In Barkley Sound this warm water was associated with an influx of mackerel (*Scomber japonicus*)

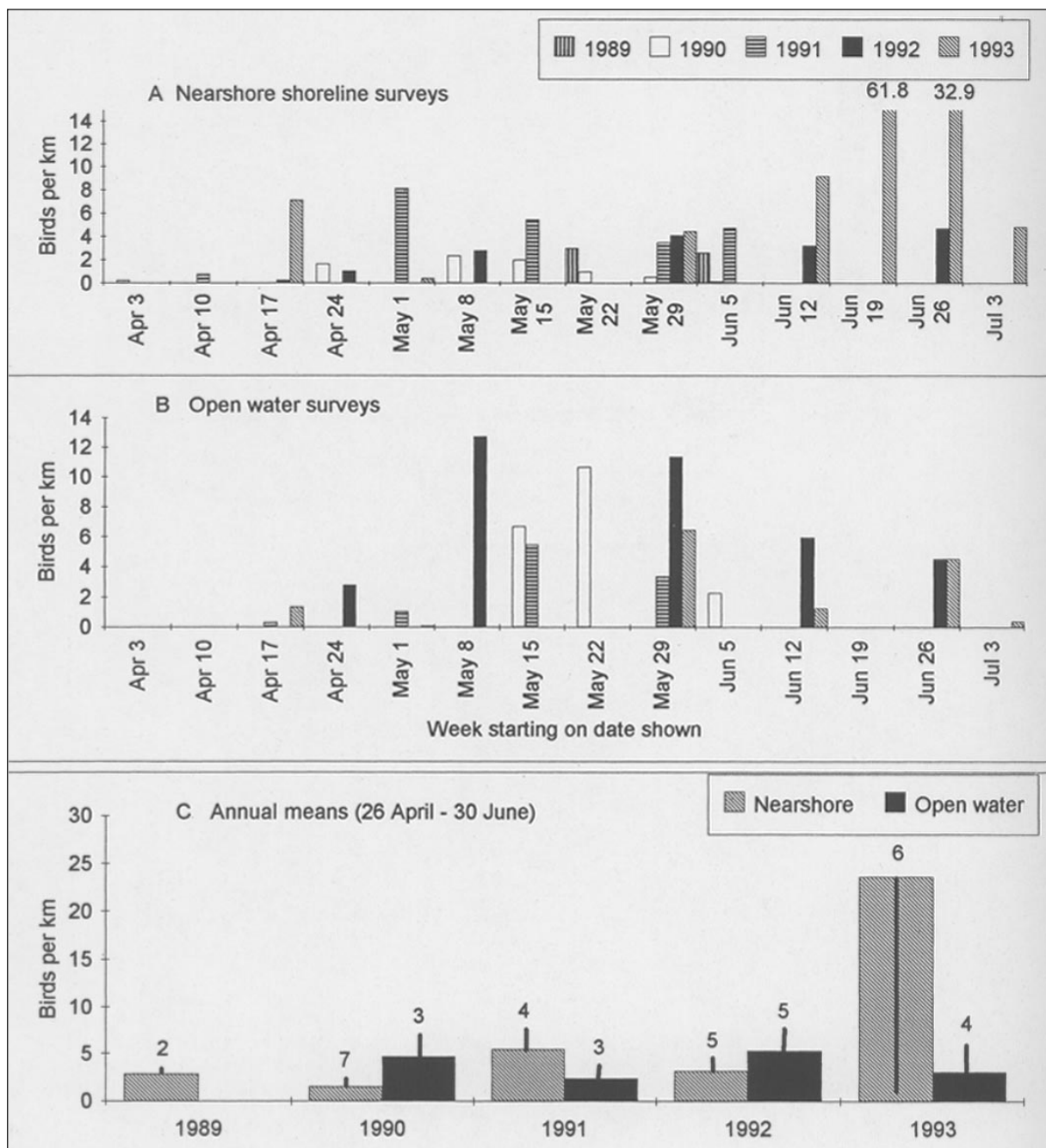


Figure 7—Densities of Marbled Murrelets in Laskeek Bay, Queen Charlotte Islands, showing seasonal patterns in nearshore surveys (A) and those in open water (B); and inter-year variations in mean densities (C). No open water surveys were made in 1989. Sample sizes show numbers of surveys used to calculate the mean values for the period 26 April through 30 June. Error bars show standard deviations (inverted for 1993 nearshore). Transect widths were 400 m throughout (Lawrence, pers. comm.).

and jack-mackerel (*Trachurus symmetricus*), which eat prey similar to that taken by murrelets, and significantly low densities of euphausiids and juvenile herring (Hargraves, pers. comm.; Tanasichuk, pers. comm.). Murrelet surveys in the Broken Islands showed no effects of these changes in 1992, relative to 1991, but in 1993 many murrelets appeared to leave the Broken Islands and the Deer Island-Trevor Channel area in June, at least a month before their usual departure (*fig. 8*).

Abundance and Distribution Relative to Distribution of Forest Stands

There are insufficient data for coarse-scale comparisons between murrelet densities at sea and rates of detections in adjacent forests. Murrelet detection frequencies in forest surveys on the east coast of Vancouver Island, which has been extensively logged, were much lower than on the west coast (Savard and Lemon in press), and this corresponds to

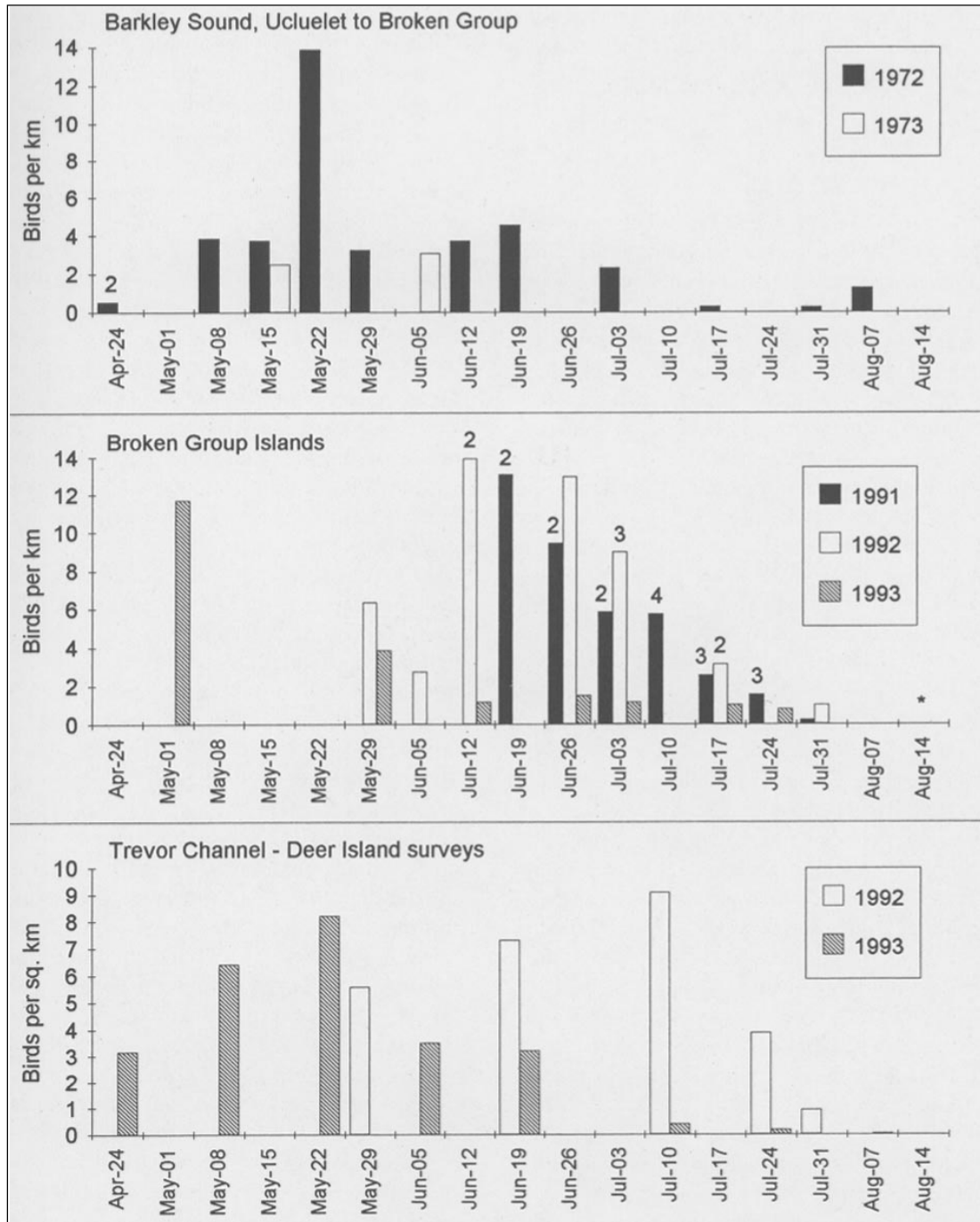


Figure 8—Densities of Marbled Murrelets in Barkley Sound, plotted in weekly intervals through the breeding season. One survey was made per week, except where indicated by numbers above the columns. The asterisk indicates a survey with no murrelets seen. Note that the units of density are not the same in all studies. Data from Hatler and others (1978) and Burger (1994).

a general pattern of low densities at sea in summer off the east coast (*appendix 1*).

On a finer scale, Burger (1994) examined murrelet densities in 19 segments of coast between Pachena Bay and Port San Juan off southwestern Vancouver Island. This 65-km stretch of coast has one of the highest known densities of murrelets in British Columbia (*appendix 1*) and is relatively straight and

unbroken, and hence more easily censused than along the highly indented coastline found in most of British Columbia. Adjacent to this area are some of the largest tracts of old-growth forest remaining on southern Vancouver Island, specifically the Nitinat-Tsusi-at-Klanawa and Carmanah-Walbran watersheds. The highest at-sea densities in both 1991 and 1993 were consistently found in four segments immediately

adjacent to these two tracts of forest, while most of the very low-density areas were adjacent to heavily logged watersheds (Burger 1994). The relative importance of marine versus forest habitat in explaining this distribution has not been determined.

Population Changes

Historical Numbers and Distribution

Rodway (1990) and Rodway and others (1992) reviewed the scanty evidence of long-term population changes in British Columbia. There is anecdotal evidence of population declines in the Strait of Georgia. Brooks (1926b) commented on the scarcity of murrelets on the east coast of Vancouver Island in 1925-1926, compared to numbers seen in 1920 and earlier, and speculated that disease or crude oil might have been responsible. Pearse (1946) reported a decline in murrelet numbers in the Comox district, eastern Vancouver Island, between 1917 and 1944 and attributed this to the removal of coniferous forests. Rodway and others (1992) found no significant trends in numbers of murrelets observed in Christmas Bird Counts made at 22 sites, some extending back as far as 1957, but relatively few counts were from regularly used wintering areas.

Recent Trends

I assessed changes in densities of Marbled Murrelets in the past 15-20 years by comparing surveys made from 1976 through 1982 with more recent surveys. Relatively few areas can be compared, and the precise routes and methods of some of the earlier surveys could not always be replicated. The paucity of annually repeated surveys makes it difficult to rule out inter-year fluctuations (perhaps related to oceanic effects) as the cause of some of the changes reported here.

Clayoquot Sound and Barkley Sound

In June 1992 and 1993, Kelson and others (in press; Kelson, pers. comm.) repeated the grid census made in southeastern Clayoquot Sound in June 1982 by Sealy and Carter (1984). In each year the entire area (294 km²; Tofino Sound excluded) was surveyed once, over periods of several days, by counting all murrelets seen within 250 m of a boat traversing a u-shaped path through each 1-km by 1-km block. The spatial distributions of the birds were broadly similar in each count, but the total numbers declined from 4,522 in 1982 to 2,701 (60 percent of the 1982 total) in 1992 and 2,622 (58 percent) in 1993. Kelson and others (in press) attributed the decline to significant reductions in old-growth forests adjacent to Clayoquot Sound.

Carter (1984) used a similar grid technique in June and July 1980 in outer Trevor Channel and the adjacent Deer Islands, one of the areas with consistently high densities in Barkley Sound (Carter and Sealy 1984). In 10 morning surveys he recorded a mean of 351.6 birds (on the water and flying; range 74-518). Repeating these censuses for the morning periods in 1992 and 1993, Burger (1994) recorded averages of only 153.0 (range 92-215; four surveys) from 2

June to 26 July 1992 and 86.0 (4-194; six surveys) from 1 May to 25 July 1993. These means represent 44 percent and 25 percent of the 1980 mean, respectively. The low 1993 numbers were partly due to an early departure from this area of murrelets in June, which was associated with persistent warm water and possible low prey densities.

In 1979, Carter (1984) counted murrelets in a 17.2-km linear transect running through outer Trevor Channel and along the open coast to Seabird Rocks. Burger (1994) counted seabirds along a virtually identical 19.5-km route in 1987, 1989, 1991, and 1993 and found significantly lower murrelet densities, with the mean values consistently less than 50 percent of the 1979 value (*fig. 9*; 1979 data versus pooled data 1987-1993: Mann-Whitney test, $U_{7,13} = 79.5$, $P < 0.01$). Other censuses suggest that 1979 was not an unusual year in this area for the study period 1979-1982 (Carter 1984, Sealy and Carter 1984a). These three replicated studies are consistent in showing a significant decline in the densities of Marbled Murrelets in Clayoquot and Barkley sounds. The changes might be partly due to coarse-scale shifts in distribution, but the Clayoquot Sound surveys covered a large area in which distribution shifts of 1-10 km should have been detected. It is likely that the 1992 and 1993 El Niño conditions caused many murrelets to leave Clayoquot and Barkley Sound temporarily. Support for this hypothesis came in spring 1994 when densities of murrelets in Trevor Channel, Barkley Sound, were 2-3 times higher than they had been in 1992 and 1993 (Burger, unpubl. data). There is no simple correlation between murrelet numbers and local sea temperatures, however, because summer temperatures were also above normal in early counts in 1979 and 1980 (but not 1982) and in later counts in 1987 and 1989 (data from H. Freeland, in Burger 1994). The effects of local ocean temperatures, upwelling events, and El Niño conditions on the distribution of Marbled Murrelets and their prey clearly need to be investigated in detail to help explain the apparent declines.

One likely cause of decline is the widespread loss of valley-bottom old-growth forests in the surrounding areas (Kelson and others in press, Sealy and Carter 1984). Between 1954 and 1990, an estimated 75 percent of the ancient rainforest of southern Vancouver Island was logged, including extensive tracts adjacent to Clayoquot and Barkley Sounds (Husband and Frampton 1991), and much of this occurred in the past decade. Gill-net fishing also killed appreciable numbers of murrelets in Barkley Sound (Carter and Sealy 1984), but does not occur here every year (Burger, pers. obs.) and is not a factor in Clayoquot Sound (Kelson and others, in press). Increased disturbances from sports fishing and recreational boating might have displaced murrelets at a few localities.

Queen Charlotte Islands

Nearshore surveys made in May and June in 1977 (Vermeer and others 1983) provide comparative data for some areas in which similar surveys were undertaken in 1990-1992 (*table 3*). The trends were not consistent; there were increases in two areas with relatively low densities, but

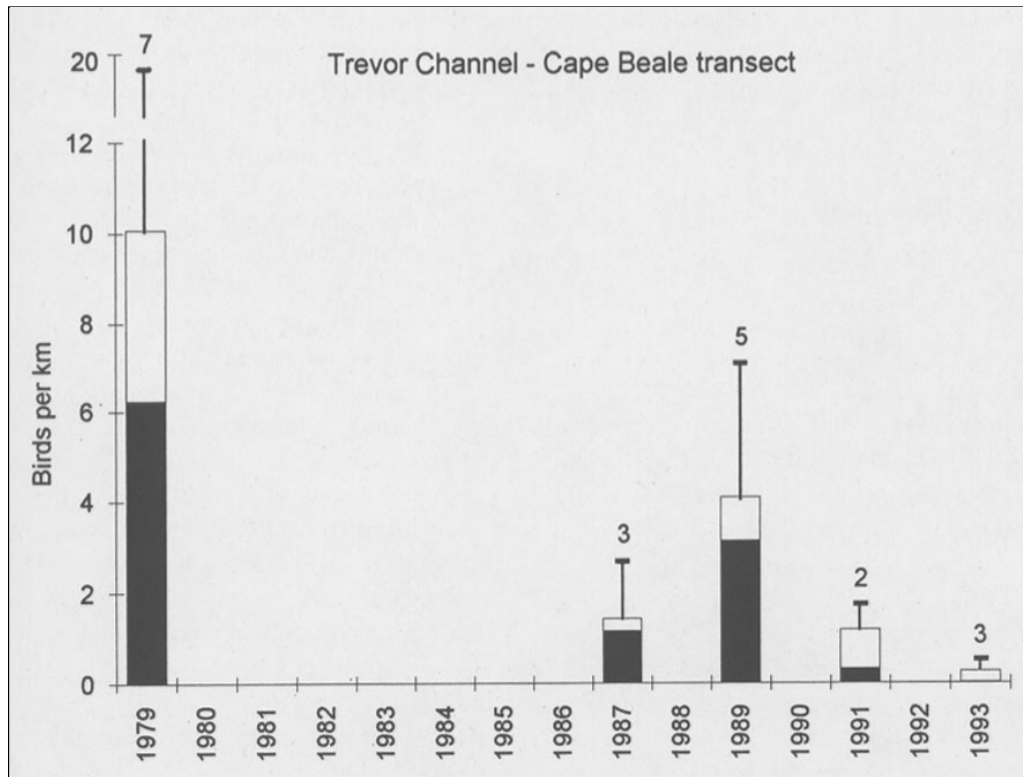


Figure 9—Mean ($\pm$ s.d.) densities of Marbled Murrelets on transects of 17.2-19.5 km in Trevor Channel, past Cape Beale and south to Seabird Rocks in June and July of 1979, 1987, 1989, 1991, and 1993 (Burger 1994, Carter 1984). The sample sizes are numbers of transects. Birds seen on the water and flying are shown in shaded and open columns, respectively.

slight declines in two areas in which many murrelets occurred. The changes were well within the year-to-year variations reported for this coast. Considerable logging of old-growth forests has occurred around Skidegate Inlet and to the north of Juan Perez Sound, but the forests adjacent to Skincuttle Inlet have not been logged. Oil spills and gill-net fisheries do not appear to have been problems for murrelets in any of these areas. The low densities in Massett Inlet shown contrast with records of flocks of 200 or more in the summers of 1946 and 1947 (Carter 1984), but large flocks were also present in May 1990 (Rodway and others 1991). There were thus no indications of significant population declines in these parts of the Queen Charlotte Islands, but the data were insufficient to reliably detect any real changes.

Threats to Marbled Murrelets at Sea in British Columbia

Oil Pollution

There is a moratorium on offshore exploration and development of oil fields in British Columbia, and this seems likely to continue. Threats to murrelets come from catastrophic spills from large vessels as well as chronic small-volume spills (Burger 1992, Vermeer and Vermeer 1975). The Canadian Coast Guard (1991) reported annual

transits of 7,000 freighters and tankers off British Columbia, including at least 1,500 tankers. Each year at least 300 loaded tankers enter the Strait of Juan de Fuca (Shaffer and others 1990). Overall, the annual shipments of crude oil and refined petroleum products average 26.0 and 15.0 million m³, respectively, in southern British Columbia and northern Washington (Shaffer and others 1990). Vessel traffic was estimated to increase by 6-11 percent between 1989 and 1991 (Canadian Coast Guard 1991). A probability model predicted that spills exceeding 1,000 barrels are expected in southern British Columbia and northern Washington every 2.5 years for crude oil, and every 1.3 years for all petroleum products (Cohen and Aylesworth 1990), and this prediction was close to the actual pattern of spills between 1974 and 1991 (Burger 1992). These studies indicate a high risk from oiling for Marbled Murrelets. This is particularly pertinent in inshore areas off southwestern Vancouver Island in summer and southern Strait of Georgia and Puget Sound in winter, when high murrelet densities coincide with the greatest volumes of tanker traffic and other shipping (Burger 1992).

The *Nestucca* spill in December 1988 killed an estimated 143 Marbled Murrelets off Vancouver Island (Burger 1993a), which represents about 0.9 percent of the 16,000 birds thought to occur off Vancouver Island (Rodway 1990). Marbled

Table 3—Density estimates (birds per linear km) of Marbled Murrelets at four nearshore sites in the Queen Charlotte Islands surveyed in May–June 1977 and again in spring or summer 1990, 1991 or 1992. See appendix 1 for details

Sample area	1977	1990	1991	1992
Masset Inlet	0.0	0.3	—	—
Skidegate Inlet	0.5	1.0	—	—
Juan Perez Sound	4.7	—	3.2	3.6
Skincuttle Inlet	7.4	—	3.5	—

Murrelet carcasses were rarely found in surveys of beached birds in southern British Columbia, and were not among the small sample of birds killed by chronic oiling but could easily have been overlooked (Burger 1993b).

Other Toxic Chemicals

High levels of polychlorinated biphenyls (PCBs), dioxins, and furans have been found in some piscivorous birds in inshore waters of British Columbia, although Marbled Murrelets were not sampled (Elliott and Noble 1993). Levels of these contaminants and of organochlorides appear to be declining in water birds sampled in British Columbia (Elliott and Noble 1993, Elliott and others 1992).

Gill Nets

Little is known about the effects of gill nets on seabirds in British Columbia. In 1988, the gill-net effort totaled 54,770 net-days, concentrated in summer and fall in inshore areas (Barlow and others 1990). Anecdotal evidence from fishermen suggests that Marbled Murrelets are among the bird species most often killed. Carter and Sealy (1984) estimated that the bycatch of 200 Marbled Murrelets caught in gill nets in Barkley Sound in 1980 represented a loss of 7.8 percent of the expected fall population (including loss of fledglings caused by deaths of parent birds). There have been no other studies of this problem in British Columbia, but it clearly needs to be examined in detail.

Other Effects of Fishing and Aquaculture

Competition with the fishing industry for prey species does not appear to be a significant issue for murrelets in British Columbia. The herring stocks appear to have recovered after periods of overfishing in the 1960's and are now strictly regulated. Sand lance, zooplankton, and other prey species are not fished in appreciable amounts. Sport fishing continues to increase, and disturbance from the hundreds of small boats, plus occasional bycatch of murrelets on lures is possibly a localized problem.

Habitat degradation and disturbance at fish and shellfish pens can affect Marbled Murrelets, and many aquaculture farms exist or are planned in sheltered inshore waters favored by murrelets (e.g., Clayoquot, Barkley, and Desolation sounds). Marbled Murrelets were not among the species

considered to be most affected by aquaculture in British Columbia (Rueggeberg and Booth 1989).

Conclusions

Proper management of the Marbled Murrelet in British Columbia requires an improved estimate of the provincial population and better understanding of its distribution and relative abundance in the breeding and nonbreeding seasons (Kaiser and others 1992). The census coverage of marine areas has greatly increased over the past decade, but quantitative surveys are still lacking for large tracts of the convoluted 27,000-km coastline (*fig. 4*). The differences in distribution between exposed and sheltered waters (e.g., *fig. 6*) and the variability within and among seasons (e.g. *fig. 7* and *8*) make it very difficult to estimate regional populations from single-season shoreline transects. We need to know a lot more about the factors which affect the murrelet's marine distribution, such as prey distribution and effects of tides, sea temperature, salinity, and seafloor topography, before we can plan and interpret census transects and monitor population dynamics. Regularly repeated surveys made over many years, such as those performed in Laskeek Bay and Barkley Sound, will be very valuable in showing both short- and long-term patterns.

Most of the urgent gaps in our knowledge can be filled by relatively simple, inexpensive studies of fine-scale distribution and foraging ecology if they are carefully planned to collect the most pertinent data. There are also opportunities to tap the expertise of the burgeoning number of birders and naturalists who visit remote coastal areas of British Columbia. The establishment of a long-term data base, meshed with a Geographic Information System, would facilitate the accumulation of data from both dedicated and opportunistic censuses. Other priority problems, such as making a province-wide marine census, measuring population demographics, or investigating the effects of gill nets or logging, require more dedicated, expensive studies.

Acknowledgments

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Appendix 1—Summary of densities of Marbled Murrelets reported from at-sea surveys in British Columbia from May through July

Region Location	Year	Dates	Mean no. km surveyed	No. of surveys	Survey method ¹	Habitat types ²	Boat size ³	Murrelet density ⁴ (birds per km)		Reference ⁵
								Mean	Max	
N. coast Queen Charlotte Islands										
N. coast Graham Island	1977	May – Jun	128	1	LA	E–NW	m/l	0.00	–	Vermeer and others (1983)
Masset Inlet	1977	May – Jun	180	1	LA	I–OC	m/l	0.00	–	Vermeer and others (1983)
Masset Inlet	1990	4 Jun	18	1	LA	I–OC	s	0.27	–	Rodway and others (1991)
Naden Harbour	1977	May – Jun	42	1	LA	I–OC	m/l	0.00	–	Vermeer and others (1983)
W. coast Queen Charlotte Islands										
W. Graham Island: outer coast	1976	Jun – Aug	125	1	LA	E–NW	m/l	3.00	–	Vermeer and others (1983)
W. Graham Island: inlets	1977	May – Jun	278	1	LA	I–OC	m/l	0.09	–	Vermeer and others (1983)
W. Moresby Island: outer coast	1976	Jun – Aug	135	1	LA	E–NW	m/l	5.16	–	Vermeer and others (1983)
W. Moresby Island: inlets	1977	May – Jun	162	1	LA	I–OC	m/l	0.15	–	Vermeer and others (1983)
Rennell Sound	1990	4 May – 1 Jun	34.2	5	LA	I–OC	s	2.52	4.19	Rodway and others (1991)
Tasu Sound	1990	20 Jul	30	1	LA	I–OC	s	1.63	–	Lawrence (pers. comm.)
Sunday Inlet	1990	19 Jul	5	1	LA	I–OC	m	4.00	–	Lawrence (pers. comm.)
Pocket Inlet	1990	19 Jul	2	1	LA	I–OC	m	1.00	–	Lawrence (pers. comm.)
Mike Inlet	1990	19 Jul	2.5	1	LA	I–OC	m	0.00	–	Lawrence (pers. comm.)
Gowgaia Bay	1990	19 Jul – 1 Aug	7	2	LA	I–OC	m	1.57	2.00	Lawrence (pers. comm.)
Flamingo Inlet	1990	23 – 30 Jul	7	3	LA	I–OC	m	0.57	1.00	Lawrence (pers. comm.)
Louscoune Inlet	1990	22 Jul	20	1	LA	I–OC	m	0.75	–	Lawrence (pers. comm.)
E. coast Queen Charlotte Islands										
Skidegate Inlet	1977	May – Jun	115	1	LA	I–IC	m/l	0.46	–	Vermeer and others (1983)
Skidegate Inlet	1990	28 Apr – 12 May	30	3	LA	I–IC	s	1.01	1.64	Rodway and others (1991)
Skidegate Inlet: Long Inlet	1990	28 Apr – 12 May	8	4	LA	I–IC	s	9.31	18.38	Rodway and others (1991)
Skidegate Channel	1990	28 Apr	44	1	LA	I–IC	s	1.23	–	Rodway and others (1991)
Cumshewa Inlet, Selwyn Sound	1977	May – Jun	89	1	LA	I–IC	m/l	0.33	–	Vermeer and others (1983)
Logan Inlet, Darwin Sound	1977	May – Jun	138	1	LA	I–IC	m/l	1.78	–	Vermeer and others (1983)
Laskeek Bay: nearshore	1989	26 May – 9 Jun	27.8	4	LS (400)	S–NW/S–IS	s	3.29	4.03	Gaston (1989)
Laskeek Bay: nearshore	1990	11– 31 May	20	5	LS (400)	S–NW/S–IS	s	2.18	3.75	Gaston (1991)
Laskeek Bay: nearshore	1991	2 – 18 May	20	2	LS (400)	S–NW/S–IS	s	8.73	10.45	Gaston and others (1992)
Laskeek Bay: nearshore	1992	11 May – 28 Jun	20	4	LS (400)	S–NW/S–IS	s	6.48	8.15	Gaston and Lawrence (1993)
Laskeek Bay: nearshore	1993	3 May – 10 Jul	22	7	LS (400)	S–NW/S–IS	s	20.92	61.76	Gaston and Heise (in press)
Laskeek Bay: open water	1990	17 May – 5 Jun	22	3	LS (400)	S–OW	s	5.87	7.50	Gastom (1991)
Laskeek Bay: open water	1991	2 May – 2 Jun	22	3	LS (400)	S–OW	s	2.28	3.70	Gaston and others (1992)
Laskeek Bay: open water	1992	11 May – 28 Jun	22	4	LS (400)	S–OW	s	6.01	8.95	Gaston and Lawrence (1993)
Laskeek Bay: open water	1993	3 May – 10 Jul	18.7	5	LS (400)	S–OW	s	2.53	6.46	Gaston and Heise (in press)

continues

Appendix 1—continued

Region Location	Year	Dates	Mean no. km surveyed	No. of surveys	Survey method ¹	Habitat types ²	Boat size ³	Murrelet density ⁴ (birds per km)		Reference ⁵
								Mean	Max	
S. Laskeek Bay – Lyell Island	1992	17–27 Jun	64	2	LS (400)	S–OW	s	3.91	5.60	Gaston and Lawrence (1993)
Juan Perez Sound	1977	May – Jun	121	1	LA	S–NW/S–IS	m/l	4.72	–	Vermeer and others (1983)
S. Juan Perez Sound: nearshore	1991	2 – 28 July	40	4	LS (400)	S–NW/S–IS	s	3.24	4.90	Lawrence and Backhouse (1991)
S. Juan Perez Sound: nearshore	1992	30 Jun – 31 Jul	50	4	LS (400)	S–NW/S–IS	s	8.63	9.60	French (1993)
Juan Perez–Lyell Island nearshore	1992	31 Jun – 31 Jul	150	4	LS (400)	S–NW/S–IS	s	2.30	2.94	French (1993)
S. Juan Perez Sound: open water	1991	2 – 28 July	6.8	4	LS (400)	S–OW	s	3.38	7.00	Lawrence and Backhouse (1991)
S. Juan Perez Sound: open water	1992	30 Jun – 31 Jul	5.9	4	LS (400)	S–OW	s	1.90	3.39	French (1993)
Skincuttle Inlet	1977	May – Jun	87	1	LA	S–NW/S–IS	m/l	7.40	–	Vermeer and others (1983)
Skincuttle Inlet: nearshore	1991	30 Jun – 1 Aug	47	5	LS (400)	S–NW/S–IS	s	3.53	4.32	Lawrence and Backhouse (1991)
Skincuttle Inlet: open water	1991	3–31 July	19	5	LS (400)	S–OW	s	0.92	2.84	Lawrence and Backhouse (1991)
Poole Inlet	1991	23 Jul	12	1	LS (400)	S–NW/S–IS	s	16.20	–	Lawrence and Backhouse (1991)
Collison Bay	1991	4 Aug	77	1	LS (400)	S–NW/S–IS	s	9.63	–	Lawrence and Backhouse (1991)
Houston Stewart Channel	1977	May – Jun	169	1	LA	S–NW	m/l	2.15	–	Vermeer and others (1983)
Central Mainland										
Chatham Sound	1990	15–30 May	27	1	LS(1000)	S–NW	m	0.00	–	Kaiser and others (1991)
Skeena Estuary	1990	15–30 May	23	1	LS(1000)	S–NW/S–IS	m	3.10	–	Kaiser and others (1991)
Principe Channel	1990	15–30 May	138	1	LS(800)	S–NW/S–IS	m	0.12	–	Kaiser and others (1991)
Caamano Sound	1990	15–30 May	63	1	LS(1000)	E–NW	m	1.30	–	Kaiser and others (1991)
Surf, Racey Inlets	1990	15–30 May	31	1	LS(1000)	I–IC	m	0.60	–	Kaiser and others (1991)
Campania Sound	1990	15–30 May	21	1	LS(1000)	S–NW/S–IS	m	3.20	–	Kaiser and others (1991)
Boxer Reach	1990	15–30 May	14	1	LS(1000)	F–IC	m	0.60	–	Kaiser and others (1991)
Bishop Bay	1990	15–30 May	9	1	LS(600)	I–IC	m	1.44	–	Kaiser and others (1991)
Fraser Reach	1990	15–30 May	40	1	LS(1000)	F–IC	m	2.20	–	Kaiser and others (1991)
Graham Reach	1990	15–30 May	40	1	LS(1000)	F–IC	m	0.40	–	Kaiser and others (1991)
Hiekish Narrows	1990	15–30 May	9	1	LS(1000)	F–IC	m	3.50	–	Kaiser and others (1991)
“Small inlets”	1990	15–30 May	27	1	LS(1000)	I–IC	m	4.10	–	Kaiser and others (1991)
Sheep Pass	1990	15–30 May	21	1	LS(1000)	F–IC	m	1.30	–	Kaiser and others (1991)
Sheep Pass	1990	27 Jun	33.1	1	LS(1000)	F–IC	m	4.86	4.86	Kaiser and others (1991)
Mussel Inlet	1990	15–30 May	19	1	LS(600)	F–IC	m	3.66	–	Kaiser and others (1991)
Mussel Inlet	1990	26–28 June	31.4	4	LA	F–IC	m	4.81	6.15	Kaiser and others (1991)
Kynoch Inlet	1991	3 May – 11 Jun	29.2	4	LS(600)	F–IC	m	2.72	4.89	Prestash and others (1992a)
Kynoch Inlet	1990	15–30 May	20	1	LS(800)	F–IC	m	2.48	–	Kaiser and others (1991)
Mathieson Channel	1991	2–23 May	30.7	7	LS(600)	F–IC	m	2.79	11.67	Prestash and others (1992a)
Mathieson Channel	1990	15–30 May	60	1	LS(1000)	F–IC	m	0.90	–	Kaiser and others (1991)

continues

Appendix 1—continued

Region Location	Year	Dates	Mean no. km surveyed	No. of surveys	Survey method ¹	Habitat types ²	Boat size ³	Murrelet density ⁴ (birds per km)		Reference ⁵
								Mean	Max	
Milbanke Sound	1991	2 May – 2 Jun	108	3	LS(600)	E–NW/S–IS	m	0.89	1.23	Prestash and others (1992a)
Milbanke Sound	1990	15–30 May	48	1	LS(1000)	E–NW/S–IS	m	4.20	–	Kaiser and others (1991)
Queen's Sound	1990	15–30 May	34	1	LS(1000)	E–NW/S–IS	m	0.10	–	Kaiser and others (1991)
FitzHugh Sound	1990	15–30 May	36	1	LS(1000)	S–IS/S–NW	m	0.20	–	Kaiser and others (1991)
Cape Caution	1990	15–30 May	103	1	LS(1000)	E–NW/S–NW	m	0.00	–	Kaiser and others (1991)
Currie Island – Cape Mark	1991	13 May, 1 Jun	86.7	2	LS(1000)	S–NW/S–IS	m	0.21	0.21	Prestash and others (1992a)
NW. Vancouver Island										
Scott Islands	1986	13 & 23 July	83.2	2	LA	E–NW/E–OW	m	0.00	0.00	Burger (unpubl. data)
Nootka Sound	1991	4 May - 10 July	56.8	5	LA	S–NW/I–OC	s	1.34	6.31	Savard and Lemon (1992)
Kyuquot Sound	1991	14 May - 26 July	28.1	9	LA	S–NW/I–OC	s	0.17	1.19	Savard and Lemon (1992)
Checleset Bay	1991	27 June - 26 July	29.2	6	LA	S–NW/I–OC	s	0.71	1.18	Savard and Lemon (1992)
Brooks Bay	1991	20 June - 17 July	31.7	5	LA	E–NW/I–OC	s	2.98	4.63	Savard and Lemon (1992)
Quatsino Sound	1991	8 May-18 June	91.7	4	LA	S–NW/I–OC	s	0.03	0.06	Savard and Lemon (1992)
NE. Vancouver Island										
Goletas Channel	1991	26 June-27 July	81.3	3	LA	I–IC/F–IC ?	s	1.31	2.17	Savard and Lemon (1992)
Queen Charlotte Strait	1991	23 May - 18 July	72.7	3	LA	S–NW/S–IS	s	0.96	1.28	Savard and Lemon (1992)
Johnstone Strait	1991	20 May - 19 July	78.2	3	LA	S–NW	s	0.80	1.16	Savard and Lemon (1992)
Discovery Passage	1991	3-29 July	37.9	2	LA	S–NW	s	2.23	2.41	Savard and Lemon (1992)
Baynes Sound	1991	25 May- 4 July	66.2	2	LA	S–NW/S–IS	s	0.86	1.47	Savard and Lemon (1992)
E. Strait of Georgia										
Desolation Sound: Okeover Inlet	1990	9 Jun-8 Aug	72.4	27	LA	I–IC	s	5.11	11.02	Kaiser and others (1991)
Jervis Inlet	1987	May, June	135	2	LA	F–IC	m	0.63	0.85	Vermeer (1989)
Burrard Inlet-E. Howe Sound	1989	13 - 14 Jun	65	2	LA	S–NW	s	0.46	–	Lemon (pers. comm.)
Head Burrard Inlet	1989	13 - 14 Jun	36	2	LA	I–IC	s	0.53	–	Lemon (pers. comm.)
Indian Arm	1989	13 - 14 Jun	38	2	LA	I–IC	s	0.08	–	Lemon (pers. comm.)
Point Grey to Sandheads	1989	13 - 14 Jun	17.5	2	LA	S–NW	s	2.69	–	Lemon (pers. comm.)
W. Strait of Georgia										
Saanich Inlet	1986	May - Jul	96	6	LS(300)	F–IC	s	0.05	0.10	Morgan (1989)
Sidney - Mandarte Island	1992	15 May - 28 Jul	9.5	11	LS(300)	S–NW/S–IS	m	2.08	5.05	Clowater (pers. comm.)
SW. Vancouver Island										
NW. Clayoquot Sound	1982	1-25 Jun	244.5	1	GR	E–NW/I–OC	s/m	2.27	–	Sealy and Carter (1984)
SE. Clayoquot Sound	1982	1-25 Jun	646.5	1	GR	S–OW/S–NW	s/m	7.39	–	Sealy and Carter (1984)
SE. Clayoquot Sound	1992	17-30 Jun	586.0	1	GR	S–OW/S–NW	s/m	4.61	–	Kelson and others (in press)
SE. Clayoquot Sound	1993	16-26 Jun	586.0	1	GR	S–OW/S–NW	s/m	4.91	–	Kelson (pers. comm.)

continues

Appendix 1—continued

Region Location	Year	Dates	Mean no. km surveyed	No. of surveys	Survey method ¹	Habitat types ²	Boat size ³	Murrelet density ⁴ (birds per km)		Reference ⁵
								Mean	Max	
Long Beach (Tofino-Ucluelet)	1982	1-25 Jun	123.0	1	GR	E-NW	s/m	9.90	-	Sealy and Carter (1984)
Barkley Sound	1982	1-25 Jun	952.5	1	GR	S-IS/S-OW	s/m	3.58	-	Sealy and Carter (1984)
Barkley Sound: Ucluelet - Broken Group Islands	1972	8 May - 31 Jul	19.2	10	LA	S-IS/S-OW	s	3.97	13.85	Hatler and others (1978)
Barkley Sound: Ucluelet - Broken Group Islands	1973	15 May, 5 Jun	19.2	2	LA	S-IS/S-OW	s	2.79	3.07	Hatler and others (1978)
Barkley Sound: Broken Group Islands	1991	27 May - 30 Jul	8.8	16	LS(400)	S-IS	s	5.78	16.59	PRNP wardens (pers. comm.)
Barkley Sound: Broken Group Islands	1992	4 Jun - 21 Jul	8.8	10	LS(400)	S-IS	s	8.30	21.14	PRNP wardens (pers. comm.)
Barkley Sound: Broken Group Islands	1993	5 May - 27 Jul	8.8	7	LS(400)	S-IS	s	3.02	11.70	PRNP wardens (pers. comm.)
Barkley Sound: Deer Islands	1979	10 May - 31 Jul	31.4	41	LA	S-IS	s	1.15	-	Porter (1981)
Barkley Sound: Deer Islands	1986	14 May, 26 Jul	19.7	2	LA	S-IS	s	4.91	7.70	Burger (unpubl. data)
Barkley Sound: Deer Islands	1988	2 May - 20 June	19.7	3	LA	S-IS	s	5.96	9.45	Burger (unpubl. data)
Barkley Sound: Trevor/Deer Islands	1979	16 Jun - 6 Jul	48	37	LA	S-IS/S-OW	s	5.54	10.79	Carter (1984)
Barkley Sound: Trevor/Deer Islands	1992	2 Jun - 26 Jul	40	4	LA	S-IS/S-OW	s	3.43	4.83	Burger (unpubl. data)
Barkley Sound: Trevor/Deer Islands	1993	1 May - 25 Jul	40	6	LA	S-IS/S-OW	s	2.81	6.85	Burger (unpubl. data)
Alberni Inlet - upper Trevor Channel	1988	May - Jul	130	4	LA	F-OC/S-NW	m	0.67	1.64	Vermeer and Morgan (1992)
Trevor Channel - Cape Beale - Seabird Rocks	1979	10 May - 31 Jul	17.2	9	LS(500)	E-NW	m	8.20	27.48	Carter (1984)
Trevor Channel - Cape Beale - Seabird Rocks	1987	24 Jun - 30 Jul	19.5	3	LS(300)	E-NW	m	1.42	2.84	Burger (unpubl. data)
Trevor Channel - Cape Beale - Seabird Rocks	1989	14 Jun - 14 Jul	19.5	5	LS(300)	E-NW	m	4.08	7.98	Burger (unpubl. data)
Trevor Channel - Cape Beale - Seabird Rocks	1991	24-31 Jul	19.5	2	LS(300)	E-NW	m	1.18	1.57	Burger (unpubl. data)
Trevor Channel - Cape Beale - Seabird Rocks	1993	13 May - 28 Jul	19.5	4	LS(300)	E-NW	m	0.28	0.55	Burger (unpubl. data)
Pachena Bay	1991	5-7 June	10.2	2	LA	I-OC	s	2.94	-	PRNP wardens (pers. comm.)
Pachena Point - Owen Point	1991	2 Jun - 26 Jul	49.1	4	LA	E-NW	s	14.20	25.93	PRNP wardens (pers. comm.)
Pachena Point - Owen Point	1993	17 Jun	49.1	1	LA	E-NW	m	12.46	-	Burger (unpubl. data)
Cullite Cove to Owen Point	1993	20 May - 8 Jun	8.7	33	LS(300)	E-NW	s	12.08	28.05	Stewart (pers. comm.)
Owen Point - Port Renfrew	1991	2 Jun - 26 Jul	7.1	4	LA	I-OC	s	0.94	1.97	PRNP wardens (pers. comm.)
Owen Point - Port Renfrew	1993	17 Jun	7.1	1	LA	I-OC	m	1.55	-	Burger (unpubl. data)

¹LA = linear transect, all birds counted; LS(x) = linear strip transect (transect width x m); GR = grid-census, all birds counted within a 1 x 1 km grid. To convert birds per sq. km in grid censuses to birds per km, linear distances were assumed to be 1 km per quadrat for inshore areas and 2 km for fjord and channel quadrats (see Sealy and Carter 1984).

²E = exposed ocean (E-OW: >1 km; E-NW: nearshore <1 km); S = strait or sound (S-OW: open water >1 km from shore; S-NW: nearshore <1 km from shore; S-IS: among sheltered islands); F = fjord (F-OC: facing open coast; F-IC: facing sheltered inner coast); I = inlets (I-OC: facing open coast; I-IC facing sheltered inner coast)

³Boat size: s = small (<6m length); m = medium (6-20 m); l = large (>20 m)

⁴Units of density are in birds per linear km. In some studies the densities were reported in other units, but have been converted.

⁵PRNP = Pacific Rim National Park