DECLINE OF THE MARBLED MURRELET IN CLAYOQUOT SOUND, BRITISH COLUMBIA: 1982–1993

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ABSTRACT—In 1992 and 1993, we repeated at-sea surveys of marbled murrelets (*Brachyramphus marmoratus*) in Clayoquot Sound, British Columbia, that were conducted originally in 1982. Murrelet distribution was determined by counting birds in 341 contiguous 1-km^2 quadrats in fiord, channel, and inshore marine habitats. Counts for this area totaled 4500 birds in 1982, 2704 birds in 1992, and 2622 birds in 1993 which constituted a 40% decline in the population size from 1982–1993. Birds were clumped in all surveys, with the highest densities in inshore (28, 14.3, 7.85 birds/km^2 in 1982, 1992, and 1993, respectively) and channel (11.8, 9.1, 14.2 birds/km^2 in 1982, 1992, and 1993, respectively) marine habitats. The average change in the number of birds in each quadrat between the 1982 and 1992-93 surveys was significant for all quadrats combined, and individually for inshore quadrats. We consider the loss of nesting habitat in old-growth forest to be the probable cause of most of the observed population decline. By 1992 approximately 15–24.5% of the originally forested area in Clayoquot Sound had been logged. Oil spills, gill-net fishing, and oceanographic conditions (El Niño) were also considered as possible factors contributing to the population decline. This study is the first in North America to document a decline in a marbled murrelet population using a single, standardized at-sea survey technique.

Marbled murrelets (*Brachyramphus marmoratus*) nest on tree branches in the canopies of old-growth and mature forests from southern Alaska to California (see recent summaries in Singer et al. 1991, Carter and Morrison 1992, Ewins et al. 1993, Hamer and Nelson 1995a). Standardized methods have been developed to monitor the activity of birds at inland nesting locations (*e.g.*, Paton et al. 1990), but nests are difficult to locate and population size must be determined and monitored using surveys at ocean foraging areas (Sealy and Carter 1984). Previous to 1982, few at-sea surveys had been conducted for this species, and population size and distribution still are incompletely known for most areas on the west coast of North America (Carter and Morrison 1992). Thus, it has been difficult to document population trends for this species related to the loss of old-growth forest nesting habitat and mortality from oil spills and gill-net fishing. These threats are cause for concern and have led to the recent federal listing of the marbled murrelet as threatened in British Columbia, Washington, Oregon and California (Rodway 1990, U.S. Fish and Wildlife Service 1992) and state listing as endangered in California (California Fish and Game Commission 1992).

In British Columbia, portions of the coast have been surveyed for marbled murrelet populations (Carter 1984, Sealy and Carter 1984, Kaiser et al. 1991, Lawrence and Backhouse 1991, Savard and Lemon 1992). Provincial estimates of 45,000–50,000 breeding birds (Rodway et al. 1992) are poorly substantiated for the most part because many areas have not been surveyed and survey data have been difficult to convert into reliable population estimates (Rodway et al. 1992, 1995). In addition, marbled murrelet populations have been considered to have declined in some areas in the province, based on anecdotal evidence (Brooks 1926, Pearse 1946) and loss of nesting habitat, yet quantitative data have not been available to investigate the degree of possible declines.

Estimates of population size for large geographic areas have been published only for Clayoquot and Barkley sounds on the west

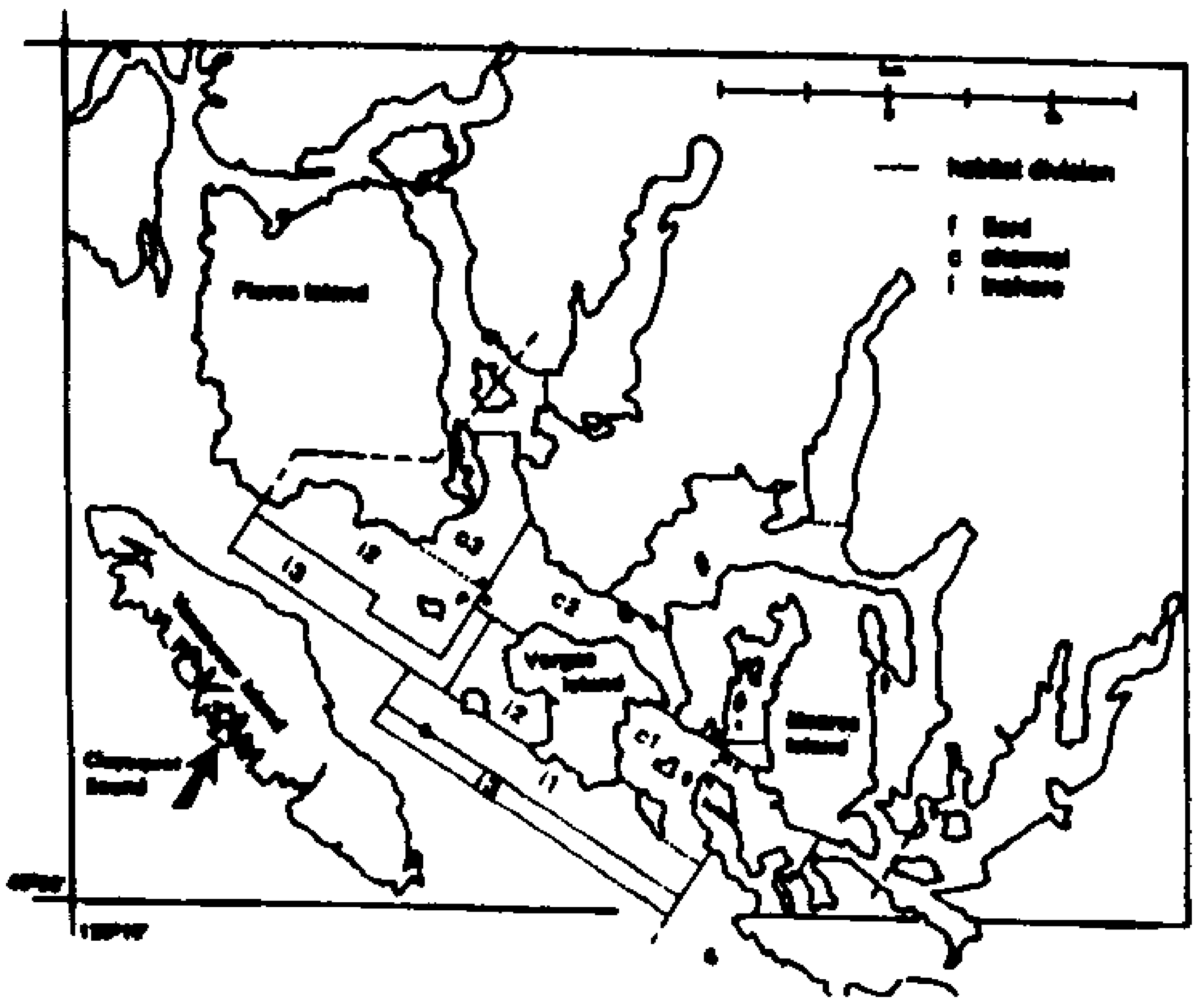

FIGURE 1. Southeast Clayoquot Sound showing the boundaries of the surveys, the marine habitat divisions and specific channel and inshore areas.

coast of Vancouver Island (Sealy and Carter 1984), and the eastern Moresby Islands of the Queen Charlotte Islands (Lawrence and Backhouse 1991). The at-sea surveys of marbled murrelets conducted in Clayoquot Sound in 1982 also generated a description of murrelet distribution (Sealy and Carter 1984). To examine the trend in the distribution and size of this population, we conducted at-sea surveys of murrelets in this area in 1992 and 1993, using the same methodology as Sealy and Carter (1984). In this paper, we present the results of the 1992 and 1993 surveys, compare the number and distribution of marbled murrelets to 1982 (Sealy and Carter 1984), and examine possible causes for the differences over this 11-yr period.

METHODS

Sealy and Carter (1984) surveyed murrelets in 1982 in a contiguous grid of 1-km^2 quadrats established to cover all inshore and nearshore waters within 2-6 km of shore in Clayoquot Sound. Partial quadrats resulted near shore in some areas because of the convoluted shoreline. Sealy and Carter (1984) divided the Sound into northwest and southeast portions. In 1982, 90% of murrelets were counted in the southeast portion of Clayoquot Sound. Therefore, in 1992, only southeast Clayoquot Sound from Siwash Cove (Flores Island) to Chesterman's Beach (south of Tofino) was resurveyed (Fig. 1). Additionally, small areas of inshore and fiord waters (27 and 53 km^2, respectively) also were excluded in 1992 and 1993 because these areas contained very few birds in 1982. The area surveyed in 1992 was surveyed again in 1993, and portions of northwest Clayoquot Sound and north Long Beach also were surveyed. All comparisons among the 3 yr were limited to the 1992 survey area. A total of 341 quadrats, covering an area of 293 km^2, was surveyed during 6–13 June 1982, 17–30 June 1992, and 16 June–2 July 1993. In 1993, 268 quadrats covering 211 km^2 were also surveyed from 22 April to 2 May. Surveys were conducted between 0500–1400 hr (PDT) in 1982 and between 0600–1400 hr in 1992 and 1993.

Sealy and Carter (1984) divided quadrats in Clayoquot Sound into 3 habitat types (fiord, channel and inshore) based on Kessel's (1979) general classification system. In the study area, inshore waters were exposed to open ocean conditions within 2–6 km from shore; channel waters were partly bounded and protected by land, with 2 or more entrances and usually < 2 km wide; and fiords were long, narrow, protected inlets with 1 entrance and < 2 km wide. In 1992–1993, contiguous areas of channel, inshore, and fiord areas were defined (Fig. 1). We attempted to survey each contiguous area entirely (*e.g.*, C1, C2) and specific fiord areas on a single survey day to minimize the effects of local movements of birds.

In all 3 yr, murrelets were counted by 1 observer from a 4-m inflatable boat powered by a 15-hp outboard motor at speeds between 5–20 km/hr, depending on the density of birds. The single observer recorded observations and stopped when required to look at the chart for navigation. Quadrats were defined by lining up landmarks such as shorelines, islands, rocks and reefs as much as possible, but when away from shore, some approximation of distances was necessary and a compass was used to aid in orientation. This was not extremely difficult because few areas were more than 1–2 km from shore in 1 or more directions within the study area. The boat was steered through each quadrat in either a "U-shaped" or "S-shaped" path, whichever was required to link quadrats and avoid rocks, taking care not to double count on the corners. This method attempted to observe and count all birds within quadrat boundaries, therefore, birds were counted out to 250 m on both sides of the boat. Surveys were only conducted in good conditions, in seas < 0.5 m usually on calm or rippled water.

In all surveys, the outer rows of quadrats (Inshore 3 [i3]; Fig. 1) were surveyed by 1 observer using a fixed-distance transect method from 10–12-m long fishing vessels steered by radar through the center of the quadrats, as in Sealy and Carter (1984). The division between quadrats was determined by time increments, recording observations in 1–2-min blocks. The speed of the fishing boat was recorded for these blocks and varied from 7–13 km/hr with sea conditions. Binoculars were used to scan far from the boat and to confirm identification when necessary.

The number and flock size of marbled murrelets

TABLE 1. Numbers of marbled murrelets in marine habitats of southeast Clayoquot Sound in 1982, 1992 and 1993.

	Inshore	Channel	Fiord	Total
Area (km^2)	109	124	60	293
1982				
Number of birds (%)	3056 (67.9)	1458 (32.4)	8 (0.18)	4522
Birds/km^2	28.0	11.8	.13	15.4
1992				
Number of birds (%)	1560 (57.8)	1126 (41.7)	15 (0.55)	2701
Birds/km^2	14.3	9.1	0.25	9.2
1993				
Number of birds (%)	856 (32.6)	1764 (67.3)	2 (0.08)	2622
Birds/km^2	7.9	14.2	0.03	8.9
1993 spring				
Area	45	121	55	211
Number of birds (%)	354 (21.7)	1160 (69.2)	150 (8.9)	1674
Birds/km^2	8.1	9.6	2.7	7.6

on the water or flying were recorded in all quadrats, but only numbers of birds on the water were used to determine population size and distribution. The number of birds counted in each quadrat was compared between survey years by calculating the difference (*e.g.*, subtracting the number of birds in 1992 from the number of birds counted in 1982) for each quadrat. The average difference was compared between all survey years for all quadrats with birds present and for channel and inshore quadrats using paired *t*-tests (Zar 1984). Copies of marine charts marked with the grid system and numbered quadrats have been archived at the Royal British Columbia Museum in Victoria, British Columbia, and at the Western Foundation of Vertebrate Zoology in Camarillo, California.

RESULTS

In 1992, 2704 birds were counted on the water in southeast Clayoquot Sound (Table 1). An additional 419 birds were counted flying over quadrats (without landing on or taking off from the water), however, they were not included in the calculation of densities or population size because they were considered to be *en route* to areas yet to be counted or from areas already counted (after Sealy and Carter 1984). The average density observed in the 341 quadrats surveyed was 9.2 birds/km^2. Birds were clumped with highest densities in inshore and channel waters (14.4 and 9.1 birds/km^2, respectively) and much lower density (0.3 birds/km^2) in fiord waters (Table 1, Fig. 2). In 1992, 185 quadrats (54.3%) were empty, occurring mainly in fiord and inner channel waters. For 156 occupied quadrats, 53.8% were low density (1–10 birds/quadrat), 41.0% were medium density (11–50 birds/quadrat) and 5.2% were high density (> 51 birds/quadrat). The highest number of birds (188) was observed in an inshore quadrat. Of 2704 birds observed, most (36.9%) occurred in pairs, followed by single birds (24.4 %), groups of 3 birds (10.2%), 4 birds (8.6%), 5 birds (5.2 %), 6–10 birds (8.0 %) and 11 or more birds (6.7%). The largest flock size observed on the water was 18 birds. Thirteen juvenile murrelets (based on plumage differences [Carter and Stein 1995]) were observed within quadrats from 19–26 June, which represented 0.6% of the total number observed during that period.

In 1993, we counted 2622 birds on the water and 202 flying birds in southeast Clayoquot Sound (Table 1). The highest density of birds occurred in channel waters in 1993 (14.2 birds/km^2), followed by inshore waters (7.9 birds/km^2) and very low densities of birds in fiord waters (0.03 birds/km^2) (Table 1, Fig. 3). A small shift in the distribution of birds occurred between 1992 and 1993, with a higher proportion in channel waters (67.3% in 1993) and a smaller proportion counted in inshore waters (32.6% in 1993; Table 1). For 124 occupied quadrats, 54.1% were low density, 31.4% were medium density, and 14.5 % were high density. Most observations were of pairs of birds (37.1 %), followed by single birds (21.9%), 3–5 birds (18.0%), ≥ 11 birds (12.1%), and 6–10 birds

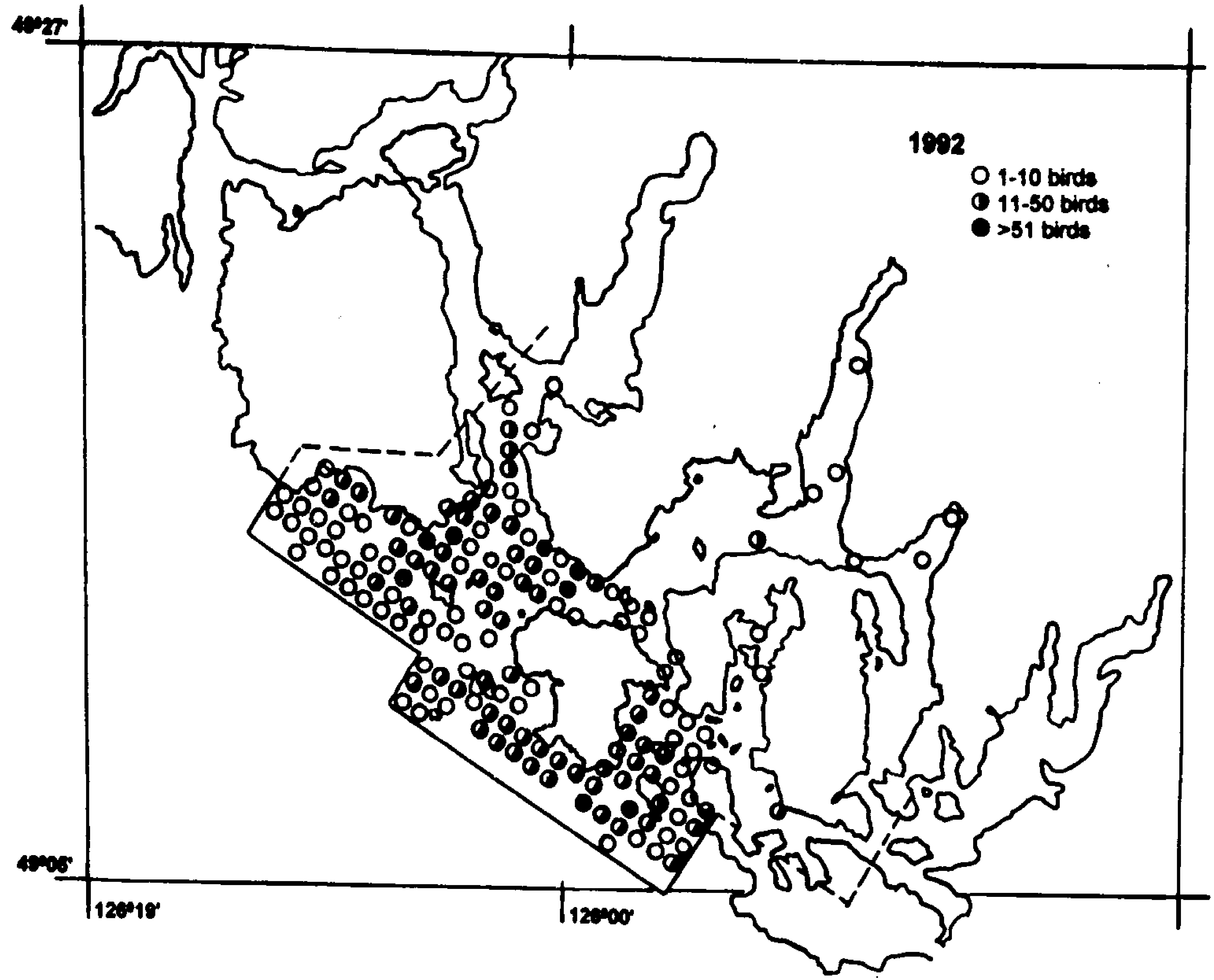

FIGURE 2. Map of southeast Clayoquot Sound showing the distribution and density of birds in each 1-km quadrat for the 1992 area surveys.

(10.9 %). Four juveniles were observed during surveys. On additional surveys done from 22 April to 5 May, 1674 birds were counted with an average of 7.6 birds/km^2 (Table 1). During these "spring" surveys, pairs of birds were more prevalent (43.1%), whereas single birds were less prevalent (11.4%) than in surveys conducted in June. Eight birds (0.5%) were observed in basic plumage during the spring survey. These birds probably were subadults undergoing late pre-alternate molt (Carter and Stein 1995).

Comparison to the 1982 Survey

In 1982, 4500 birds were counted on the water and 528 birds were observed flying within the same area of southeast Clayoquot Sound that was surveyed in 1992-93 (Table 1; Sealy and Carter 1984). Thus, for the entire study area, numbers of birds on the water were 40.0% and 41.7% lower in 1992 and 1993, respectively, than in 1982. Within inshore waters, murrelet numbers declined from 3056 birds in 1982 to 856 birds in 1993 (Table 1). The greatest change occurred in i3 waters where counts decreased from 1065 birds in 1982 to 11 birds in 1993 (Table 2). Numbers of juvenile birds were 4 in 1982, 13 in 1992, and 4 in 1993.

The clumped dispersion pattern of murrelets in the study area was similar in 1982, 1992 and 1993 (Figs. 2–4). The overall distribution also was similar with most birds occurring in inshore and outer channel habitats in all years, especially in 2 main aggregations southeast of Flores and Vargas islands. In fiord waters, birds were found in very low densities (< 0.2 birds/km^2) and in the same general areas in all years, except during the spring 1993 surveys (Table 1).

In 1982, Sealy and Carter (1984) identified 2 large aggregations of murrelets in southeast Clayoquot Sound that contained 60% of all birds counted. These aggregations were de-

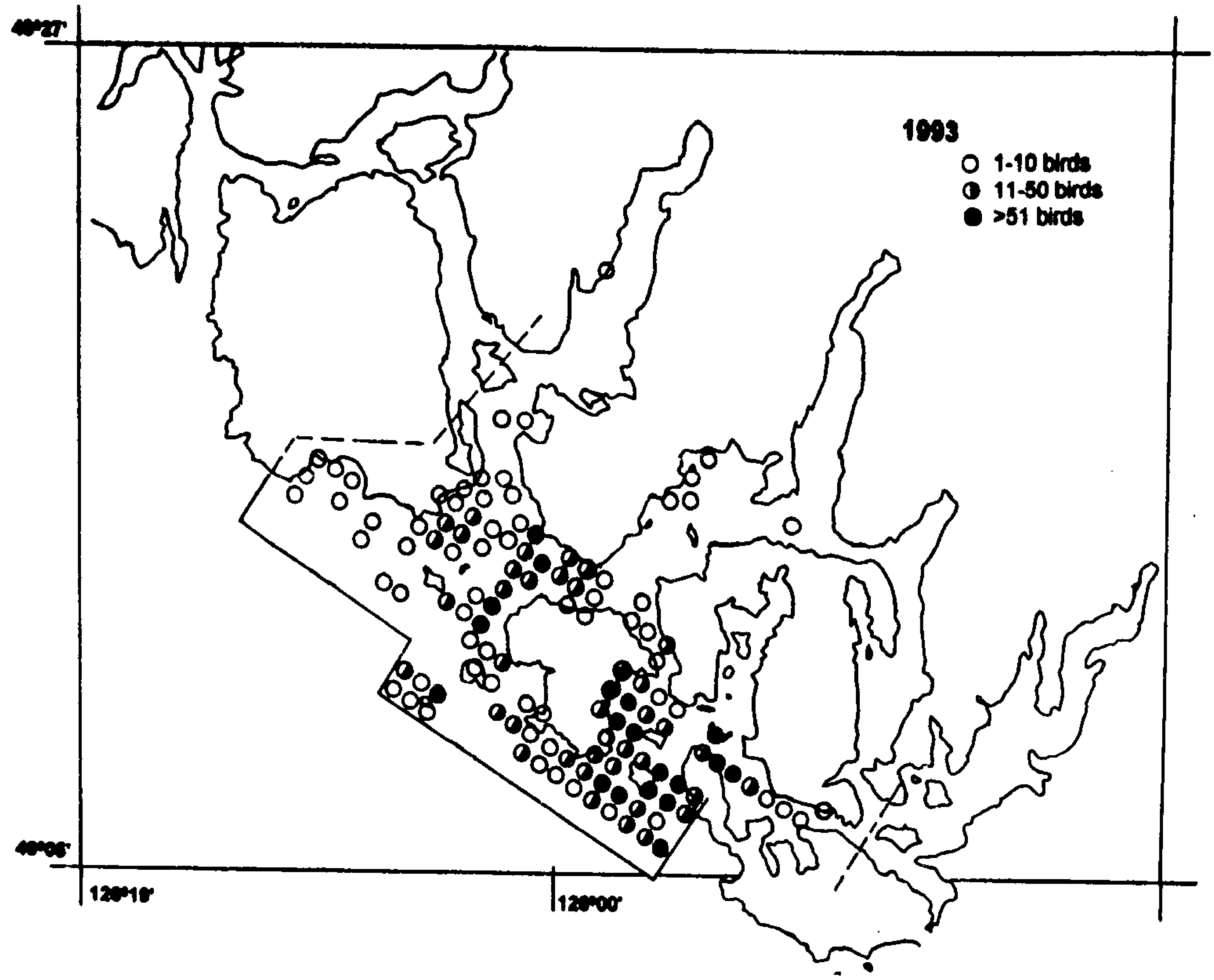

FIGURE 3. Distribution and density of birds in each 1-km quadrat in Clayoquot Sound in 1993.

fined as areas of contiguous medium-density and high-density quadrats and were located in channel and inshore habitats southeast of both Flores and Vargas islands (Figs. 1, 4). In 1992–1993, aggregations also were found in these general locations (Figs. 2, 3). The aggregation located southeast of Flores Island was smaller in area and numbers of birds in 1992–1993, whereas the aggregation southeast of Vargas Island occurred in an area of similar size and contained slightly higher numbers in 1992 (501 birds) and 1993 (940 birds) than in 1982 (417 birds). In 1993, this aggregation occurred in more sheltered waters than in previous years (Fig. 3).

TABLE 2. Marbled murrelet numbers in specific channel and inshore areas of Southeast Clayoquot Sound in 1982, 1992 and 1993.

Location	Area (km^2)	Number of birds 1982	1992	1993
Channel 1 Tofino area	24.0	204	294	1063
Channel 2 Calmus passage	23.0	480	436	575
Channel 3 Ahousat area	25.0	821	371	110
Inshore 1 Outer Vargas	32.3	415	877	665
Inshore 2 Ahous Bay	43.5	1605	608	231
Inshore 3 Large boat transects	38.0	1065	78	11

Considering all occupied quadrats ($N = 205$), 8.9 fewer birds were observed per quadrat in 1992 ($p < 0.01$), and 9.2 fewer birds were observed per quadrat in 1993 ($p < 0.01$) compared to 1982. Numbers of birds per quadrat did not differ between 1992 and 1993 ($p = 0.9$). For 109 inshore transects, 13.7 fewer birds were observed per quadrat in 1992 ($p = 0.02$), and 20.6 fewer birds were observed per quadrat in 1993 ($p < 0.01$) compared to 1982. There were 6.3 fewer birds per inshore transect in 1993 compared to 1992 ($p < 0.01$). For 165 channel transects, birds per transect in did not differ in 1992 and 1993 compared to 1982, but there was an

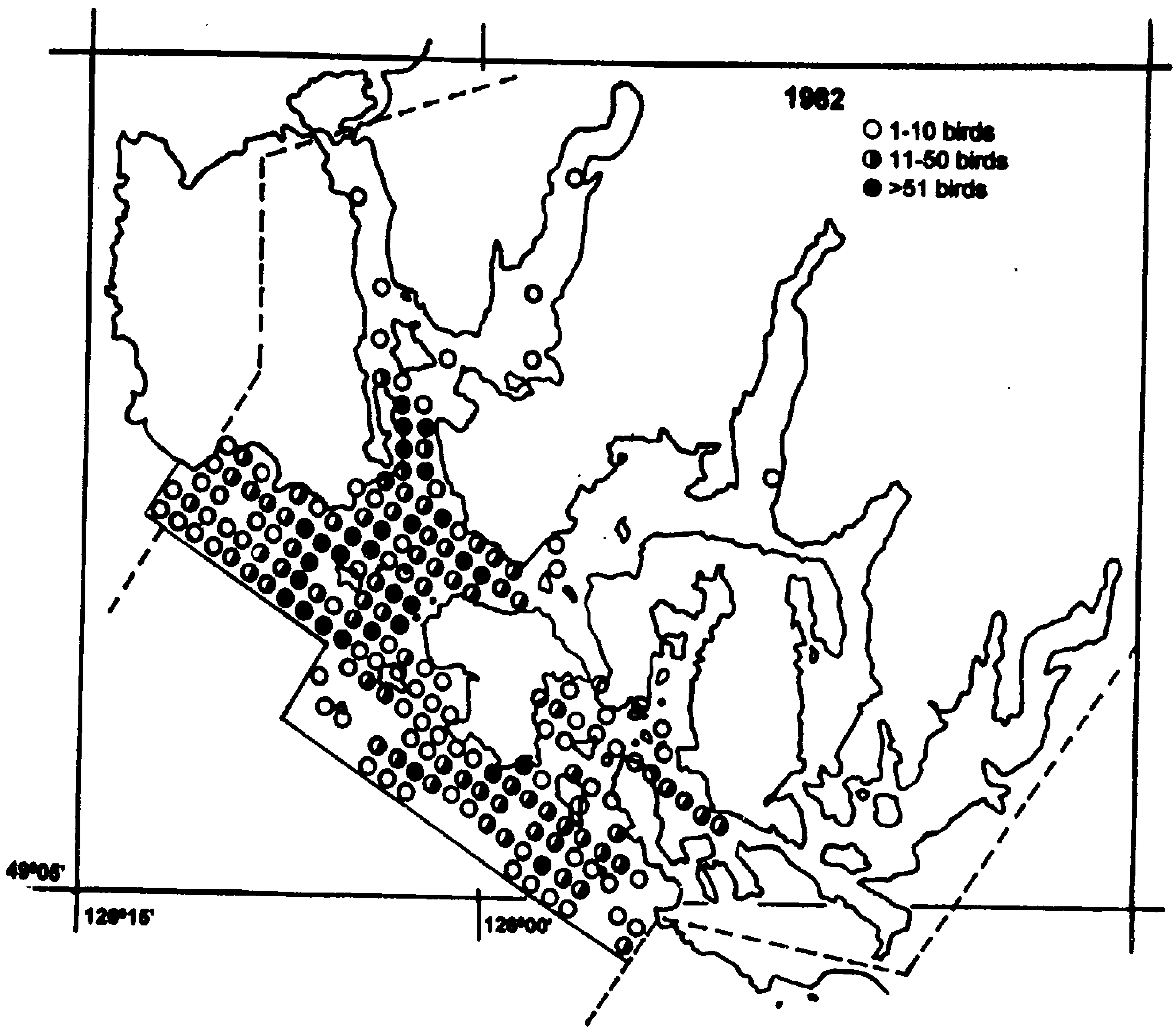

FIGURE 4. Distribution and density of birds in each 1-km quadrat in Clayoquot Sound in 1982.

average of 4.0 more birds per transect in 1993 than in 1992 ($p = 0.02$).

DISCUSSION

To best assess long- and short-term trends in the at-sea numbers of marbled murrelets in Clayoquot Sound, it would be desirable to conduct a survey each year. Also, given the difficulties of interpreting at-sea survey data, trends should be confirmed using several different survey techniques. At this time, we must rely on surveys conducted 10–11 yr apart to make a general assessment of population trend. Despite the standardization of our at-sea survey technique, several factors must be considered that may affect the variability of numbers and distribution of murrelets at sea, and their countability in each survey. Changes in the natural environment and anthropogenic threats to the murrelet population, which may have resulted in changes in population size, also must be examined.

Variability in Numbers of Birds at Sea

This survey technique was designed to reveal the distribution and approximate population size of the marbled murrelet in an area with a mosaic of marine habitats (as found along the coasts of northern Washington, British Columbia and Alaska). In such areas, bird densities change dramatically over short distances. In Clayoquot and Barkley sounds, marbled murrelets have a clumped dispersion pattern that reflects selection of certain habitats for foraging and feeding as well as local movements (Carter 1984, Sealy and Carter 1984, Carter and Sealy 1990). It is difficult to sample a small area to describe accurately the general abundance or

association with certain habitats because of high count variability (*e.g.*, Savard and Lemon 1992), and extrapolations from smaller to larger areas to determine estimates of population size are unreliable. Our surveys attempted to account for variable bird distributions by covering a large area, but because of this we were unable to examine variation in numbers seasonaly within the same quadrats.

To minimize variability caused by daily movements, the dates and time of day of 1992 and 1993 surveys were standardized with the 1982 surveys. The 1982 counts were conducted in June to coincide with the nestling period of murrelets, and during the morning because murrelet numbers varied less during that time (Carter 1984, Carter and Sealy 1990). We surveyed large contiguous areas on each survey day. In Clayoquot and Barkley sounds, murrelets formed feeding aggregations that tended to occur in the same general areas from day to day during the nestling period (Carter 1984, Sealy and Carter 1984, Carter and Sealy 1990). Local movements occurred and numbers fluctuated within specific areas but aggregations were present each day at particular localities, presumably because of a clumped dispersion of prey (Carter 1984, Carter and Sealy 1990).

Methods

Differences in weather/sea conditions and observers may have affected results. The 1982 survey was conducted by H. R. Carter, and the 1992 and 1993 surveys were conducted by J. D. Kelson. Prior to the 1982 survey, H. R. Carter had several years experience conducting seabird and murrelet surveys. On the other hand, J. D. Kelson had counted murrelets during only 1 season, but had the benefit of Carter's assistance and explanation of survey methods, as well as a data recorder to facilitate data collection. Detailed maps and descriptions of methods were provided to duplicate exactly the 1982 survey. Weather and sea conditions occurring within the study area included fog and swells in the inshore waters, and wind and chop in fiord and channel areas. As these factors can effect the detectability of murrelets, surveys were done only when swells were < 0.5 m and seas were flat or rippled. Weather conditions were more strictly adhered to in 1992–1993 than in 1982 but generally surveys were conducted in good viewing conditions in all years.

Recent studies done in California and Oregon indicate that all murrelets may not be detected beyond 100–150 m from small boats (Ralph et al. 1990, Strong 1995). These studies also used 2–3 persons observing and driving instead of 1 person in our surveys. Our counts of birds out to 250 m on each side of a small boat, or out to 500 m on each side of a larger vessel, may have produced underestimates of actual population sizes. Therefore, our density and population results represent relative estimates, but the same methods were employed in 1982 and 1992–1993 so that these relative estimates could be compared. Data from large and small boat surveys were combined to make this comparison even though the methods were different. The large vessel surveys conducted in the i3 area (Fig. 1) probably produced the most variable results because the navigation methods were less precise and the transect width was greater. This area had the largest change in murrelet numbers in our 3 surveys (Table 2, Fig. 2).

El Niño

Seabird populations on the west coast of North America (as far north as southern British Columbia) can be affected by El Niño oceanographic conditions (Vermeer 1979, Ainley et al. 1988, Ainley and Boekelheide 1990, Wilson 1991, Vermeer 1992). El Niño conditions often are detected by anomalously high sea-surface temperatures and can create food shortages that cause poor breeding success, and possibly subadult and adult mortality among certain seabird species. In British Columbia, lowered reproductive success of seabirds has been noted during El Niño years at Triangle Island off the north end of Vancouver Island (Vermeer 1979), but there is little other information on the effect of El Niño on seabirds and their prey. Because southern British Columbia is found at the northern end of the California Current, it is likely that the effects of El Niño are ameliorated compared to California.

Freeland (1992) examined sea-surface temperature anomalies at Amphitrite Point, near Clayoquot Sound, from 1934 to 1991. In January–June 1982 (prior to and during the 1982 survey), temperatures were about average as was also found in 1984–1986 and 1991. However, 1–1.5° C higher than normal temperatures occurred in 1980, 1981, July 1982-1983, 1987,

1988, 1990, 1992 and 1993. Thus, El Niño conditions began in mid-1982 in Clayoquot Sound as also noted in California (Ainley and Boekelheide 1990). However due to late timing, the effects of the 1982 El Niño were minimal, leading to lower reproductive success in only a few species in California.

In January–August 1992 and April–May 1993, water temperatures at Amphitrite Point were about 1–1.5° above average (H. J. Freeland, pers. comm.), indicating the presence of El Niño conditions on the west coast of Vancouver Island. In nearby Barkley Sound, murrelets fed extensively on Pacific herring (*Clupea harengus*), Pacific sandlance (*Ammodytes hexapterus*) and northern anchovy (*Engraulis mordax*) in 1979 and 1980 (Carter 1984, Carter and Sealy 1987b, Rodway et al. 1992). In 1992 and 1993, influxes of mackerel (*Scomber japonicus*) and horse mackerel (*Trachurus symmetricus*) occurred in Barkley Sound that decimated local stocks of juvenile herring and euphausids (B. Hargreaves, pers. comm.). Mackerel also were observed in Clayoquot Sound and may have affected prey abundance or distribution for murrelets. If prey changes caused some murrelets to leave the study area, all murrelets may not have been equally countable in all survey years. Some birds could have moved farther offshore, to northwest Clayoquot Sound or south to the Long Beach area. In 1982, 556 and 1214 birds were counted in northwest Clayoquot Sound and Long Beach areas, respectively (Sealy and Carter 1984). Morgan et al. (1991) reported a flock of 235 murrelets on the continental shelf south of Clayoquot Sound in 1986.

Although our data showed similar numbers of birds in 1992 and 1993, El Niño conditions may have affected murrelet distribution within the study area between years. The movement from inshore to channel waters indicated a shift to shallower water. In 1993, murrelet aggregations formed in the shallow sandy banks N and SE of Vargas Island and SE and SW of Tofino, in spite of heavy boat traffic in these areas (Fig. 2B).

Other possible effects of El Niño conditions over longer time periods are decreased reproductive success and reduced juvenile survival (Ainley et al. 1988, Ainley and Boekelheide 1990). Beached bird surveys indicated above-average mortality of fledgling rhinoceros auklets (*Cerorhinca monocrata*) and common murres (*Uria aalge*) in 1992 in Barkley Sound; however, no information on murrelets was available from these surveys (A. E. Burger, pers. comm.). In 1993, a dead juvenile murrelet was found in Clayoquot Sound, but no information is available yet on the cause of death (I.A. Manley, unpubl. data).

Gill-net Fishing and Oil Pollution Mortality

Marbled murrelets have been killed in gillnets in Alaska, British Columbia and California (Carter and Sealy 1984, Carter et al. 1995). Carter and Sealy (1984) estimated that 6.2% of breeding birds were killed annually in 1979 and 1980 in Barkley Sound. No gill-net fishing occurred in Clayoquot Sound between 1982 and 1992, but murrelets breeding in Clayoquot Sound may be killed by gill-nets in other areas, possibly near southern Vancouver Island in the fall or Puget Sound in winter. Similarly, no major oil spills have occurred in or near Clayoquot Sound but local breeders may be killed by oil pollution in wintering areas or during movements. At least 100 murrelets were killed in the December 1988 *Nestucca* and the July 1991 *Tenyo Maru* oil spills off the Washington Coast, but the origins of dead birds were not determined (Rodway et al. 1989; Burger 1991; Carter and Kuletz 1995; R.G. Ford, pers. comm.). Murrelets appear to move from breeding areas on the west coast of Vancouver Island to the Strait of Georgia, Juan de Fuca Strait and Puget Sound in the fall and winter (Rodway et al. 1992, Speich et al. 1992, Vermeer and Morgan 1992). Winter distribution of murrelets from the Clayoquot Sound population is not known, but it is unlikely that mortalities from spills to date have amounted to significant levels because birds appear to be distributed widely during winter.

Loss of Nesting Habitat

The permanent removal of old-growth forest nesting habitat by logging has been identified as the greatest threat facing marbled murrelets in British Columbia and throughout their range in North America (Sealy and Carter 1984, Marshall 1988, Carter and Morrison 1992, Rodway et al. 1992, U.S. Fish and Wildlife Service 1992). Marbled murrelets probably nest widely in all forested areas of Clayoquot Sound, with local concentrations of birds and nests occurring in large-volume, low-elevation forests near the

coast (Manley et al. 1992, Rodway et al. 1993, Hamer and Nelson 1995a, Jordan and Hughes 1995, Manley and Kelson 1995). Two marbled murrelet nest sites found in Clayoquot Sound were in large old-growth trees (1.25 and 2.28 m dbh) located at 580 m and 14 m elevation (Manley et al. 1994).

By 1954, 2.8% of the old-growth forests had been removed (Conservation International 1992). By 1972, 15.2% of old-growth forests had been removed, mainly in southeast Clayoquot Sound. Sealy and Carter (1984) determined that 7.4% of old-growth forests had been removed, using 1977-1980 data submitted by logging companies to the British Columbia Forest Service and other forestry documents. However, by comparing these results with Landsat satellite imagery, Trans Mercator (TM) projection (Conservation International 1992), it is clear that the degree of old-growth forest removal was underestimated using this technique. By 1990, 37,000 ha of forest had been logged representing 24.5% of habitats that the Sierra Club (from Landsat TM) considers forested area, or 15.1% of habitats that British Columbia Ministry of Forests considers forested area. This discrepancy is due to differing opinions of whether scrub and bog forest habitats represent truly forested areas. In any case, scrub and bog forests probably do no offer potential habitat to nesting murrelets. Of the 37,000 ha logged, 93% occurred in coastal western hemlock forests less than 600 m elevation (Pojar et al. 1987), essentially the lowest elevation, largest volume forests in Clayoquot Sound. It is therefore likely that considerable murrelet nesting habitat no longer exists. The observed 40% decline in Clayoquot Sound may be related to the removal of 15–25% of old-growth forest nesting habitat by logging.

Management Recommendations

The degree, rate and progress of decline of marbled murrelets in Clayoquot Sound needs to be substantiated further and carefully monitored. In particular, surveys need to be conducted in non-El Niño years to determine if large changes in murrelet populations and distribution occur due to this natural phenomenon. Feeding ecology, nesting habitat, productivity, and winter ecology require study to assess better the impact of the factors discussed here. It will be important to repeat at-sea surveys periodically. Locations of murrelet nesting areas also must be determined to understand better the impacts of habitat loss. Local and regional management strategies should be developed to prevent local extinction in Clayoquot Sound and elsewhere in southern British Columbia.

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