SEASONAL AND SPATIAL VARIATIONS IN DENSITIES OF MARBLED MURRELETS *BRACHYRAMPHUS MARMORATUS* OFF SOUTHWESTERN VANCOUVER ISLAND

ALAN E. BURGER[1] & E. ANNE STEWART[2]

[1]*Department of Biology, University of Victoria, Victoria, British Columbia, V8W 3N5, Canada (aburger@uvic.ca)*
[2]*Box 41, Bamfield, British Columbia, V0R 1B0, Canada*

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ABSTRACT

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The ocean off Vancouver Island, British Columbia, is a productive area supporting diverse marine life, including a globally important breeding population of Marbled Murrelets *Brachyramphus marmoratus*. We report on the year-round at-sea distribution and densities of this murrelet off southwestern Vancouver Island based on monthly vessel surveys in 1993–2000. Surveys covered three ocean zones: Nearshore (sheltered waters, usually < 20 m deep, within 1–2 km of shore; 69 surveys), Inshore (exposed coastal waters, < 50 m deep, within 6 km of shore; 38 surveys), and Offshore (exposed open seas over the continental shelf, > 50 m deep, generally > 6 km from shore; 29 surveys). Year-round mean densities (± standard deviation, in birds/km^2) for Nearshore, Inshore and Offshore waters were 4.5 ± 5.8, 1.5 ± 1.2, and 0.2 ± 0.2, respectively. During peak breeding season (May–July), densities were 13.7 ± 2.3, 3.3 ± 0.2 and 0.2 ± 0.1 birds/km^2, respectively. Our data confirm that most murrelets leave this area outside of the breeding season, and very few move into the open ocean at this time. Post-breeding movements, molt locations, and winter distribution of these birds remain poorly known, highlighting the need for more surveys outside the breeding season and across the murrelet's range. Due to high vessel traffic, including many oil tankers, and ongoing chronic oil spills, murrelets off southwestern Vancouver Island are exposed to high risk of oil pollution, particularly during the summer and close to shore. Gill nets and disturbance from boats are additional risks.

Key words: at-sea surveys, distribution, Marbled Murrelet, southwestern Vancouver Island, year-round densities

INTRODUCTION

Year-round censuses of mid- to high-latitude seabirds at sea are rare (e.g., Briggs *et al.* 1987). This is largely due to the limitations and expense of vessel or aircraft time, in addition to inclement winter weather. Such censuses, however, are essential for assessing the roles of seabirds in marine ecosystems; factors affecting or limiting local populations; migration patterns; and risks from oil spills, fishing, and other human activities (Arimitsu *et al.* 2023). We report on surveys of Marbled Murrelets *Brachyramphus marmoratus* (hereafter murrelets) off southwestern Vancouver Island, British Columbia, Canada, by repeatedly sampling fixed transect routes year-round in three distinct marine zones. Southwestern Vancouver Island supports a globally significant breeding population of this threatened species (Burger 2002, Piatt *et al.* 2007, COSEWIC 2012), but year-round densities, movements, and marine habitat use in this area remain poorly documented.

The goals of our study are three-fold. First, we provide year-round density data across a range of marine habitats used by murrelets. In particular, our surveys off fill a spatial gap between the nearshore surveys (generally < 1 km from land) usually undertaken to monitor murrelets, especially during their breeding season (e.g., Carter 1984, Burger *et al.* 2008, Lorenz *et al.* 2016), and pelagic surveys of seabirds usually done > 3 km from land (e.g., Hay 1992, Logerwell & Hargreaves 1996, Kenyon *et al.* 2009). The continental shelf and coastal ecosystems off Vancouver Island are highly productive, supporting important fisheries and large populations of resident and migratory seabirds (Vermeer *et al.* 1987, 1989; Hay 1992; Logerwell & Hargreaves 1996; Burger 2003; Burger *et al.* 2004; Kenyon *et al.* 2009), but none of these studies focused on Marbled Murrelets. Murrelet use of offshore marine habitats across their range remains unclear. Off Alaska, USA, murrelets are regularly found in offshore pelagic seas up to 300 km from land, especially outside the breeding season (Piatt *et al.* 2007, Kuletz *et al.* 2013). However, in the California Current (continental USA from Washington to California), murrelets are seldom found more than 5 km from shore and there is no evidence of movements offshore outside the breeding season (Briggs *et al.* 1987, Nur *et al.* 2011, Adams *et al.* 2014).

Second, we contribute to understanding the seasonal movements of murrelets relative to their breeding locations. Some murrelets breeding in the forests of southwestern Vancouver Island remain in nearshore waters outside of the breeding season, but the majority move away and densities decrease in fall through spring (Burger 1995, 2002; Burger *et al.* 2008). We examine whether these birds disperse further offshore when not tied to breeding sites.

Third, we provide essential baseline information on the exposure of murrelets to oil spills, gill-netting, boat disturbances, and other anthropogenic risks. In particular, our data fill a spatial gap in information on marine bird densities near the mouth of the Strait of Juan de Fuca, which is important for four reasons. First, there is heavy tanker and other shipping traffic (Serra-Sogas *et al.* 2008, O'Hara *et al*. 2013, McWhinnie *et al.* 2021, O'Hara *et al.* 2021), which will significantly increase with the completion of the Trans Mountain oil pipeline to Vancouver in 2024, adding an additional 350 tankers per year (Bertram *et al.* 2023a). Second, this area has frequent oil pollution, including smaller spills that are often unreported (O'Hara *et al.* 2013, Fox *et al.* 2016). Murrelets are among the most vulnerable birds to oil spills, because they spend most of their time on the water and are often found near active shipping lanes (King & Sanger 1979, Carter & Kuletz 1995). Third, murrelets are at high risk of entanglement with gill nets (Carter *et al.* 1995). Although gill-netting off British Columbia has decreased in recent decades, this remains a concern for Marbled Murrelets (Bertram *et al.* 2021). Fourth, murrelets in this area are negatively impacted by disturbances from vessel traffic and recreational boats (Hentze 2006, Bellefleur *et al.* 2009). Our data date back two decades but remain valuable because there have not been any comparable surveys in this area since then. Current at-sea survey efforts over extensive areas off Vancouver Island will cover part of our study area (Fox *et al.* 2023).

Marbled Murrelets are a threatened species in Canada, where they have been the focus of considerable research (Burger 2002, Piatt *et al.* 2007, COSEWIC 2012). Southwestern Vancouver Island supports an estimated 11 500–14 300 murrelets in summer (Burger 2007), making up 11%–16% of British Columbia's breeding population (ECCC 2021). Several studies covered the marine distribution and densities of murrelets in this area, but with few exceptions (Burger 1995, Sealy 2020), these were restricted to the summer breeding season (Carter 1984; Sealy & Carter 1984; Carter & Sealy 1990; Kelson *et al.* 1995; Mason *et al.* 2002; Burger *et al.* 2008; Ronconi & Burger 2008, 2011). Our data are the first to show year-round densities in a range of marine habitats. Our study did not include deep fjords or coastal lakes (e.g., Nitinat Lake), in which murrelets are known to occur in small, scattered groups (Carter & Sealy 1986, Henderson & Sealy 2024, EAS & AEB pers. obs.).

METHODS

Study area and habitat definitions

Surveys covered three marine habitats (Nearshore, Inshore, and Offshore) whose definitions were modified from Kessel (1979). Here, Nearshore waters are protected coastal waters, including bays and inlets, that are generally shallow (usually < 20 m deep), within 1–2 km of shore, and have little heavy wave action. Inshore waters are exposed coastal waters that are less than 50 m deep, within 6 km of shore, and experience wave action from the open ocean. Offshore waters are exposed open seas over the continental shelf that are > 50 m deep and generally > 6 km from shore. We use the term Offshore for consistency with our other terms, but some researchers use the term to denote oceanic waters beyond the continental shelf break (e.g., Logerwell & Hargreaves 1996), which were not sampled in our study.

We sampled Nearshore waters within Trevor Channel, Barkley Sound, along a 43-km transect route that ran parallel to the shoreline at distances of 200–600 m from shore for most of the route (Fig. 1A). This is the same marine area sampled by Carter (1984), but with different sampling methods. Data from our Nearshore surveys are presented in two ways: a) the full data set covering surveys between July 1994 and July 2000 (hereafter "Nearshore all data," *n* = 69 surveys); and b) data from July 1994 to December 1995, which more closely matched the timing of the Inshore and Offshore surveys (hereafter "Nearshore matching data," *n* = 34).

Inshore waters were sampled between May 1993 and December 1995 along an L-shaped transect route averaging 19.4 km. It ran down the middle of Trevor Channel, across the shallow ocean front near Cape Beale onto the shelf, and then parallel to the shore to end at Seabird Rocks (Trevor and Beale transect legs in Fig. 1B; *n* = 38 surveys).

Offshore waters were sampled over the same period (1993–1995) along a 117-km transect route, following a rough rectangle in a clockwise direction from Seabird Rocks (Fig. 1B; *n* = 29 surveys). Offshore water depths were 50–60 m on the Pachena leg, the Inshelf leg, and the shoreward half of the Crosshelf leg; 60–220 m on the Canyon leg, which covered the shelf edge and part of the Juan de Fuca Canyon; and 80–120 m on the Offshelf leg and the seaward half of the Crosshelf leg. Between November and mid-March, when daylight was limiting, the transect ran diagonally across the shelf from the seaward end of the Canyon leg to the junction of the Trevor and Beale legs. The average distance covered in the Offshore surveys year-round was 93 km per survey.

Sampling protocols

In all three sample sets, murrelets and all other marine birds (Burger 2003, Burger *et al.* 2004) were counted from a vessel moving at a relatively constant speed that averaged 8 knots (14.8 km/h) and usually stayed within a range of 7–10 knots (13.0–18.5 km/h). The vessel was occasionally slowed to permit counting and identification of birds in dense flocks. Observations were made by two observers simultaneously, one on either side of the vessel, who scanned horizontally from straight ahead to 90° from the vessel's track. All birds within 150 m on either side of the vessel were included in the 300-m wide strip transect. Tests in these waters found 39%–59% detectability of Marbled Murrelets within 150 m of a rigid-hull inflatable boat (hull length 5 m) travelling at approximately 10 km/h (Ronconi & Burger 2009). This boat was similar to those used in our Nearshore surveys. Detectability was likely higher from our larger Offshore and Inshore survey vessels, but all densities, particularly those from Nearshore surveys, are likely underestimates. Birds within the transect strip were recorded in one-minute intervals, during which time a vessel travelling at 8 knots moves 250 m. Birds flying more than 250 m ahead of the vessel, following the vessel, or crossing behind the vessel were not counted. Flying birds and those on the water were recorded separately, but these data were pooled in this analysis to simplify comparisons among habitats and with other pelagic data (Kenyon *et al.* 2009). Fine-scale analyses of habitat use and spatial grouping reported elsewhere focused on birds on the water (Burger *et al.* 2008).

Survey data were recorded vocally on a tape recorder by the observers (Nearshore) or on paper by a third person (Inshore and Offshore). Surveys were usually restricted to periods when winds and seas were at Beaufort sea state 3 or less (i.e., winds < 5.5 m/s, wave heights of 0.6 m or less, scattered white-caps from breaking wavelets), although data were collected during a few Offshore transects during brief periods of stronger winds to maintain continuity. In Nearshore and Inshore waters, Ronconi & Burger (2009) reported no significant difference in detecting murrelets from a small boat in sea states 1–3, but there was slightly higher detection in calm seas (sea state 0).

Nearshore surveys in Trevor Channel were made from open motorboats (hull length 4–5 m; eye level: 1.5–2.0 m above sea level). In most cases, the driver was one of the two observers.

Navigation was conducted using nautical charts from the Canadian Hydrographic Service and conspicuous landmarks. Inshore and Offshore surveys usually occurred from the 11-m research vessel M/V *Alta* (eye level: 2.0–2.5 m above sea level) and occasionally from other similar vessels, using Global Positioning System (GPS) for navigation. During Offshore transects, several observers took turns on duty to avoid fatigue.

Nearshore surveys were scheduled twice per month throughout the year, except when rough seas (i.e., continued Beaufort sea state > 3) precluded surveys in some winter months. Inshore and Offshore surveys were scheduled monthly; some winter surveys were missed due to bad weather, while 2–4 additional Inshore surveys were scheduled in some summer months (for sampling details, see Table A1 in the Appendix, available on the website).

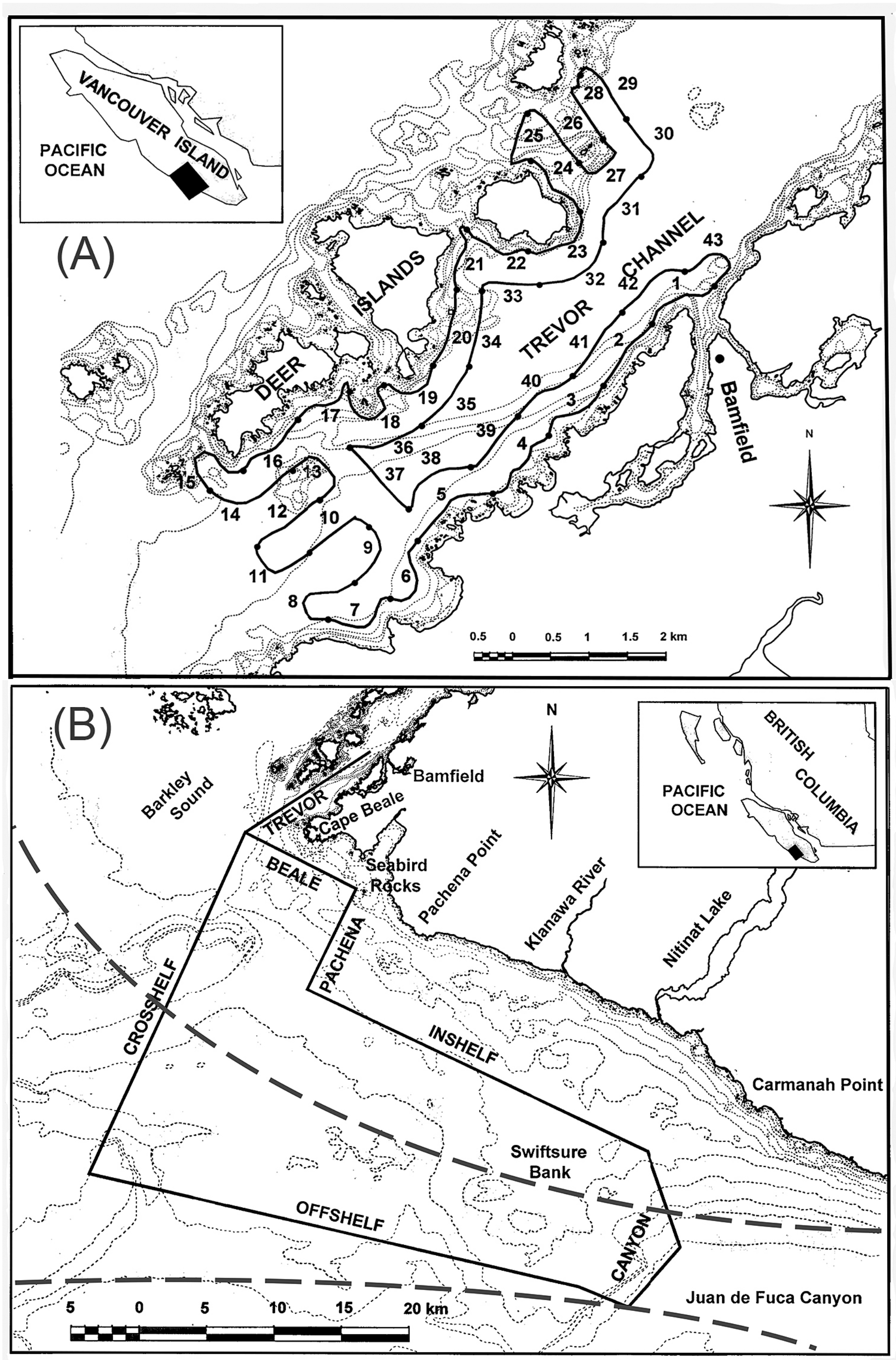

Fig. 1. Transect routes used for seabird counts off southwestern Vancouver Island, British Columbia, Canada. A) Nearshore surveys were made along a 43-km route in Trevor Channel. Numbers along the route indicate the kilometer marker. Depth contours are shown at intervals of 2, 5, 10, 20, 30, 40, and 50 m. B) Inshore surveys along the Trevor and Beale legs averaged 19 km, while Offshore surveys along the remaining legs over the shelf totalled 117 km. Depth contours are shown at intervals of 2, 5, 10, 20, 30, 50, 70, 100, 130, 150, 200, and 300 m. Bold dashed lines show the approximate boundaries of the shipping lanes transiting the Strait of Juan de Fuca, based on Serra-Sogas *et al.* (2008).

TABLE 1
Mean densities (birds/km²) of Marbled Murrelets *Brachyramphus marmoratus* in Nearshore (all data), Inshore, and Offshore vessel surveys off Vancouver Island, British Columbia, Canada. In each case, the means and standard deviations (SD) are calculated from monthly averages.

	Nearshore	Inshore	Offshore
a) Year-round (n = 12 months)			
No. of surveys	69	38	29
Density ± SD	4.49 ± 5.79	1.50 ± 1.19	0.15 ± 0.21
% occurrence in surveys	97	82	52
Maximum no. birds per survey[a]	642	57	19
b) Peak breeding season (n = 3 months, May–July)			
No. of surveys	39	13	9
Density ± SD	13.72 ± 2.30	3.31 ± 0.17	0.24 ± 0.13
% occurrence in surveys	100	100	67

[a] High counts occurred during the peak of breeding for the Nearshore and Inshore surveys, but in February for the Offshore surveys.

To calculate mean densities throughout the year and within the peak breeding season (May–July), we used the mean for each month to avoid bias due to unequal monthly sampling (i.e., n = 12 year-round, n = 3 for peak breeding season).

RESULTS

Monthly trends and mean densities were similar in the "Nearshore all data" set (1994–2000) and the "Nearshore matching data" set (1994–1995; Fig. 2); further analysis focused on the all-data set.

Marbled Murrelets were found predominantly in the Nearshore waters, and to a lesser extent in the Inshore waters closest to the shore (Table 1, Fig. 2). Year-round, murrelets were found in 97% of Nearshore and 82% of Inshore surveys, and they were found in all surveys in these zones during the breeding peak. Very few murrelets ventured out to the Offshore zone at any time of year, but they were more likely to occur there in the months preceding the breeding season (Fig. 2).

DISCUSSION

Year-round, and especially during the breeding season, we found murrelets concentrated in the sheltered Nearshore zone and to a lesser extent in the more exposed Inshore zone. This distribution is consistent with other studies, which found most murrelets off Vancouver Island within 800 m of shore and in waters of 30 m or less in depth (Carter 1984, Carter & Sealy 1990, Burger 1995, Burger *et al.* 2008, Ronconi & Burger 2011). Likewise, the extremely low densities in the Offshore zone agree with other studies off Vancouver Island that were largely limited to summer sampling and showed little use of these waters by Marbled Murrelets, despite extensive use by other fish-eating alcids and other seabirds (Hay 1992, Logerwell & Hargreaves 1996, Burger *et al.* 2004, Kenyon *et al.* 2009). Our data are the first to show that this pattern persists throughout the year.

Our data show extensive post-breeding emigration by murrelets breeding in the forests of southwestern Vancouver Island. Murrelets left the area in late July and August, immediately after the end of breeding, and densities through the fall were extremely low. Several other studies show the same rapid decline in at-sea densities in late July and August in the Nearshore and Inshore waters in this area, following intensive use in May through mid-July (Carter 1984; Burger 1995; Burger *et al.* 2004, 2008; Ronconi & Burger 2011). Some murrelets returned to the area in winter (December–March), but the bulk of the local population returned at the onset of the breeding season in late April and May (Fig. 2).

The late-summer emigration of murrelets from these waters contrasts with an influx of other fish-eating alcids (Rhinoceros Auklets *Cerorhinca monocerata* and Common Murres *Uria aalge*) and many other seabirds, including into the zones closest to shore (Burger *et al.* 2004, 2008; Kenyon *et al.* 2009; Ronconi & Burger 2011). The relative abundance of possible prey in the Inshore and Offshore zones, estimated from hydroacoustic traces, was highest in summer, but significant numbers of prey fish remained throughout the year in the upper 20 m of the water column, which is accessible to murrelets (Burger *et al.* 2004). Ronconi & Burger (2011) attributed part of this emigration by murrelets to their avoidance of foraging in close proximity to the larger Common Murres, but it seems unlikely that such avoidance would apply across the large spatial range in which we sampled. Clearly, the emigration of murrelets from southwestern Vancouver Island is a regular annual event that cannot be explained by local scarcity of prey.

The late-summer emigration of murrelets from southwestern Vancouver Island occurs when post-breeding adults begin their complete prebasic molt and are flightless for several weeks (Nelson 2020). The low densities in August through December in all waters of this region, including the Inshore areas < 1 km from the rocky shore (Burger *et al.* 2008, Ronconi & Burger 2011), indicate that the molt takes place elsewhere for most local breeders.

It remains unclear where these murrelets from southwestern Vancouver Island go at the end of the summer, where they molt, and where they overwinter. The data presented here, corroborating results from previous surveys (Vermeer *et al.* 1987, 1989; Hay 1992, Kenyon *et al.* 2009), show that few move into offshore pelagic waters, unlike some of the murrelets breeding in Alaska

(Piatt *et al.* 2007, Kuletz *et al.* 2013). Burger (1995) suggested that many move into the sheltered waters of the Salish Sea (i.e., Strait of Georgia, Puget Sound, and eastern end of the Strait of Juan de Fuca), on the basis of increased winter numbers in some areas there. Surveys in the Salish Sea confirm the increase in murrelet numbers in fall through winter, although systematic surveys there are sparse outside of the breeding season (Speich *et al.* 1992; Bower 2009; Davidson *et al.* 2010; Butler *et al.* 2018a, 2018b; Ethier *et al.* 2020; Butler *et al*. 2021). Some surveys in this region show no increase in murrelet numbers during the non-breeding period (Pearson *et al.* 2022, Bertram *et al.* 2023a).

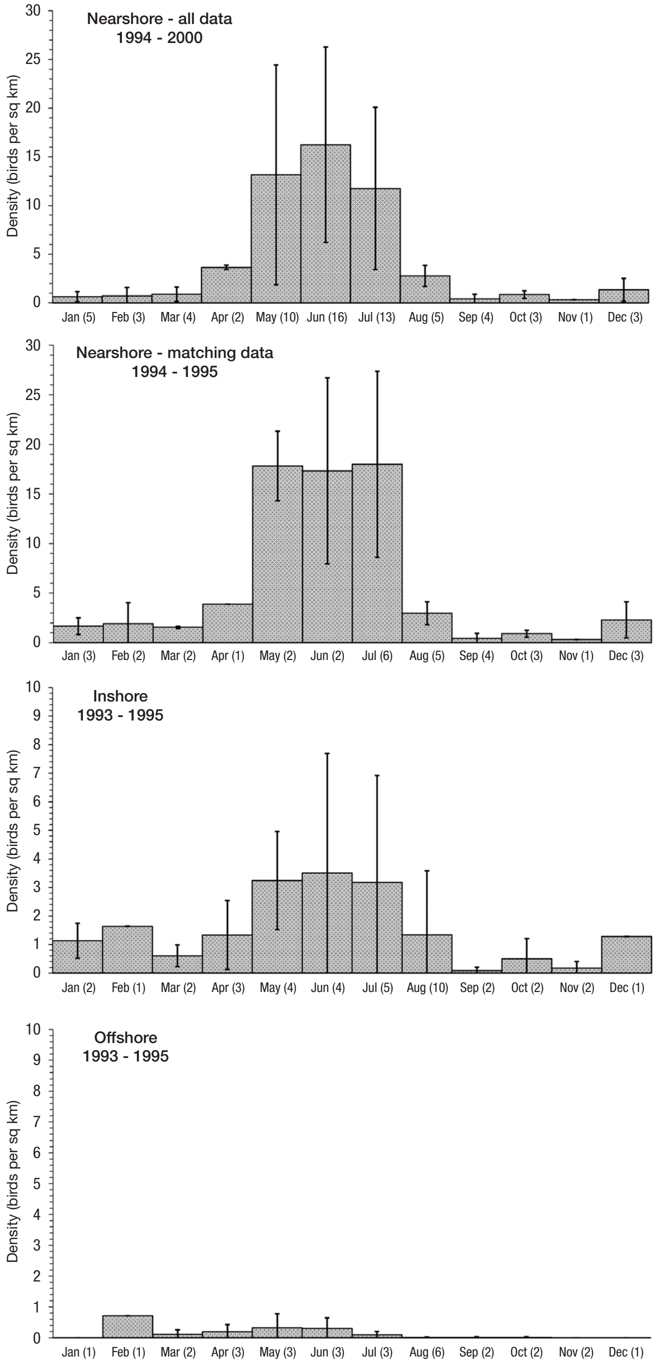

Fig. 2. Mean monthly densities (± standard deviation) of Marbled Murrelets *Brachyramphus marmoratus* from Nearshore, Inshore, and Offshore surveys off southwestern Vancouver Island, British Columbia, Canada. Nearshore surveys spanned 1994–2000, while Inshore and Offshore surveys spanned 1993–1995. Nearshore data were extracted for 1994–1995 in addition to the full 1994–2000 set, as they more closely matched the timing of Inshore and Offshore surveys (see text for details). Numbers in parentheses along the x-axis show the number of surveys in that month (see the Appendix, available on the website). Note that the y-axis scales on the Nearshore graphs differ from those on the Inshore and Offshore graphs.

Non-breeding murrelets can undertake long-distance movements. Bertram *et al.* (2023b) documented flights of over 2000 km in three satellite-tracked birds from British Columbia to Alaska, including one from southwestern Vancouver Island that travelled 2158 km from Clayoquot Sound to the Alexander Archipelago in Alaska. Parker *et al.* (2004) showed that radio-tagged juvenile murrelets from Clayoquot Sound showed progressive post-fledging northward movements up the western coast of Vancouver Island and onto the mainland coast. In contrast, radio-tagged adults in this study left Clayoquot Sound at the end of the breeding season but were not detected moving northward despite intensive aerial searching. It is not clear whether these tracking results indicate large-scale post-breeding movements northwards. The uncertainties around post-breeding movements, molt locations, and wintering distribution highlight the need for additional systematic surveys outside of the breeding season across the murrelets' range.

The high densities of murrelets in the Nearshore and Inshore zones that we sampled, plus those in the adjacent waters < 1 km from the exposed shores (Burger *et al.* 2008, Ronconi & Burger 2011), make up a substantial portion of the overall British Columbia population (Burger 2007, COSEWIC 2012, ECCC 2021). Their location near the mouth of the Strait of Juan de Fuca puts them at high risk of oiling, from both potential catastrophic spills from the freighters and tankers that transit directly through the study area (McWhinnie *et al.* 2021, O'Hara *et al.* 2021, Bertram *et al.* 2023a) and from smaller, chronic spills (O'Hara *et al.* 2013, Fox *et al.* 2016). Although relatively few murrelets (i.e., those in the Offshore transects) were found directly in the major shipping lanes transiting the Strait of Juan de Fuca (Fig. 1B), any oil spilled here would rapidly spread into the Inshore and Nearshore zones and impact many murrelets there. Murrelets in our study area are also at risk from gill-netting (Bertram *et al.* 2021) and from disturbance by vessels, especially the recreational boats that are common within the Inshore and Nearshore zones (Hentze 2006, Bellefleur *et al.* 2009).

High summer densities of murrelets indicate that these anthropogenic factors could have the greatest impact during the breeding season. Our data, which show low winter densities, explain the low mortality of Marbled Murrelets in the winter of 1988/89, after the *Nestucca* oil spill in this area: only 12 carcasses were found on Vancouver Island and an estimated 143 murrelets were among the ~56 000 seabirds killed in total (Ford *et al.* 1991, Burger 1993). A summer spill affecting Nearshore and Inshore waters off Vancouver Island, however, would likely have a devastating impact on this threatened species.

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