

# Bird in Hot Water: Responses by Marbled Murrelets to Variable Ocean Temperatures off Southwestern Vancouver Island

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## ABSTRACT

Periodic warm-ocean episodes are known to have negative impacts on some seabirds in the Pacific Northwest. Effects on the threatened marbled murrelet (*Brachyramphus marmoratus*) are not known. I review the responses of the murrelet to variable nearshore temperatures for 1979 through 1998, which includes 3 El Niño–Southern Oscillation (ENSO) events and a general warming trend. Counts of murrelets in systematic marine transects at 5 sites in British Columbia covering 4–8 years per site showed considerable intra- and inter-seasonal variation, with negative effects of warm seas evident at 3 sites. Samples were generally too small for rigorous statistical testing. Inland surveys over 8 years in old-growth forests in Carmanah-Walbran showed significant effects of ocean temperature. Specifically, the mean frequency of occupied detections, a measure of near-nest flight behaviours, was strongly negatively correlated with nearshore ocean temperature. Surveys in the Ursus Valley, Clayoquot Sound, over 4 years showed a similar, but not significant, trend. Although the link between occupied detections and nesting success is unclear, these results suggest that warm nearshore conditions somewhat inhibit breeding activity. Reduced prey availability in warm seas is a likely cause. This finding has important implications for conservation and monitoring of this species. Inland surveys of flight detections are often used to delineate and map suitable habitat for murrelets as part of logging plans, and could be seriously flawed if they sampled years with depressed activity. If murrelet breeding is inhibited by warm oceans then global warming, coupled with continued loss of nesting habitat in old-growth forests, is likely to lead to significant population declines. Most research, monitoring, and management focus on their forest nesting habitat, but marbled murrelets are seabirds, and changes in their marine environment require equal consideration.

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**Key words:** at-sea surveys, *Brachyramphus marmoratus*, El Niño, inland surveys, marbled murrelet, ocean temperature effects, Vancouver Island.

The marbled murrelet (*Brachyramphus marmoratus*) is a widespread seabird, which nests solitarily in large old-growth trees through most of its range (Hamer and Nelson 1995, Nelson 1997). It is listed as threatened in Canada and the United States and is on the British Columbia Red List (i.e., a species likely to become endangered if threats are not dealt with and trends reversed). Loss of nesting habitat from logging is the primary threat through its range, but oil spills, gill nets, and increased predation at nests are additional threats (Ralph et al. 1995a). In this paper I analyze the effects of variable nearshore sea temperatures on counts of murrelets in marine census transects, and on detections of murrelets in inland forests. I use data from several multiyear studies on southwestern Vancouver Island, which supports

one of the highest densities of murrelets south of Alaska (Burger 1995a,b, Burger et al. 1997, Rodway and Regehr 1998, Bahn et al. 1998).

Changing ocean temperatures profoundly influence marine ecosystems in the northeast Pacific (McGowan et al. 1998), including British Columbia (Freeland 1992). Variable sea temperatures and El Niño events are known to affect seabirds in the northeast Pacific (e.g., Vermeer et al. 1979, Hodder and Graybill 1985, Hatch 1987, Ainley and Boekelheide 1990, Wilson 1991). The effects on marbled murrelets are not well known, but the density and distribution of the murrelet's prey are likely to be affected by ocean temperatures (Ainley et al. 1995, Ralph et al. 1995a).

The solitary, tree-nesting behaviour of marbled murrelets precludes censusing and monitoring of breeding success at the nest site, as is usual for most other seabirds. Consequently, specialized research and monitoring techniques have been developed for both marine and inland

habitats (Ralph et al. 1994, RIC 1997). Boat transects in nearshore seas are used to estimate population densities, marine habitat preferences, and juvenile recruitment (e.g., Sealy and Carter 1984, Carter and Sealy 1990, Becker et al. 1997, Kuletz and Kendall 1998). Inland, the presence and relative densities of marbled murrelets are determined by recording visual and auditory detections made during standardized surveys at dawn, when the birds are most active in and above the forests (Rodway et al. 1993a,b; Ralph et al. 1994, 1995a). The inland surveys are routinely used to assess occupancy and the relative importance of forest stands, and hence have important implications for land management and timber harvests in the Pacific Northwest. Annual variations in inland detections and possible effects of marine influences have seldom been studied (Ralph et al. 1995a,b). There are compelling reasons to understand the responses of marbled murrelets to ocean conditions, because data indicate long-term warming in coastal waters, including British Columbia (Thomson et al. 1984, Freeland 1992, McGowan et al. 1998).

## METHODS

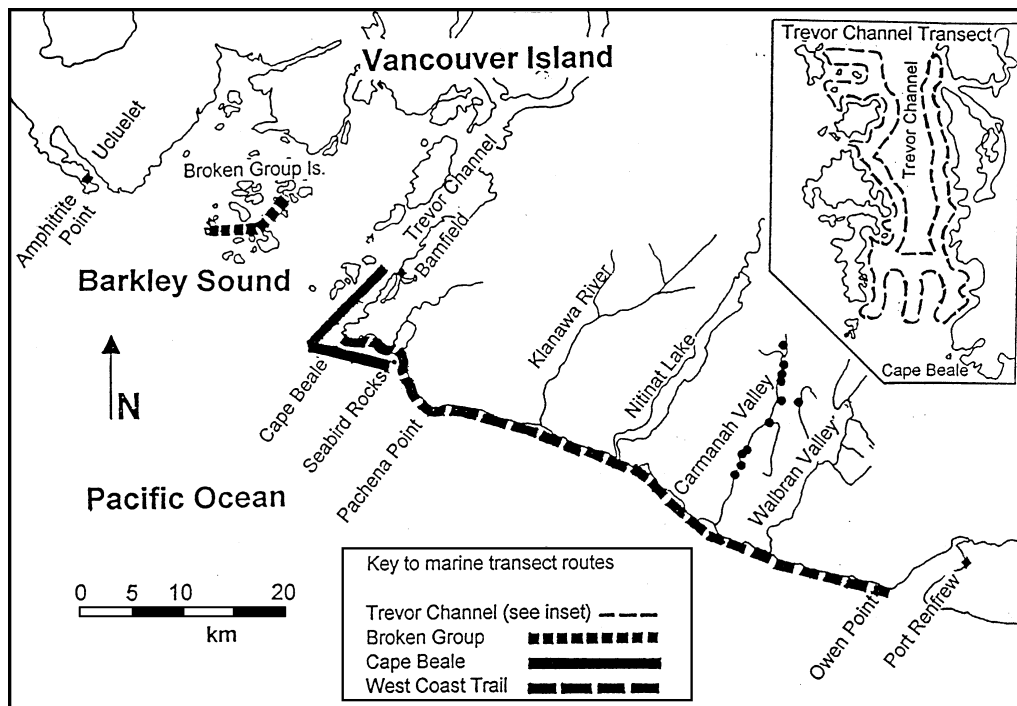
### SEA TEMPERATURES

Monthly mean sea surface temperatures from Amphitrite Point light station were obtained from the Institute of Ocean

Sciences, Sidney, B.C. (<http://www.ios.bc.ca/ios/osap/data/>). This light station provided a 63-year series of daily temperature records, which are useful indicators of nearshore ocean conditions off southwest Vancouver Island (Freeland 1992). I used mean temperatures for the period April through July, which is the time of greatest marine production in this region, and includes the core of the murrelet's breeding season. Temperature anomalies (positive for unusually warm water) were calculated as the difference between the mean monthly temperatures during the study period and the monthly means from the complete 63-year series.

### MARINE SURVEYS

In and near Barkley Sound, marbled murrelets were counted along 4 repeatedly sampled transects: Trevor Channel (43 km), the Broken Group Islands (8.8 km), the West Coast Trail (66.6 km), and the Cape Beale survey route (19.5 km; Fig. 1). Methods differed somewhat among the areas, but were consistent within each area. Small boats (4–6 m long; observer eye height 1.5–2.5 m above the sea) were used for the Trevor Channel and Broken Group transects, and larger vessels (8–12 m long; eye height 2.0–3.5 m) for the West Coast Trail and Cape Beale routes. In all transects the observers scanned ahead and on both sides of the vessel, while travelling at 15–20 km/hour, slowing to count larger groups of birds or identify plumage types. Two or more

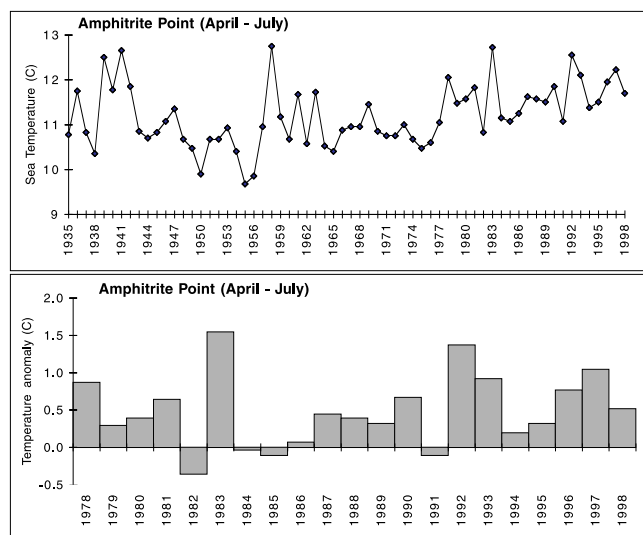


**Figure 1.** Study area on southwest Vancouver Island, showing the locations of the Amphitrite Point light station, 4 marine transect routes, and the 11 inland stations in the Carmanah–Walbran watersheds (solid dots).

observers were generally used, but in a few Trevor Channel and Broken Group surveys a single observer recorded sightings on a tape recorder. Binoculars were used to confirm identifications and plumage types, but were not used to scan for murrelets. All surveys were undertaken when the sea was relatively calm (Beaufort scale 3) and it was not raining heavily. Surveys were completed in the mornings, when counts in this region were least variable (Carter 1984). In most surveys, birds within or beyond strip boundaries 150 or 200 m on either side of the vessel were recorded separately; however, for consistency, I used all birds visible on either side of the vessel. The West Coast Trail data included birds seen on the water and flying, but all other data were birds on the water only. Observers were trained in identification of birds and census methods, and most were experienced seabird biologists.

The Trevor Channel survey covered the same area sampled intensively by Carter (1984), including sheltered nearshore water and an exposed channel. The Broken Group route covered sheltered water among islands. The West Coast Trail transect ran 200 m offshore in shallow nearshore sea exposed to the open Pacific Ocean. The Cape Beale route, also sampled by Carter (1984), covered open channel and exposed, deeper waters.

I also compared data from boat surveys made in Clayoquot Sound in 1982 by Sealy and Carter (1984) and repeated in the 1990s by Kelson et al. (unpublished data, 1995) using the same methods.



**Figure 2.** Sea surface temperatures recorded at Amphitrite Point. The upper graph shows the mean temperatures during April through June in each year, and the lower graph shows the temperature anomaly (deviation from the long-term average) from 1978 to 1998.

#### INLAND AUDIOVISUAL SURVEYS

Data were analyzed from 11 inland stations sampled in each year in the Carmanah–Walbran watersheds (Fig. 1; Burger 1994) and 12 stations sampled annually in the Ursus Valley in Clayoquot Sound (Bahn and Newsom 1999). Each station was sampled 2–4 times per year, at >10 day intervals, and annual means were calculated for each station. All stations were in continuous, unlogged, old-growth forest in the Coastal Western Hemlock biogeoclimatic zone and the West Vancouver Island windward maritime and montane ecoregions. Vegetation of these stands was analyzed in Burger (1994), Bahn (1998), and Rodway and Regehr (1998). Trained observers recorded murrelet activities during 2-hour (minimum) dawn watches, using the standardized fixed-station protocol (Ralph et al. 1994, Resources Inventory Committee 1997). No surveys were conducted if it was raining heavily.

The unit to measure inland murrelet activity was the “detection,” defined as “the sighting or hearing of one or more murrelets acting in a similar manner” (Paton 1995). A subset of these, named “occupied detections,” represented behaviours likely to occur in near nests, including: birds flying into, out of, through, or below the forest canopy; birds perching, landing, or attempting to land in trees; birds calling from a stationary position in the canopy; and birds circling above or below the canopy (Ralph et al. 1994, Paton 1995).

#### RADAR COUNTS

Murrelets entering the Bedwell and Ursus watersheds were counted at dawn using a high-frequency marine surveillance radar stationed at the mouth of the Bedwell River. This method, described by Burger (1997), estimates of the total number of murrelets, breeding and nonbreeding, entering the watersheds. Surveys in which there was rain for >10 minutes during the peak of pre-sunrise activity were discarded. About 75% of the murrelets counted at the Bedwell mouth were estimated to be destined for the Ursus Valley.

## RESULTS

#### SEA SURFACE TEMPERATURES

Mean sea temperatures at Amphitrite Point for the spring and early summer (April through July) showed considerable fluctuations over the years, but there has been an increasing trend since the late 1970s (Fig. 2). From 1978 to 1998, mean temperatures were above average, with the exception of 4 years (1982, 1984, 1985, and 1991). Peaks of high temperature associated with El Niño events were evident in 1983, 1992–1993, and 1997.

MARINE SURVEYS

Survey data from the core of the breeding season, 15 May through 16 July were selected. Counts of marbled murrelets in and near Barkley Sound in 4 survey areas varied considerably among years (Fig. 3). No significant correlations were found between murrelet numbers and sea surface temperature in any of the 4 survey areas. In all 4 survey areas, counts were consistently low in 1993, which was the second

successive year with high sea temperatures.

The mean counts made by Carter (1984) in 1979 on the Cape Beale transect and in 1980 in Trevor Channel were higher than those made between 1987 and 1998 in these areas (Fig. 3). This result might be due to an overall decline in murrelet densities over the intervening years, or to changes in ocean conditions. Carter's counts were done when sea temperatures were similar to those experienced in

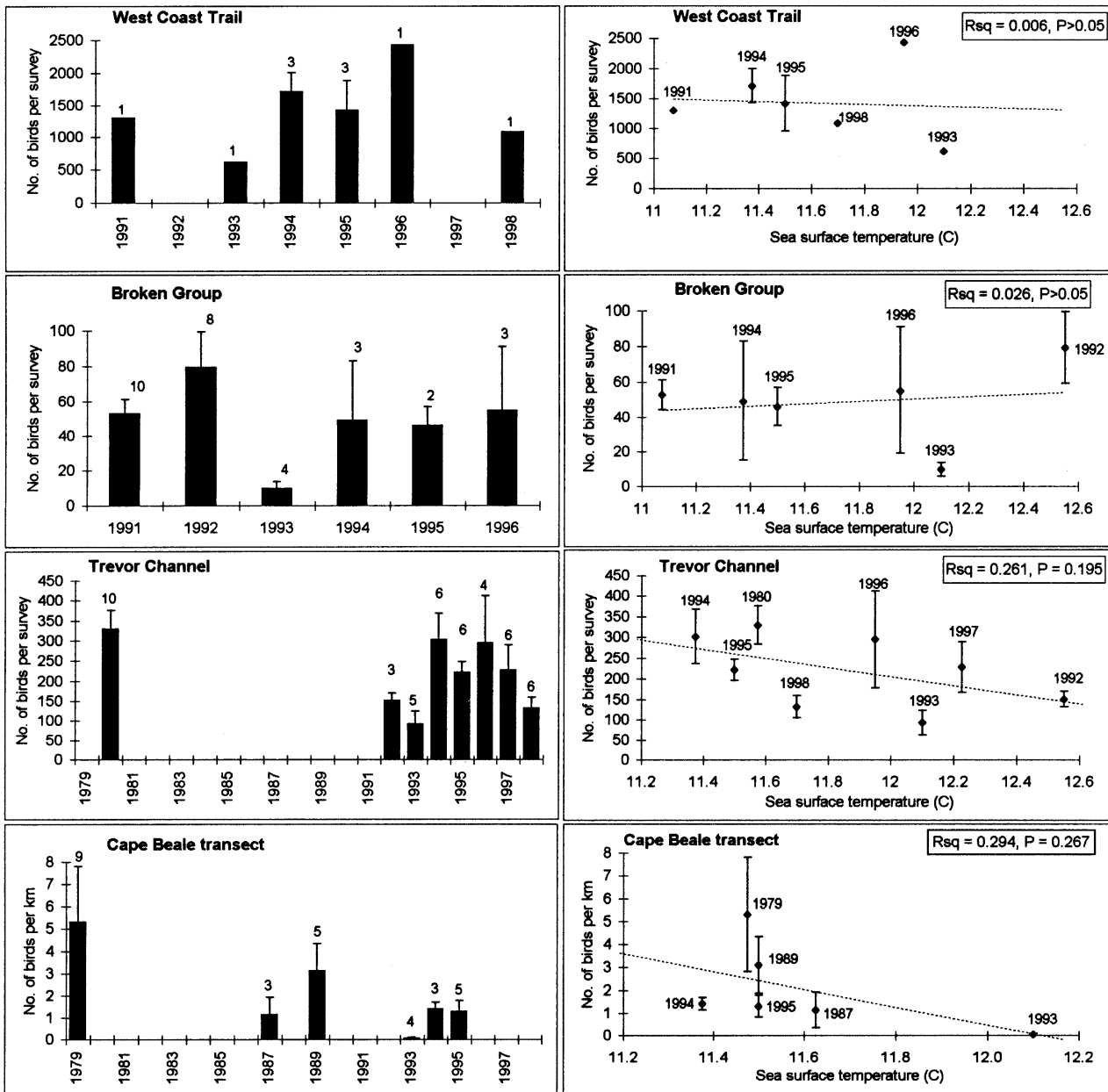


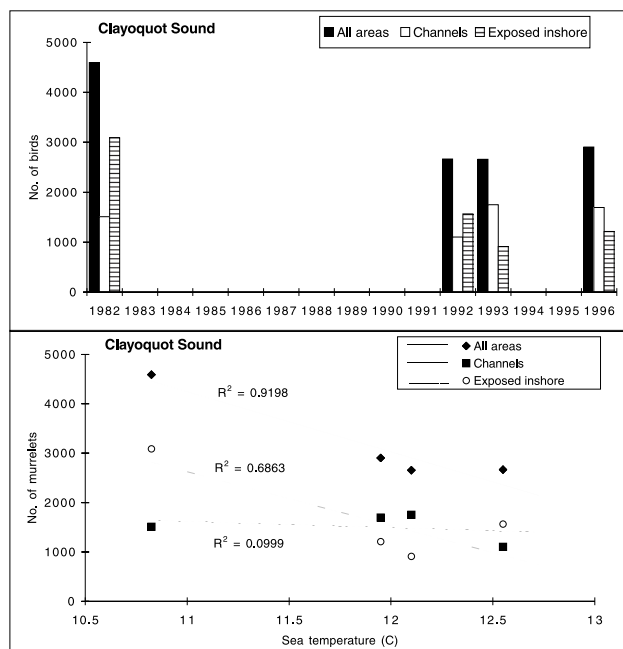
Figure 3. Counts of marbled murrelets in marine transects in and near Barkley Sound. The graphs on the left show annual means (±SE) from 15 May through 16 July. The sample sizes are the numbers of transects; years with no data had no transects. The right hand graphs show the same data plotted against mean sea temperatures. None of the correlations were significant and the dotted lines are the trend lines and not significant regressions.

1987–1998 (Fig. 3), suggesting that temperature effects, if any, were not entirely responsible for the changes.

Counts of murrelets made in Clayoquot Sound declined between 1982 and the 1990s, which was attributed largely to the effects of logging in the area (Kelson et al. 1995). Closer inspection of the data revealed that changes were evident only in the exposed inshore areas, and not in the sheltered channels (Fig. 4). Sea temperatures in 1982 were unusually cool (Fig. 2), and there was a significant negative correlation between counts of murrelets and sea temperature, which was entirely due to the changes in the exposed inshore areas (Fig. 4). It was not possible with this small sample to separate the effects of time (changes over the years) and sea temperature, but both clearly need to be considered if larger samples become available.

#### INLAND AUDIOVISUAL SURVEYS

Mean values of total detections in Carmanah–Walbran were relatively constant through the 8 years sampled, with the exception of high counts in 1994 (Fig. 5). Total detections were not significantly correlated with sea surface temperatures. Occupied detections, a better estimate of near-nest activities, varied more widely, with particularly low frequencies in 1992, 1993, and 1998. Occupied detection frequency showed a significant, negative correlation with mean sea temperatures, and 64% of the variation in occupied detection frequency could be explained by variations in sea temperature



**Figure 4.** Counts of marbled murrelets in Clayoquot Sound (data from Sealy and Carter 1984; Kelson et al. 1995; J. Kelson, unpubl. data). Data from sheltered channels in the sound were plotted separately from those from the more exposed, inshore areas.

( $r^2 = 0.64$ ) (Fig. 5).

The sample of inland surveys in the Ursus Valley (4 years) was not adequate for rigorous statistical testing (Fig. 6). As in Carmanah–Walbran, the occupied detections showed greater variation than total detections. Both measures showed some decline with increasing sea temperature, but these correlations were not statistically significant.

#### RADAR COUNTS

The numbers of marbled murrelets entering the Bedwell–Ursus watersheds varied among the 4 years sampled (Fig. 6). The mean counts declined with increasing sea temperatures, but this trend was not statistically significant.

## DISCUSSION

#### RESPONSES BY MARBLED

#### MURRELETS TO VARIABLE OCEAN CONDITIONS

Fluctuations in the physical environment of the northeast Pacific occur at several time and spatial scales. Significant inter-decadal changes in temperatures, currents, and climate have been identified, accompanied by large biological changes, termed regime shifts (McGowan et al. 1998). These include changes in densities, distribution, recruitment, and food webs, affecting a wide range of organisms. Imposed on these decadal changes are shorter events, lasting months or a few years, including ENSO events. This study was done during a 20-year warm phase, in which 3 shorter El Niño events occurred. A detailed review of ocean processes off Vancouver Island is beyond the scope of this paper, but probably no “normal,” stable condition exists in marine ecosystems. The biology of marbled murrelets, like other marine organisms, changes frequently at different time and spatial scales.

In general, warmer nearshore temperatures off southwestern Vancouver Island seemed to have negative effects on marbled murrelets. Counts at sea showed a negative trend with temperature at 3 of the 5 survey locations. This finding was statistically significant at only 1 location, but all the sample sizes were small and intra-seasonal variations were large, reducing the chances of detecting significant trends. Inland, murrelet detections showed a negative trend with temperature in both the Carmanah–Walbran and Ursus samples. This negative correlation was significant for occupied detections in Carmanah–Walbran, the location with the longest data series. Radar counts at the Bedwell showed a similar trend, but the sample was too small for rigorous statistical testing.

The present data suggest that during unusually warm years murrelets moved out of the sampled marine areas and performed fewer near-nest occupied behaviours in the forests. Longer series of marine and inland surveys are needed to adequately test these patterns. The data were all

obtained in the 1980s and 1990s, during a prolonged warm phase in the northeast Pacific, and so do not sample the full range of ocean conditions experienced off Vancouver Island. Furthermore, populations of marbled murrelets in this area have been affected by the loss of nesting habitat caused by intensive logging of old-growth forests over the past 2 decades (Sealy and Carter 1984, Rodway et al. 1992, Burger 1995b, Kelson et al. 1995). Separating the effects of ocean temperatures and declines due to logging is problematic, particularly for the Clayoquot Sound marine counts (Fig. 4).

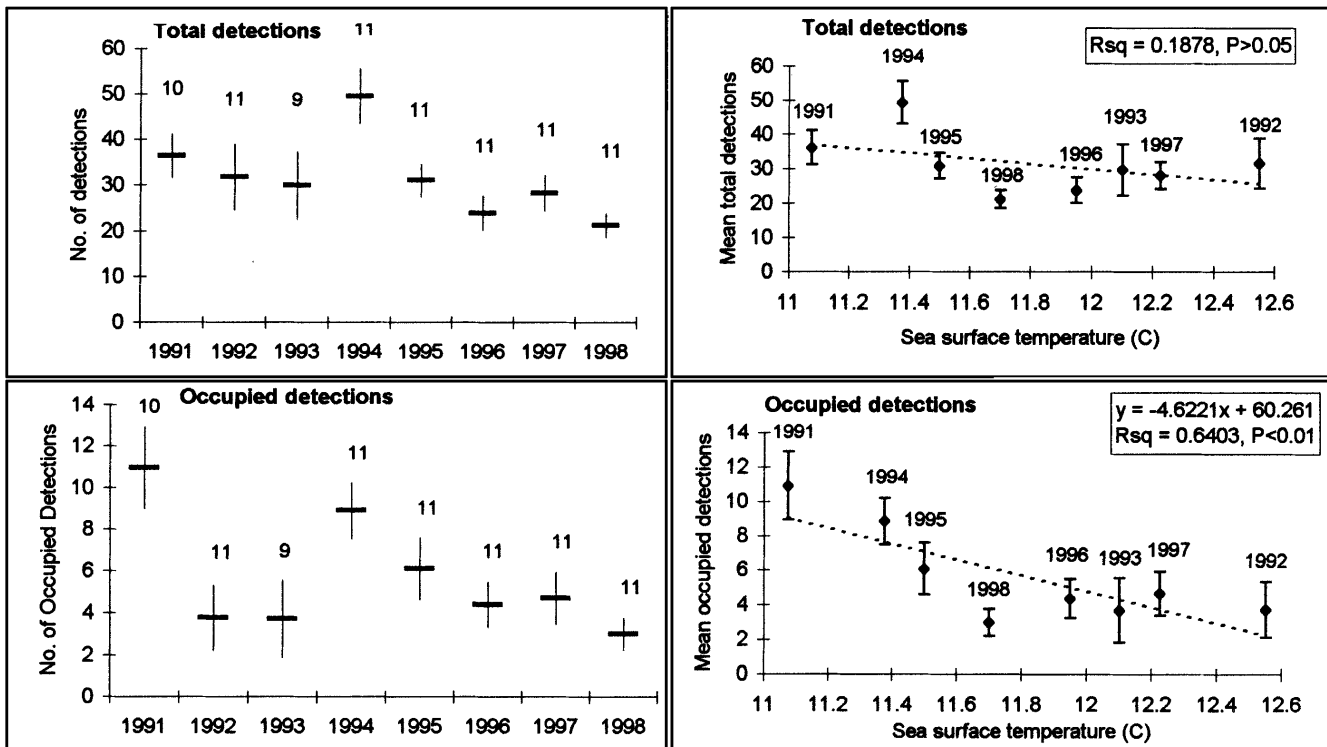
**POSSIBLE CAUSAL FACTORS**

In the northeast Pacific, warm water (El Niño) events are associated with reduced upwelling, lowered productivity of phytoplankton and zooplankton, and reduced recruitment and availability of small schooling fish (Wooster and Fluharty 1985, Freeland 1992, McGowan et al. 1998). These changes often have negative effects on seabirds, including dietary changes, reduced local densities of birds at sea and in colonies, lower breeding success, failure to breed, and increased mortality (Vermeer et al. 1979, Hodder and Graybill 1985, Bayer 1986, Ainley and Boekelheide 1990,

Wilson 1991). The effects of El Niño conditions on marbled murrelets have not been described, apart from 1 study off central California which included few murrelets (Ainley et al. 1995). In this study, murrelets were least abundant during El Niño periods, and in all years their spatial distribution was negatively correlated with sea temperature.

During the breeding season, marbled murrelets off southwest Vancouver Island prey mainly on small schooling fish, predominantly sand lance (*Ammodytes hexapterus*) and juvenile herring (*Clupea harengus*) (Carter 1984; A. E. Burger, pers. observation). Other small schooling fish (e.g., juvenile salmonids), and euphausiids (mainly *Thysanoessa spinifera*) were also likely to be important prey (Burkett 1995).

Several processes might have affected prey availability off Vancouver Island during unusually warm years. First, densities and recruitment of *Thysanoessa spinifera* were sensitive to temperature, and declined significantly in and near Barkley Sound during the 1992 El Niño event (Tanasichuk 1998a,b). This decline could have affected murrelets directly if they fed on euphausiids, or indirectly because euphausiids were important prey for schooling fish. Second, large schools of mackerel (*Scomber japonicus*) and jack mackerel



**Figure 5.** Mean frequencies ( $\pm$ SE) of all detections (total) and occupied detections recorded at 11 stations in the Carmanah–Walbran watersheds in each year, during the period 15 May through 16 July. The left graphs show the annual means and the right graphs show the same data plotted against mean sea temperatures. Occupied detections were significantly correlated with temperature and the regression line and equation are shown. Total detections were not significantly correlated with temperature. The dotted line indicates the trend, not a significant regression.

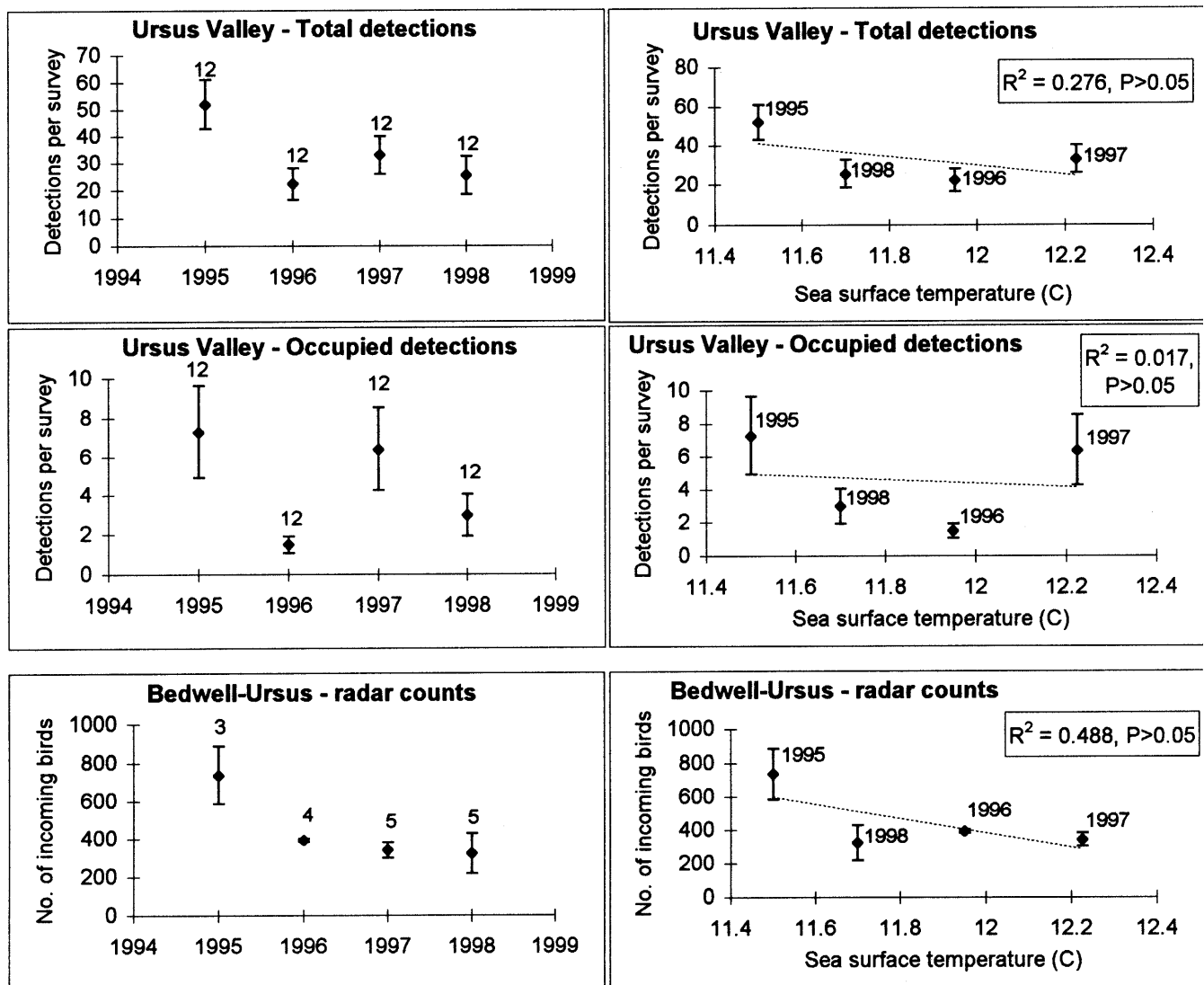
(*Trachurus symmetricus*) invaded Barkley Sound and adjacent seas during the warm years in the 1990s. These species eat similar prey to that taken by marbled murrelets (Hart 1973), but are usually uncommon off Vancouver Island (Hay et al. 1992). The mackerel decimated local stocks of juvenile salmonids and juvenile herring (B. Hargreaves, pers. comm.). Third, unusually warm water might also reduce the availability of existing prey to murrelets. In particular, sand lance avoid unusually warm surface layers (Field 1988); this might make them inaccessible to murrelets in deep water (>40 m) (Mathews and Burger 1998). Finally, the sightings of schools of Pacific sardines (*Sardinops sagax*) increased noticeably

off southwest Vancouver Island through the late 1990s. Sardines in British Columbia are usually adults (Hart 1973) and probably too large for murrelets to eat. Their presence might, however, cause declines in other smaller schooling fish which the murrelets eat.

#### CONSERVATION AND MANAGEMENT

##### CONSEQUENCES OF VARIABLE OCEAN CONDITIONS

If marbled murrelets are sensitive to changes associated with warmer sea temperatures, there are important consequences for conservation and management. In the short term, the effects of sea temperature on detections made during audio-



**Figure 6.** The left graphs show the annual mean frequencies ( $\pm$ SE) of all detections (total) and occupied detections recorded at 11 stations in the Ursus Valley, Clayoquot Sound, and the count made with radar of murrelets entering the Bedwell-Ursus watersheds. The graphs on the right show the same data plotted against sea temperatures. None of the correlations were significant and the dotted lines show the trends only.



visual surveys must be carefully considered. Audiovisual surveys are the standard method for assessing the presence and relative densities of murrelets, and occupancy of stands in the forests (Ralph et al. 1994, 1995a, Resources Inventory Committee 1997). Many management decisions are based on 1 or 2 seasons of audiovisual surveys. If these surveys coincided with warm years with few occupied detections, the distribution, occupancy, and relative densities of murrelets could be seriously underestimated (Burger 1995b). This type of error could be avoided by completing multiyear surveys, or at least by comparing detections with local sea temperatures and other evidence of prey availability.

Global warming has long-term implications on marbled murrelets in British Columbia. For example, the regression in Figure 5 indicates that there would be no occupied detections if the nearshore sea temperature exceeded 13°C. This interpretation is probably simplistic, but such temperatures are possible and could have serious negative effects on murrelets. Unsuitable marine conditions could cause emigration or reduced breeding activity even if suitable nesting habitat remained in the forests. The combination of unsuitable foraging conditions at sea and continued loss of nesting habitat inland could severely reduce murrelet populations. Most conservation and management of marbled murrelets are focused on their forest nesting habitat, but we should not forget that these are seabirds, dependent on productive nearshore marine ecosystems. Conservation strategies for this species need to integrate both the marine and inland ecological requirements.

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