Kees Vermeer
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(editors)

The ecology, status, and conservation of marine and shoreline birds on the west coast of Vancouver Island

Occasional Paper
Number 75
Canadian Wildlife Service

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Introduction

Kees Vermeer, Robert W. Butler, and Ken H. Morgan

This book presents the proceedings of a symposium on the ecology, status, and conservation of marine and shoreline birds on the west coast of Vancouver Island. The symposium was held on 8 April 1991 at the Institute of Ocean Sciences, Sidney, B.C. The objective of the symposium was to combine various disciplines to provide a review of what is currently known about the marine biology of the west coast of Vancouver Island, with particular emphasis on birds. These proceedings are complementary to those of a symposium on marine and shoreline birds in the Strait of Georgia, on the inner coast of British Columbia (Vermeer and Butler 1989).

The present proceedings consist of four sections. In Part I, *The physical and biological environment*, the physical oceanography of the west coast of Vancouver Island, the availability of zooplankton to marine birds, the distribution and habitat of prey fish, possible conflicts between invertebrate fisheries and marine birds, and the interactions between kelp and other organisms are described, as well as the diet of birds and its importance as a tool for monitoring the biological environment.

Part II, *Population and breeding ecology of marine and shoreline birds*, includes papers on breeding populations of the Scott Islands, which contain the main concentrations of nesting marine birds on the west coast of Vancouver Island, and on nesting populations and aspects of the biology of Pelagic Cormorants, Glaucous-winged Gulls, and American Black Oystercatchers. Studies of those breeding populations were made to assess the impact of the 1989 *Nestucca* oil spill on marine birds. The fourth paper in this section concerns itself with Marbled Murrelet activities during the nesting season in the Carmanah Valley. Much of the nesting habitat of that species occurs in old-growth forest, whose existence is threatened because of extensive logging.

Part III, *Distribution of marine and shoreline birds at sea*, includes papers on bird populations and their habitats offshore, in fjords, in estuaries, and over eelgrass beds. Part IV, *Oil pollution and conservation of marine and shoreline birds*, deals with the effects of oil from the *Nestucca* spill on marine birds, the effects of environmental disturbances, and conservation measures that are necessary to protect marine birds.

Recommendations are made in several papers of the symposium proceedings. One major recommendation of international significance is to monitor changes in the nesting populations, diets, and reproductive success of seabirds on Triangle Island. This island, located offshore of the extreme northwestern tip of Vancouver Island, has the largest breeding concentration of seabirds in British Columbia. This offshore location and the presence of many planktivorous and piscivorous seabirds make Triangle Island ideal for monitoring pelagic bird populations and changes in their prey. Together with a number of strategically located seabird monitoring colonies off California (already established), Alaska, Kamchatka, and Japan, a field station on Triangle Island would provide marine biologists with a major tool to measure, as well as an early-warning system to determine, the effects of annual physical changes, El Niños, and global warming in the temperate North Pacific Ocean on seabird populations and their prey.

Although the papers and sections vary in scope and depth, this book provides the most recent overview of what is known of marine and shoreline birds and their environment on the west coast of Vancouver Island. We hope that these proceedings will become an important reference for people in many professions and that the recommendations in the individual papers will be acted upon by decision makers to preserve the marine bird resource and its biological environment.

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Part I

The physical and biological environment

The physical oceanography of the west coast of Vancouver Island

Howard J. Freeland

1. Abstract

The physical oceanography of the west coast of Vancouver Island is reviewed, with emphasis on those aspects that might affect the behaviour of marine birds.

2. Résumé

On présente un aperçu de l'océanographie physique sur la côte ouest de l'île de Vancouver et met particulièrement l'accent sur les propriétés qui se rapportent à la vie des oiseaux marins.

3. Introduction

Since 1979, a considerable amount of research time and effort has been expended by physical oceanographers on attempts to understand the oceanography of the west coast of Vancouver Island. The studies include CODE (the Coastal Ocean Dynamics Experiment) from 1979 to 1982, SuperCODE overlapping with CODE and running one year later, and CODE-II in 1985; the Vancouver Island Coastal Current Experiment (1984); the La Pérouse Project (1985 and continuing); and project MASS (Marine Survival of Salmon) from 1987 to 1990.

The west coast of Vancouver Island is a difficult area to study and understand. As shown in Figure 1, the southern part of the island is cut by a deep canyon, the Juan de Fuca Canyon, which feeds into the Juan de Fuca Strait. The associated canyon system appears to have a major influence on the local physical oceanography and on the biological productivity of the Vancouver Island continental shelf. Immediately north of this canyon system, the continental shelf is about 50 km wide. There is no wider continental shelf along the west coast of the Americas to the south of this point. Near the north end of Vancouver Island lies Brooks Peninsula. It looks impressive on Figure 1, but it is even more impressive from the sea, as it rises with near-vertical sides to an elevation of about 500 m with almost no beach. Brooks Peninsula is almost as impressive below water as it is above. The peninsula reaches across the continental shelf and forms almost a complete obstruction. The continental shelf at Brooks Peninsula has a width of about 2 km, well short of the 50-km width seen a short distance to the south. Although little has been written about flows around Brooks Peninsula, the peninsula carries a notorious local folklore of highly variable and intense currents. Thus, at both the northern and southern ends of Vancouver Island, we encounter significant barriers to the flow of alongshore currents.

This paper constitutes an overview of the oceanography of the west coast of Vancouver Island; broader surveys have been presented elsewhere. I would direct the reader to a book by Rick Thomson (Thomson 1981) for another overview of the oceanography. For information on the background flow fields, refer to Freeland et al. (1984) and Thomson et al. (1989). For information on flow past Brooks Peninsula, refer to Freeland (1989), and see Denman et al. (1989) for further discussion of the flow patterns and biological considerations. For a discussion of flow fields near the Juan de Fuca Canyon, refer to Freeland and Denman (1982) and Freeland and McIntosh (1989). For information on the biological impact of the interaction between the flows over the canyon complex and the biological response, refer to Freeland (1988) and Denman et al. (1981).

Physical oceanographers like to separate oceanic phenomena according to time and space scales. This makes sense, because motions that take place at any given scale tend to have more or less the same dynamics—that is, they are probably all driven by the same forces. Thus, mixing processes occur with time scales in the range of seconds to several minutes; internal waves in the range of minutes to an hour or so; and tidal processes between several hours and a few days. "Steady" currents are so called because they tend to be more or less the same for periods of many days to many months. Finally, we must include climate variability, including the El Niño that

Figure 1
Map of the west coast of Vancouver Island, showing some of the locations mentioned in the text. Kains Island, Nootka Point, and Amphitrite Point are lighthouses at which sea surface temperature and salinity are sampled daily. Depth contours are 170 m (edge of the continental shelf) and 1000 m.

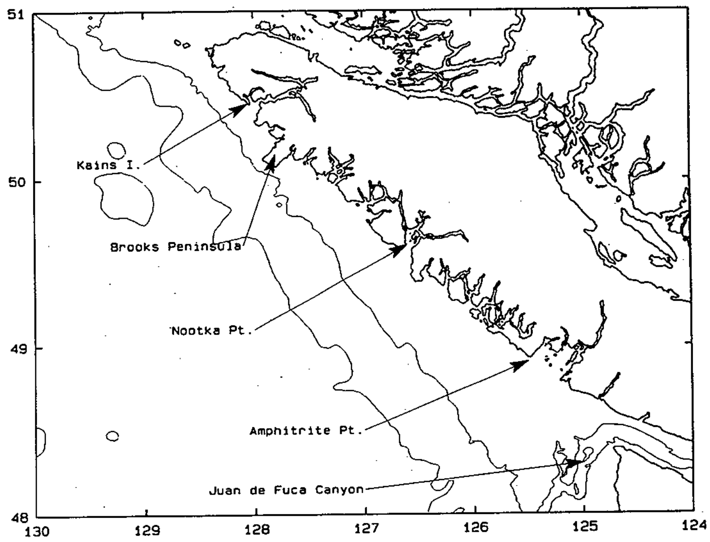


Figure 2
Space and time scales at which specific physical phenomena occur. The axes are logarithmic; at equal intervals, space scales increase by a factor of 10 and time scales increase by a factor of 60.

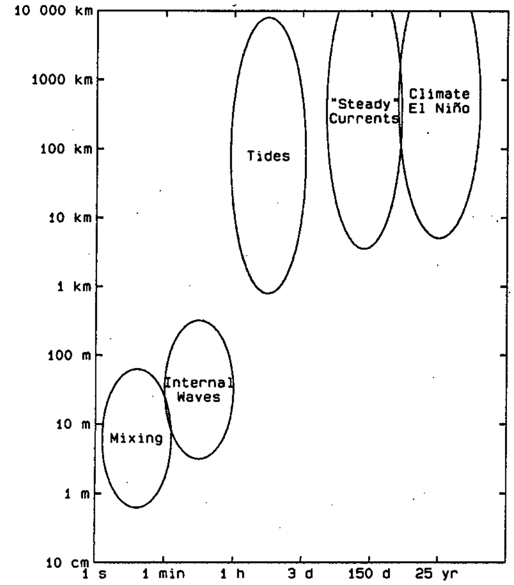
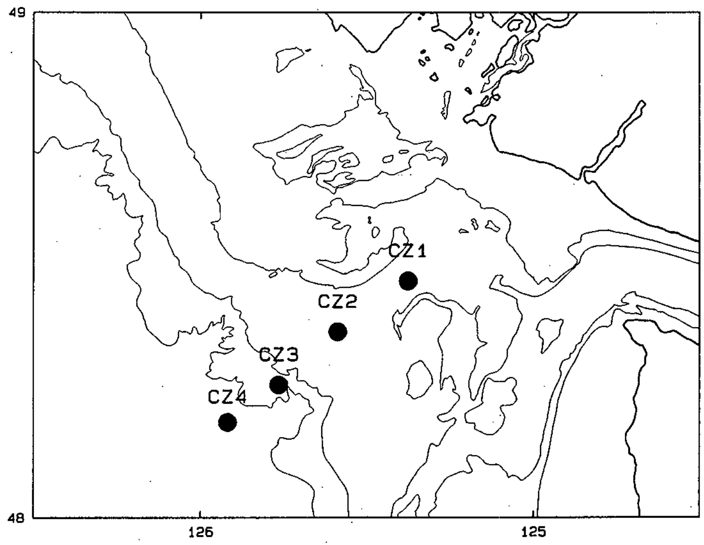


Figure 3
Map of southern Vancouver Island, showing locations of the CZ series of current meter moorings in place from May 1979 to September 1981. Depth contours are 100 m, 170 m, 500 m, and 1000 m.



occurs about every five years and long-term temperature trends with, presumably, time scales ranging from decades to centuries. As indicated on Figure 2, long time scale phenomena tend to be associated with large spatial scales, but this correlation is not perfect. In this review, I follow the order of phenomena outlined in Figure 2. In Section 4, I discuss mixing and internal waves together, in Section 5 the tides, in Section 6 the large-scale current field, and, finally, in Section 7 observations of the El Niño phenomenon and the secular climate change.

4. Mixing and internal waves

There have been few studies of the very short period motions on the continental shelf off the west coast of Vancouver Island; however, the subject has been examined in a paper by Crawford and Dewey (1989). The subject is important, because the amount of energy in the turbulence has an important controlling effect on the very bottom of the food chain. Phytoplankton need light and nutrients to grow and start the entire food chain that leads eventually to birds. However, light is available only in the euphotic zone, near the sea surface, and so the phytoplankton must remain near the surface. A variety of mechanisms, to be discussed later, can deliver nutrients onto the continental shelf. These mechanisms deliver the nutrients in dense water masses that lie on the bottom separated from the euphotic zone by, perhaps, 100 m of water column, and making those nutrients available for growth in the euphotic zone depends largely on turbulence to mix the deep water upwards. Occasionally, internal waves can help by producing large oscillations in the water column that temporarily raise nutrient-rich water parcels from, say, 100 m to perhaps 50 m, where near-surface turbulence can complete the mixing into the euphotic zone.

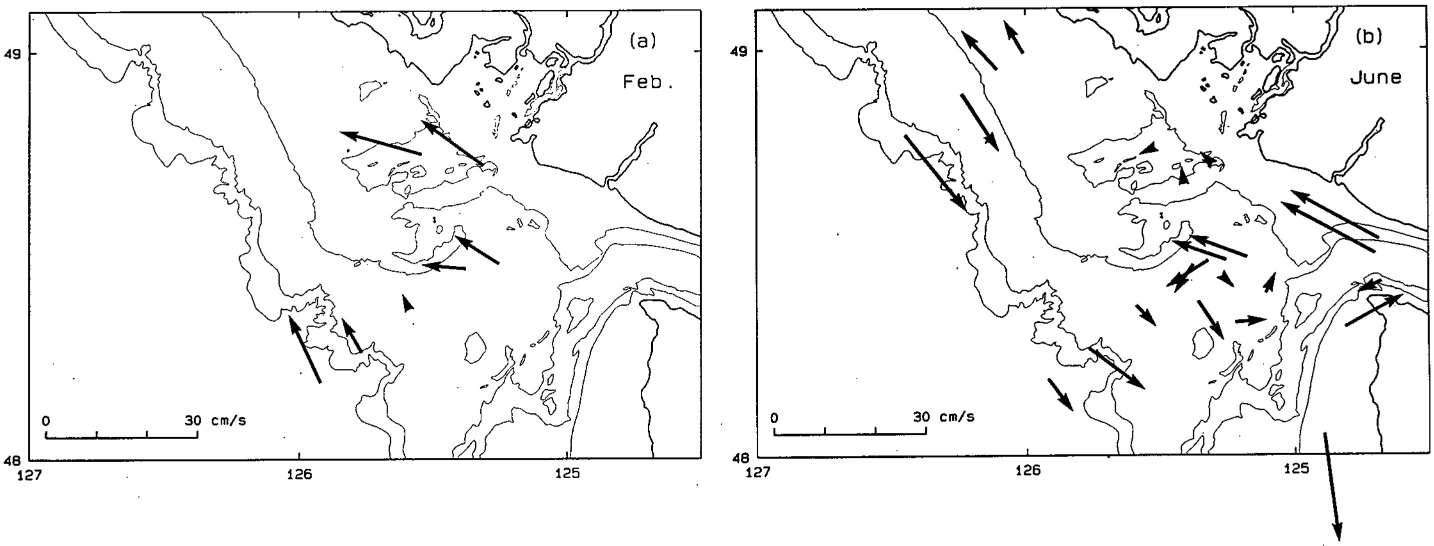
Crawford and Dewey (1989) estimated the rate of delivery of nitrogen to the euphotic zone in the area just north of the Juan de Fuca Canyon system and found that mixing right on the continental shelf is important. They also determined that turbulence originating from wind events, such as storms, is considerably more effective than turbulence generated near the ocean bottom by tidal motions.

5. Tidal motions

The first major study of the physical oceanography of the west coast of Vancouver Island began in 1979. It became evident almost immediately that there was something most peculiar about the behaviour of the tides. Figure 3 shows the location of four current meter moorings deployed across the southern shelf. The tides are all ultimately forced by either the moon or the sun, and so the frequency of the forcing is very well known. The strength of the forcing should not vary much from one site to another, over distances of a few tens of kilometres. Soon after the beginning of CODE, it was observed that the structure of the tidal velocities changed rapidly over very short distances and appeared to be quite different from the velocities expected from the tide gauge (pressure) observations. The discrepancy is observable farther north along the coast of Vancouver Island, but it is most obvious at the moorings CZ1, 2, 3, and 4 off southern Vancouver Island. Thus, the coastal ocean is not responding simply to the astronomical forcing; something else is happening to make the tidal velocity field vastly more complex.

The structure of the tides was analyzed in detail in a series of papers by Thomson and Crawford (1982), Crawford and Thomson (1984), and Crawford (1984). The reason for the peculiar change in structure of the tides is the generation, off southern Vancouver Island, of a topographic Rossby wave, or a shelf wave, at the K_1 frequency. This is a type of wave that relies on the conservation of angular momentum, or spin of a water column, for its dynamics. Crawford (1984) demonstrated quite convincingly that the energy for the wave arises from the pumping of water on and off the continental shelf by tidal flows in the Juan de Fuca Strait. A numerical model of the tides on the Vancouver Island shelf reported by Flather (1987) showed that the shelf wave disappeared when he blocked off the mouth of the Juan de Fuca Strait in his model. The shelf wave carries a cross-shelf structure to it that varies markedly over distances of 10 km or so, and this accounts for the rapid variation in the structure of the tides on the southern Vancouver Island continental shelf. The shelf wave propagates northwards and carries this complexity with it as far as Brooks Peninsula.

Figure 4
Maps of southern Vancouver Island, showing the available monthly averaged current observations in February (a) and June (b). The data are averaged over all years for which observations are available. Depth contours are 100 m, 170 m, 500 m, and 1000 m.



6. The large-scale current field

The series of experiments listed in the introduction to this paper all involved the deployment of current meter arrays. Although there is significant interannual variability in the observed currents, it soon became obvious that the variations in the ocean currents were dominated by seasonal variations. Freeland et al. (1984) compiled all available current observations and discussed the circulation field off the west coast of Vancouver Island. Since that time, there have been other current meter deployments, and I present here a series of maps that update the picture. In this presentation, I restrict discussion to the near-surface velocity field and typical winter and summer patterns.

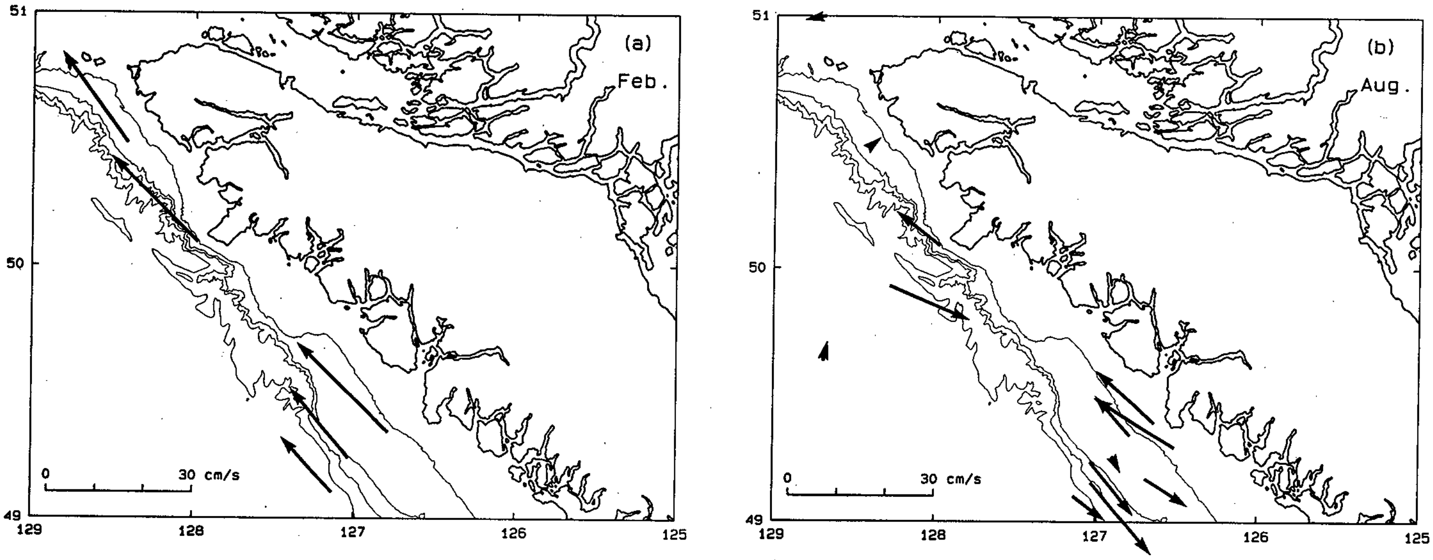
Figures 4a and 4b are maps of the flow patterns on the southern shelf region. In Figure 4a, we see a typical winter circulation pattern, for averaged February currents. The flow patterns are quite simple—northwards across the continental shelf with a suggestion of intensified flows close in to the Vancouver Island coast and at the edge of the continental shelf, with a weak minimum in mid-shelf. This distribution is a little more pronounced in the data from some other months, and the coastal maximum in flow speed appears to be correlated with the outflow from the Juan de Fuca Strait. Typical flow speeds are about 20 cm/s, or about half a knot. It should be borne in mind that these arrows show the flow averaged over a whole month; variations can be marked. In particular, flow speeds would be considerably greater during a well-developed winter storm. As the year proceeds from winter into spring, there appears to be an abrupt transition in flow at the edge of the continental shelf. This is referred to in the physical oceanography literature as the "Spring Transition" and can be observed along the coast of North America approximately from Cape Mendocino in the south to northern Vancouver Island.

In Figure 4b, a typical flow pattern is presented for summer conditions; the pattern of flow is significantly different from that presented in Figure 4a. The shelf edge flow has reversed direction, but we still see the strong northward flow close in to shore. The persistent northward flow has been named the "Vancouver Island Coastal Current," by analogy with a much better studied current, the Norwegian Coastal Current, which appears to be driven by the same type of dynamics. Although the shelf edge flow is basically wind driven, the coastal current appears to be driven by buoyancy sources—that is, fresh water coming out of the Juan de Fuca Strait. Studies of the Norwegian Coastal Current indicate that buoyant currents of this kind are notably unstable, and yet they appear to propagate well up their respective coasts. It seems likely that the continuity of the coastal current is maintained by a series of freshwater sources deployed along the coast—that is, rivers on the west coast of Vancouver Island.

The presence of these two currents across the widest part of the continental shelf appears to have one rather dramatic result. For some reason, which I believe still remains quite unclear, an eddy is spun up every summer on the southern Vancouver Island continental shelf. This eddy, which is clearly visible in the vectors shown in Figure 4b, is known as the Tully Eddy (because it was first observed by Tully [1942]), or the Juan de Fuca Eddy. The dynamical consequences of this eddy were reported by Freeland and Denman (1982). The midwater flow in the eddy is in approximate geostrophic balance, which means that a pressure gradient into the centre of the eddy is balanced by an outward Coriolis force. As we follow the balance of forces towards the bottom, flow speeds are reduced. Thus, the Coriolis force (a constant times the velocity and acting 90° to the right of the velocity) must also decrease, so that there is an unbalanced inward pressure gradient very near the bottom. Normally, that sort of situation produces a small degree of upwelling; in this case, however, the eddy is centred on the northern extremity of a small canyon, a spur off the Juan de Fuca Canyon, and this results in massive upwelling in the centre of the eddy. The upwelled water is ducted through the canyon system, comes from very great depth (up to 500 m), and is very rich in nutrients. As mentioned in Section 4, sufficient turbulence exists to mix these nutrients into the euphotic zone, so producing a region of intense primary productivity.

Figures 5a and 5b show the flow patterns observed along the northern part of the continental shelf, 5a showing conditions in February and 5b those in August. In neither of these plots do we see anything like the complexity seen off the southern shelf, which may well be a function of the lack of observations. Off Estevan Point, we see purely northward flow all the way across

Figure 5
Maps of northern Vancouver Island, showing the available monthly averaged current observations in February (a) and August (b). The data are averaged over all years for which observations are available. Depth contours are 100 m, 170 m, 500 m, and 1000 m.



the continental shelf in the winter (Fig. 5a) and a strongly sheared flow in the summer (Fig. 5b). In both cases, the strongest flows appear to be close inshore, a manifestation of the Vancouver Island Coastal Current at this latitude. The summer flow shows clear evidence of a maximum in the southward flow directly over the edge of the continental shelf. This feature appears to be repeatable from year to year. Farther north, off Brooks Peninsula, the data base is extremely weak, but we do have evidence of similar kinds of flow patterns.

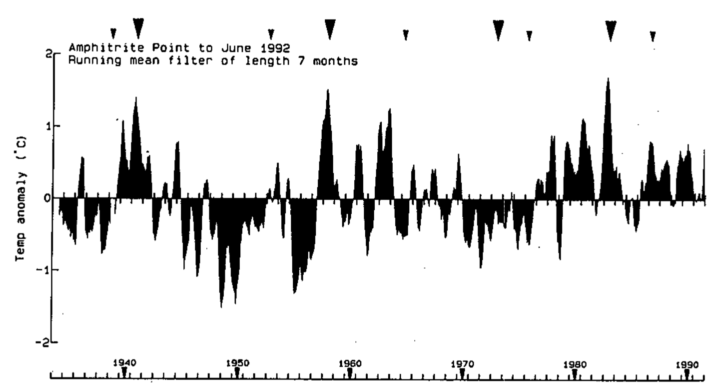
What is missing from this picture of the flow around Brooks Peninsula is the sense of any real complexity, which does show up in satellite photographs. A frequent event during the summer months is a patch of cold, upwelled water—shown very well in satellite imagery—being advected offshore in a narrow plume. Denman et al. (1989), in their Figure 7, showed the trajectory of a surface drifter released just south of Brooks Peninsula being carried rapidly offshore. These events, called squirts or jets, can carry a local coastal ecosystem far offshore until it is eventually mixed into the ocean interior. The source of these squirts and jets is still somewhat unclear. However, Freeland (1990) pointed out that the background flow past Brooks Peninsula can support lee waves in the summer, but not in the winter. This has important consequences for the flow regimes permitted in the vicinity of Brooks Peninsula and may help explain these events.

7. Climate change and El Niño

Since 1934, the keepers of lighthouses around the coast of British Columbia have been recording sea surface temperature (SST) and sea surface salinity almost daily. The data base is now quite impressive. Figure 1 shows the locations of the lighthouses reporting SST data daily from the west coast of Vancouver Island: Kains Island (in the north), Nootka Point (mid-island), and Amphitrite Point (in the south); Bamfield lies farther to the south.

Figure 6 shows a plot of the temperature anomalies at Amphitrite Point from 1934 to the present time. The anomaly is defined as the monthly averaged temperature for any given year minus the long-term average for that month. Thus, this plot

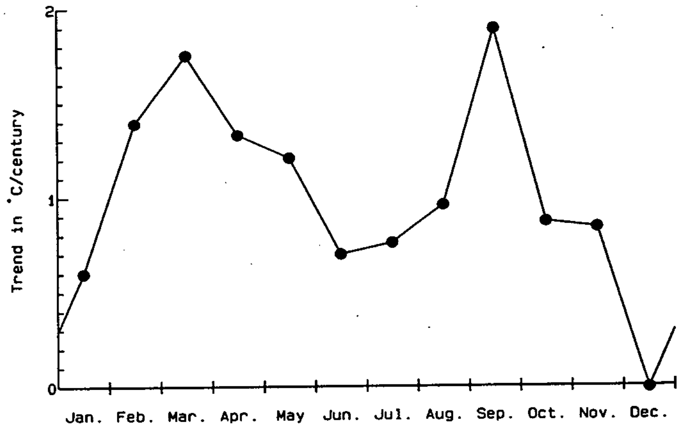
Figure 6
Sea surface temperature anomalies from 1934 to 1991 at Amphitrite Point



shows the extent to which monthly averaged SSTs are greater or less than the climatic average for that month. Clearly, there are long-term variations, and individual peaks in SST stand out. The arrow markers above the plot identify periods of El Niño activity rated as either strong (large symbols) or moderate (small symbols) by Quinn et al. (1978). In most cases, it is clear that El Niño activity is correlated with high SST anomalies off the west coast of Vancouver Island; however, there is no explanation of why the strong El Niño event of 1972 failed entirely to produce any manifestation off our coast. So, as far as we can say at the present time, a strong El Niño will probably result in a high temperature anomaly off the west coast of Vancouver Island.

Beyond the low-frequency variations that clearly occur, there is also a long-term secular trend in SST; Freeland (1990) suggested that a long-term warming of about 0.9°C per century is occurring in British Columbia coastal waters. In Figure 7, the trend as seen at Amphitrite Point is broken down by month; the long period trend is highly variable, depending upon which month is being examined. In midwinter, conditions do not appear to be changing at all—that is, December SSTs are much the same now as they were 50 years ago. A small trend occurs in midsummer values, but the largest trends occur in spring and

Figure 7
Long-term warming trend in sea surface temperature at Amphitrite Point, by month



fall, with trends of more than 1.5°C per century. Thus, the spring and fall are expected to be substantially warmer in 1991 than they were 50 years ago.

This pattern is repeated all around the coast of British Columbia. I have no obvious explanation for the apparent suppression of the long-term trends in the winter months; however, long-term global statistics and the results of large-scale modelling of the climate responding to increasing carbon dioxide both indicate that little trend is expected in midsummer temperatures, as we see here.

8. Conclusions

I hope I have conveyed the impression of excitement that many physical oceanographers feel about the west coast of Vancouver Island. The richness of the oceanography never fails to impress me, and I feel very fortunate to be able to work in one of the most interesting places on the face of the Earth. I also hope that I have conveyed a sense of doubt about many phenomena. We have learned a lot, but there is still a vast amount to be learned.

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Zooplankton on the west coast of Vancouver Island: distribution and availability to marine birds

David L. Mackas and Moira Galbraith

1. Abstract

The outer coast of Vancouver Island is biologically highly productive because of large summer inputs of upwelled nutrients and resulting dense phytoplankton blooms. The resident zooplankton populations are well fed from spring through autumn; their seasonal cycle and spatial distribution are set largely by advective patterns and bathymetry. Large and visually conspicuous zooplankton taxa (euphausiids, very large calanoid copepods, salps, medusae, and hyperiid amphipods) are the most important as seabird prey. These taxa are most abundant in spring (copepods) and summer (remaining taxa) along the edge of the continental shelf. The continental shelf is wide at the south and narrow at the north end of Vancouver Island; this may explain the northerly bias in the alongshore distribution of planktivore breeding colonies.

2. Résumé

Les eaux au large de l'île de Vancouver sont biologiquement très productives en raison de l'importante quantité de nutriments qui remontent en surface et donnent lieu à une forte prolifération de phytoplancton. Les populations résidentes de zooplancton sont bien alimentées du printemps à l'automne; leur cycle saisonnier et leur répartition spatiale sont déterminés en grande partie par les courants horizontaux et la profondeur. Les grands taxons de zooplancton très visibles (les euphausiacés, les gros copépodes calanoïdes, les salpes, les méduses et les amphipodes hypériens) constituent pour les oiseaux de mer les proies les plus importantes. Ces taxons sont le plus abondants au printemps (les copépodes) et à l'été (les autres taxons) sur le rebord du plateau continental. Ce plateau est large au sud et étroit au nord de l'île de Vancouver, ce qui peut expliquer la répartition plus au nord des colonies d'oiseaux nicheurs planctonivores.

3. Introduction

The continental shelf and slope waters off Vancouver Island are at the north end of an extensive Eastern Boundary Current upwelling domain (the California Current system) that stretches south to Baja California (Ware and McFarlane 1989). Like other Eastern Boundary Current ecosystems (such as the Humboldt Current off the west coast of South America and the Benguela and Canary currents off the west coast of Africa), the California Current system off the west coast of North America is biologically very productive because of large inputs of upwelled nutrients into the sunlit surface layer. Among the organisms that exploit this environment are large populations of resident and migratory marine birds (Vermeer et al. 1983). Zooplankton play a key role in the marine food web that supports these marine birds. Most of the abundant bird species either are directly planktivorous or feed on small planktivorous fish. The distribution and year-to-year success of local marine bird populations are therefore likely to be tied to the production and availability of zooplankton along the coast.

In this paper, we summarize recent information on the temporal and spatial distributions of zooplankton off the southern British Columbia outer coast. In particular, we identify the dominant species and describe their seasonal cycles, discuss factors affecting the availability of zooplankton as prey for marine birds, and compare spatial distributions to bathymetry and current patterns.

4. Methods

Since 1979, zooplankton have been sampled at nearly 700 sites off the outer coast of Vancouver Island. The highest sampling density and most complete seasonal coverage are for the continental shelf south of Estevan Point (49°20′N). Sampling off the northern half of Vancouver Island has occurred primarily during spring and summer months, and mostly since 1986. Most sampling stations also included water column profiles of temperature, salinity, dissolved oxygen, nutrients, and phytoplankton biomass.

At the majority of stations (about 90% of the total), zooplankton were sampled by vertical or oblique hauls with flow-metered 0.22-mm mesh ring or Bongo nets. Tow depths were 250–0 m where bottom depth exceeded 250 m (mostly seaward of the shelf break) and near bottom to surface elsewhere. At the remaining locations, a 0.25-m^2 mouth area BIONESS instrumented multiple-net sampler (Sameoto et al. 1980) fitted with 0.22-mm mesh was used to obtain vertically stratified samples (5–9 depth strata per station). Zooplankton in formalin-preserved subsamples were identified and enumerated using a dissecting microscope. Between 200 and 300 individuals were counted per sample. Sorting effort was stratified by taxa and size class to give similar expected subsampling error (about ±25–40% within any single sample) for all major taxonomic groups.

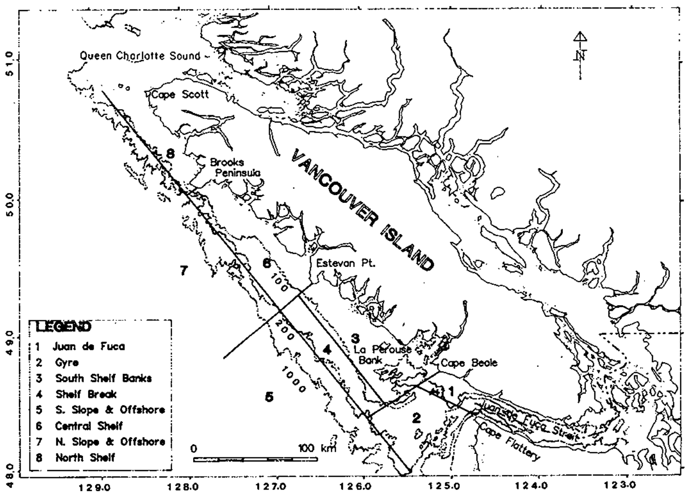
Multiplicative taxon- and stage-specific size coefficients (estimated milligrams dry weight per individual) were used to convert from abundance to biomass estimates prior to summation of developmental stages within species and species within higher taxonomic categories. From a total list of several hundred zooplankton taxa, we selected a standard and much briefer subset (Table 1) that cumulatively accounted for nearly all of the zooplankton biomass. The resulting tables of

Table 1
Major zooplankton taxa off Vancouver Island[a]

Taxon	Body weight (mg dry weight)	Display category
Euphausiids		
Euphausiid larvae	0.001–0.04	Euphausiids
Euphausia pacifica	0.65–8.5	Euphausiids
Thysanoessa inspinata	0.9–10	Euphausiids
Thysanoessa spinifera	1.25–31	Euphausiids
Amphipods		
Parathemisto pacifica	0.75–3.7	Amphipods
Primno	0.32–40	Amphipods
Copepods		
Neocalanus cristatus	0.04–2.6	*Neocalanus*
Neocalanus plumchrus	0.013–0.55	*Neocalanus*
Calanus marshallae	0.008–0.23	*Calanus*
Pseudocalanus spp.	0.0018–0.012	*Pseudocalanus*
Metridia pacifica	0.012–0.14	*Metridia*
Acartia longiremis	0.002–0.007	Other copepods
Acartia clausi	0.002–0.007	Other copepods
Eucalanus bungii	0.008–0.68	Other copepods
Euchaeta elongata	0.035–1.6	Other copepods
Oithona similis	0.0005–0.001	Other copepods
Racovitzanus antarcticus	0.016–0.1	Other copepods
Mesocalanus tenuicornis	0.007–0.04	Other copepods
Clausocalanus	0.0025–0.008	Other copepods
Ctenocalanus vanus	0.004–0.012	Other copepods
Eucalanus californicus	0.025–1.3	Other copepods
Acartia danae	0.0015–0.005	Other copepods
Aetideus divergens	0.023–0.05	Other copepods
Calanus pacificus	0.003–0.22	Other copepods
Calocalanus	0.0005–0.003	Other copepods
Centropages abdominalis	0.005–0.03	Other copepods
Microcalanus pygmaeus	0.0015–0.0035	Other copepods
Paracalanus parvus	0.0015–0.0065	Other copepods
Scolecithricella minor	0.0035–0.011	Other copepods
Oithona atlantica	0.002–0.0035	Other copepods
Corycaeus	0.001–0.005	Other copepods
Oncaea	0.002–0.004	Other copepods
Chaetognaths		
Juvenile chaetognaths	0.014–0.063	Chaetognaths
Sagitta elegans	0.1–1.0	Chaetognaths
Sagitta scrippsae	0.18–6.5	Chaetognaths
Eukrohnia hamata	0.18–1.4	Chaetognaths
Urochordates		
Salpa spp.	7–130	Salps
Larvaceans	0.01–0.2	Remainder
Doliolids	0.2–1.2	Remainder
Cnidaria		
Hydromedusae	0.5–60.0	Hydromedusae
Siphonophores	0.2–15	Other jellies
Scyphomedusae	200	Other jellies
Ctenophores		
Pleurobrachia	0.9–6.9	Other jellies
Other taxa		
Cladocera	0.005	Remainder
Conchoecia	0.1	Remainder
Barnacle larvae	0.04	Remainder
Eggs	0.0016	Remainder
Limacina	0.1–1	Remainder
Clione	0.5–3.5	Remainder
Mollusc larvae	0.002	Remainder
Tomopteris	0.04–3.5	Remainder

[a] First column lists all taxonomic categories distinguished for multivariate statistical analyses. Second column shows individual body size (mg dry weight) over the range of developmental stages (or body lengths) identified within individual taxa. Third column shows summary groupings of taxa used in plots of zooplankton community composition.

Figure 1
Major oceanographic subregions off the outer coast of Vancouver Island, based on shoreline and bottom topography and average summer current patterns. Contour lines show the 100-, 200-, and 1000-m isobaths.



estimated biomass of dominant taxa versus sample identification were used for multivariate analyses of zooplankton community composition and for summary averaging within seasonal and regional groupings (see Mackas 1992 for details of methodology).

5. Oceanographic setting

5.1 Bathymetry

Shelf width and bathymetric profile vary considerably along Vancouver Island and have a major influence on current patterns, vertical exchange rates, and resulting water properties (Freeland, this volume). Oceanographic subregions can be distinguished based on bathymetry and average circulation pattern (Fig. 1) and are used in our subsequent discussion of zooplankton community zonation. The southeastern third of the continental shelf is relatively broad (50–70 km) and bathymetrically rough. At the extreme southeast end, the Juan de Fuca submarine canyon system (z [depth] > 200 m) makes a deep cut across the shelf southwesterly from the mouth of Juan de Fuca Strait. Slightly to the northwest, the La Pérouse region off Barkley Sound includes a number of isolated banks (z = 40–80 m) and enclosed basins (z > 120 m). Bottom slopes along the edges of these banks and basins are often very steep. Northwest of the La Pérouse region, the shelf is narrower (10–40 km) and the bathymetric profile more smoothly varying. Brooks Peninsula extends far enough out from the coast that it essentially interrupts the continental shelf.

5.2 Currents and water properties

The oceanography of the continental shelf and slope region off Vancouver Island has been studied intensively for slightly over a decade (summarized by Freeland, this volume; Mackas 1992). Physical processes such as the Juan de Fuca Strait estuarine circulation, wind-driven upwelling, and tidal mixing cause large summer inputs of dissolved inorganic nutrients into the euphotic zone. Some of this input is utilized locally and produces frequent dense phytoplankton blooms near the upwelling centres. The remainder of the inorganic nutrients, plus a substantial biomass of phytoplankton and zooplankton, are redistributed alongshore and seaward by upper layer currents.

Tidally averaged currents tend to flow parallel to bathymetric contours. The Vancouver Island Coastal Current is the major current over the inner part of the shelf. It is characterized by low surface salinity (30–31.5) and is driven by the estuarine discharge from Juan de Fuca Strait plus additional freshwater input from coastal rivers. Flow of the Vancouver Island Coastal Current is, on average, along the coastline from southeast to northwest year-round and is usually strongest within about 25 km of the coast, although unstable meanders and eddies intermittently transfer low-salinity water seaward across the shelf (Freeland et al. 1984; Mackas et al. 1987; Thomson et al. 1989).

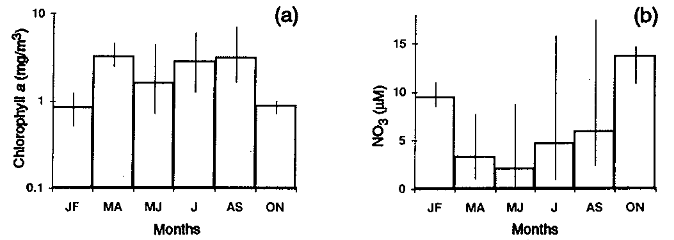
Along the outer margin of the continental shelf, current direction varies with season. In winter, surface layer flow is to the north and appears to be an extension of the Davidson Current off California (Thomas and Emery 1986). Following the March–April "Spring Transition" in large-scale weather patterns (Strub et al. 1987), the surface current direction over the outer shelf shifts to southeastward and is called the shelf break current (Freeland et al. 1984). The source water for this current is a mixture of saline upwelled water (mostly from near the north end of Vancouver Island) and low-salinity coastal water (from the Vancouver Island Coastal Current and Queen Charlotte Sound). High speeds (>20 cm/s) near the core of the shelf break current cause rapid alongshore displacement of surface layer plankton; summer season measurements with surface drifter buoys suggest transit times of only about 20 days for the full length of Vancouver Island (Mackas et al. 1989; Denman et al. 1989).

Although the average track of the shelf break current is a relatively narrow band between the 150- and 500-m isobaths, dynamic instabilities can cause large cross-shore meanders that transport narrow filaments of cold, biologically productive coastal water long distances (>100 km) seaward of the shelf break (Denman et al. 1989). Coastline and shelf break irregularities appear to be important in determining where these filaments form. Beneath the shelf break current, the opposing flow in the core of the underlying California Undercurrent (150–250 m depth) is on average to the northwest at 5–10 cm/s. California Undercurrent water is characterized by high salinity (near 34.0), low dissolved oxygen (0.5–2 mL/L), and very high dissolved nutrients (e.g., 33–40 µM nitrate); it is the major source water for summer season upwelling into the Juan de Fuca Canyon system and onto the continental shelf. From April to September (the same seasonal span as the shelf break current and the strong upwelling of California Undercurrent water), the continental shelf southeast of La Pérouse Bank and west of the mouth of Juan de Fuca Strait is the site of a persistent cyclonic gyre (referred to in the literature as the Tully Eddy or the Juan de Fuca Eddy). Upwelling of California Undercurrent water is particularly strong near the centre of this eddy.

5.3 Phytoplankton distribution

Continental shelf and slope waters off the outer coast of Vancouver Island produce a large amount of phytoplankton biomass during the spring and summer months. The seasonal cycle of phytoplankton biomass differs from that found in most other mid- and high-latitude coastal regions (Mackas 1992). The "classical" sequence in these other regions is caused by a relatively brief period of simultaneous supply of sunlight and dissolved nutrients; an intense spring phytoplankton bloom (triggered by increasing irradiance combined with stratification and shoaling of the surface mixed layer) is followed by a decline to a prolonged summer minimum (due to zooplankton grazing and depletion of dissolved nutrients in the euphotic zone).

Figure 2
Seasonal cycles of upper-layer (a) phytoplankton biomass (as mg chlorophyll a/m^3) and (b) dissolved nutrient concentration (as µM nitrate) off southern Vancouver Island, summarized from Mackas (1992). Histograms show overall area-weighted averages for regions 1–5 in Figure 1; vertical lines show the range of within-region means.



In contrast, off Vancouver Island, the post-spring bloom decline is much briefer (typically less than a month). Subsequent inputs of upwelled nutrients allow frequent summer episodes of high phytoplankton productivity. Figure 2 shows multiyear and spatially averaged seasonal cycles of nitrate and phytoplankton chlorophyll concentrations for shelf waters off southern Vancouver Island (regions 1–5 in Fig. 1). Within each region, average nutrient and chlorophyll concentrations in summer are consistently equal to or higher than those in spring. Although relatively dense phytoplankton blooms (>5 mg chlorophyll a/m^3) occur in summer at all locations inshore of about the 1000-m isobath, average chlorophyll and nitrate concentrations are highest near shore (~6 mg/m^3 and ~7 µM, respectively) and decline seaward (~3 mg/m^3 and ~2 µM in the vicinity of the shelf break, ~1 mg/m^3 and ~1 µM over the outer continental slope). Similar spatial patterns of phytoplankton and nutrient levels occur off northern Vancouver Island but are compressed in the cross-shore direction because of the alongshore decrease in width of the continental shelf. The zone of high nutrients and phytoplankton biomass is occasionally extended by spatially localized jet-like currents that transport continental shelf water well seaward of the shelf break (Denman et al. 1989).

How does the concentration of phytoplankton off Vancouver Island compare with the food requirements of herbivorous zooplankton? Feeding and metabolic rates of zooplankton are dependent on water temperature. For the 9–13°C range typical of the upper 50 m off Vancouver Island, herbivorous copepods achieve a maintenance ration at food concentrations equivalent to about 1 mg chlorophyll a/m^3 and growth saturation at about 4 mg/m^3 (Huntley and Boyd 1984). Shelf waters therefore provide a rich feeding ground for herbivorous zooplankton, allowing them to grow and reproduce at or near their physiological maximum rate.

6. Dominant zooplankton species

A large number of zooplankton taxa occur regularly off Vancouver Island, but abundance and total biomass are dominated by relatively few (Mackas and Sefton 1982; Mackas 1992). Some of the most important (and their relative body sizes) are illustrated in Figure 3. Important copepod species in terms of biomass include *Calanus marshallae*, *Neocalanus cristatus* and *N. plumchrus*, *Pseudocalanus* spp. (mostly *P. mimus*), *Metridia pacifica*, and *Acartia longiremis*. The dominant euphausiids are *Euphausia pacifica* and *Thysanoessa spinifera*. The dominant chaetognaths are *Sagitta elegans* and *Eukrohnia hamata*. *Limacina helicina* is the most common pteropod. There are several major gelatinous zooplankton taxa, including the hydromedusae *Aglantha* and *Phialidium*, the

Figure 3
Appearance and relative body size of some of the major contributors to zooplankton biomass. Because seabirds are visual predators, they will tend to select species that are conspicuous because of pigmentation or large body size.

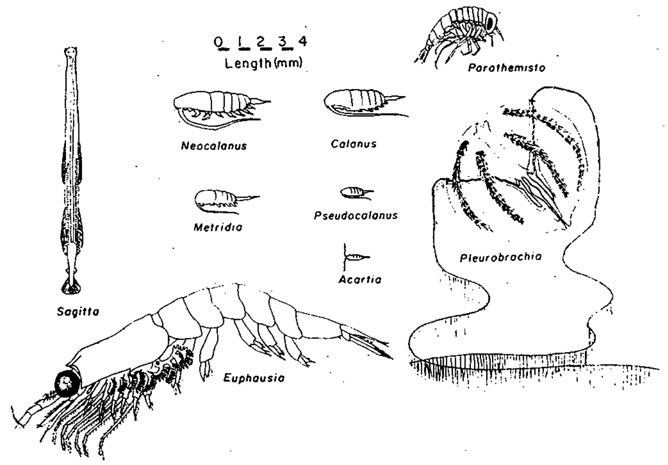
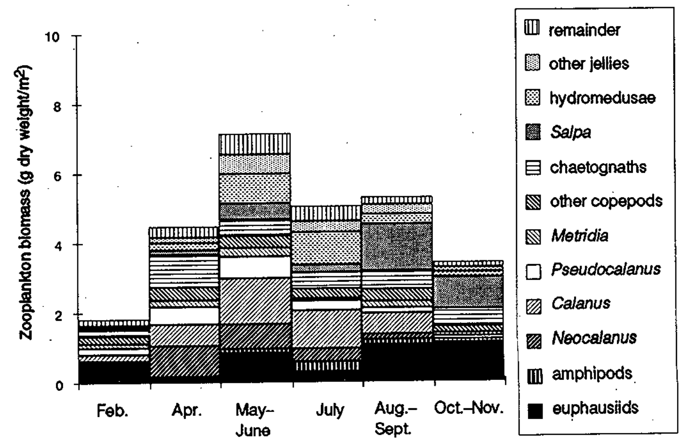


Figure 4
Area-weighted average seasonal cycles of zooplankton biomass (g dry weight/m^2) and species composition off southern Vancouver Island. Herbivorous taxa make up most of the total.



ctenophore *Pleurobrachia*, and the planktonic tunicates *Salpa fusiformis*, *S. aspera*, and *Oikopleura*.

Zoögeographically, these taxa are a mix of Subarctic Oceanic and North Temperate Neritic species. Most have an extensive range: the oceanic taxa (notably *Neocalanus* spp., *M. pacifica*, *E. pacifica*, *L. helicina*, and *E. hamata*) are dominant upper-ocean taxa throughout the subarctic North Pacific, whereas the neritic taxa (e.g., *C. marshallae, T. spinifera*, and *S. elegans*) are common along the west coast of North America from the Bering Sea to northern California. Taxa with more southerly zoogeographic affinities (e.g., *Clausocalanus* spp., *Mesocalanus tenuicornis, Ctenocalanus vanus*) are also routinely present off the coast of British Columbia, but they rarely account for more than 5–10% of the total zooplankton biomass. An interesting feature of the zoogeographic pattern is that, because of the seasonal reversal of outer shelf surface current direction (from the northwest in summer, from the southeast in winter), these "warm-water" taxa are most abundant and make a far larger percent contribution to the zooplankton community in winter than in summer.

7. Seasonal cycle

Figure 4 shows the seasonal cycle of zooplankton biomass and community composition based on averages of samples collected in 1979–89 from the southern third of the Vancouver Island coast (see Mackas 1992 for more detailed spatial and taxonomic breakdown). The biomass data shown in Figure 4 are cumulative totals over all developmental stages and species within each display category (see Table 1). Modal body size within each category varies with season. Most taxa have their peak reproductive activity in spring or summer, so the fraction of the total contributed by small-bodied juvenile stages is greater in spring and summer than in fall and winter. Average total zooplankton biomass ranges from less than 2 g dry weight/m^2 in winter to about 7 g/m^2 in May–June (individual samples are much more variable). Crustaceans (mostly euphausiids, amphipods, and copepods) cumulatively make up 50–75% of the total biomass.

Within the crustacea, euphausiids are the dominant subgroup from late summer through winter, and copepods are dominant (averaging >40% of total zooplankton biomass) from early spring through midsummer. The biomass of herbivorous copepods reaches a maximum of about 3 g/m^2 in May–June and declines through the remainder of the summer, despite continuing high availability of their phytoplankton food. Two factors appear to be responsible for the summer decline in copepod (and total zooplankton) biomass. First, some important species (notably the large copepods *N. cristatus* and *N. plumchrus*) leave the upper layer once they have accumulated sufficient size and lipid reserves. Second, the summer circulation pattern causes a high rate of advective export from the continental shelf region for taxa that remain in the upper part of the water column (Mackas 1992).

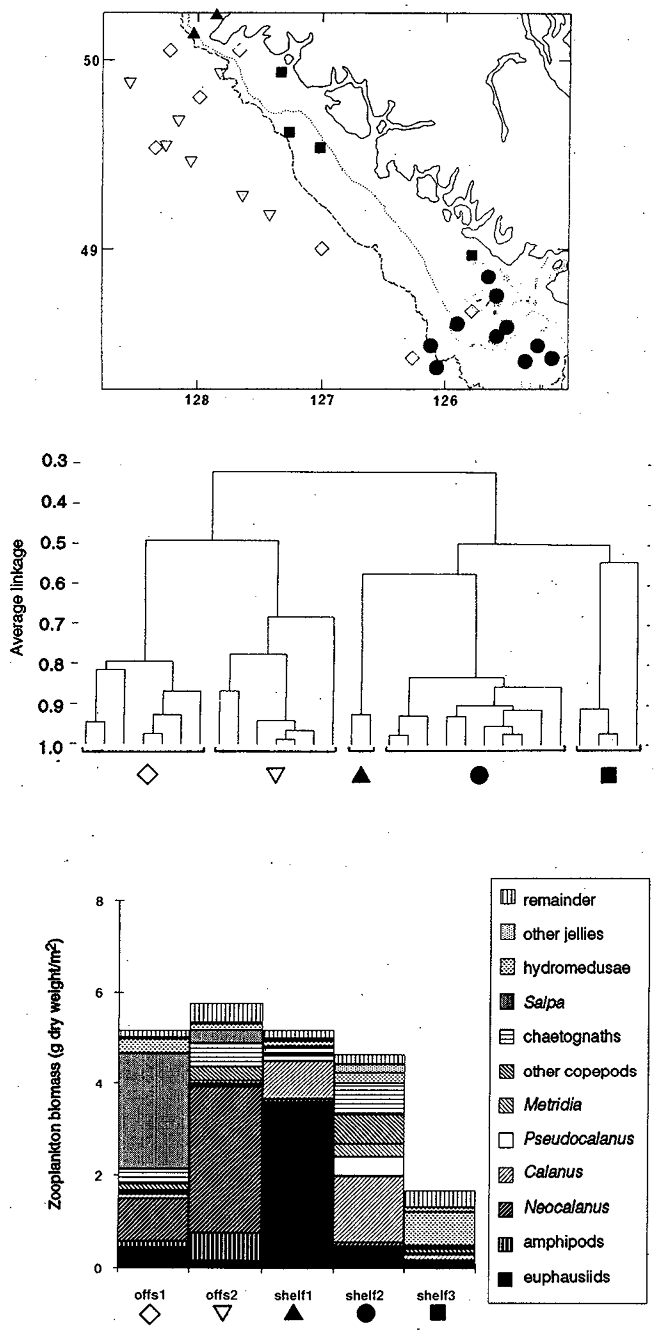
Chaetognaths and gelatinous zooplankton (medusae, salps, and ctenophores) make up most of the remaining zooplankton biomass. The medusae and ctenophores (both primarily predators of small crustacean zooplankton) have an early-summer biomass maximum. Their seasonal cycle is similar to, but slightly later than, that of the copepods. Salps (filter feeders and primarily herbivorous) are, on average, most abundant in late summer and autumn. However, their abundance is extremely variable from year to year.

8. Alongshore and cross-shore spatial zonation of zooplankton community composition

Although the dominant zooplankton taxa in a given season are likely to be present within that season at most locations off the British Columbia coast, there is considerable spatial variation in their relative contribution to the local total. Multivariate statistical methods were used to identify samples sharing a similar species dominance hierarchy. The community "patches" tend to be stretched out parallel to both bathymetric contours and current streamlines (Mackas and Sefton 1982; Mackas 1984; Mackas et al. 1991).

As an example of this pattern, Figure 5 (three panels) shows the results of a cluster analysis of zooplankton samples collected in August 1988. The major gradient in community composition is across the continental shelf break (roughly the 200-m isobath). Samples in the two offshore subgroups (open symbols) are dominated by salps and the copepods *N. cristatus* and *N. plumchrus*. Samples from the three continental shelf subgroups (shaded symbols) are dominated by *C. marshallae*, medusae, and (at two locations just north of Brooks Peninsula) the euphausiid *T. spinifera*.

Figure 5
Spatial variation in zooplankton community composition in August 1988. The upper panel maps the distribution of sample groups sharing similar species dominance hierarchy, as identified by cluster analysis (middle panel). The bottom panel shows the average zooplankton composition within each of the cluster groups.



9. Zooplankton taxa with high "availability" to seabirds

Total population size is not the sole factor determining the extent to which a given zooplankton species will be utilized by seabirds. Of at least equal importance is the ease with which the seabird predator can find and catch a nutritious ration of the prey species. Several factors contribute to high prey availability: detectability of individual prey items, existence of localized patches of very high prey density, and accessibility and detectability of these patches. For seabird predators, the ideal prey organisms are those that have high food value per unit biomass, are visually conspicuous (large individual body size, strongly pigmented), are near the sea surface during peak seabird feeding periods, and form dense aggregations at predictable (or at least remotely identifiable) sites.

Of the dominant zooplankton taxa off the British Columbia coast, the ones that best meet these criteria are the euphausiids, the pigmented gelatinous zooplankton (salps and medusae), hyperiid amphipods, and the large-bodied copepods in the genera *Neocalanus* and *Calanus*. Not surprisingly, all of these have been identified as important in the gut contents of North Pacific seabirds (e.g., Vermeer 1981; Harrison 1984; Vermeer et al. 1985; G.L. Hunt, N.M. Harrison, and J. Piatt, unpubl. data). The following subsections provide additional information on the biology and distribution of these taxa.

9.1 Euphausiids

Euphausiids are visually conspicuous because of their size (15–30 mm body length) and coloration (black eyes and reddish body pigmentation). *Thysanoessa spinifera* is the most abundant species on the continental shelf, whereas *E. pacifica* dominates at deeper locations. Late juveniles and adults of both species are strong diel vertical migrants (near the sea surface at night, moving to >100 m depth in midday), but both also occasionally swarm near the sea surface in daylight. When they do so, they attract large numbers of avian, finfish, and mammalian predators (see Mackas and Fulton 1989).

The horizontal patchiness of euphausiids is extreme; 10- to 100-fold changes in scattering layer density can occur over horizontal distances of a few kilometres. Off British Columbia, abundances much higher than the regional average occur along bathymetric "edges" such as the continental shelf break and the lateral margins of banks, basins, and the Juan de Fuca submarine canyon (Simard and Mackas 1989); these bathymetric edges are also the sites of oceanographic shear and convergence zones. Superimposed on the strong cross-shore variability is a weak north–south declining trend in euphausiid biomass (Fulton and LeBrasseur 1984); some of this gradient may be caused by intense hake predation on euphausiids off southern Vancouver Island.

9.2 Salps and medusae

Salps are filter-feeding herbivores with very high reproductive rates. Their life cycle includes an alternation between "solitary" (individuals 5–7 cm body length) and "aggregate" (individuals 2–4 cm, chains to several metres) life stages. Although most of their tissue is gelatinous and transparent, their visceral mass (about 1 cm diameter) is brilliant orange and makes salps extremely conspicuous from above the sea surface. *Salpa fusiformis* and *S. aspera* are the locally dominant species. They are "boom or bust" organisms in British Columbia waters: minor contributors to the zooplankton community at most times but occasionally overwhelmingly dominant (50–90% of the local zooplankton biomass). Although not strictly oceanic, they are most abundant off the British Columbia coast along and seaward of the shelf break and are associated with coastward intrusions of warm offshore surface water.

The most common medusae and the major contributors to total jellyfish biomass are the small hydromedusae *Aglantha* (bell diameter about 5 mm) and *Phialidium* (about 1–2 cm). Along with most other local hydromedusae, they are nearly transparent and probably relatively unimportant as seabird prey. In contrast, the hydromedusa *Aequorea* and the scyphomedusae *Aurelia* and *Cyanea* are much rarer but also much larger and more conspicuous (particularly the brightly pigmented *Cyanea*). Harrison (1984) suggested that these more conspicuous medusae may be important prey items for Northern Fulmars

Fulmarus glacialis, shearwaters (*Puffinus* spp.), storm-petrels (*Oceanodroma* spp.), and gulls (Larids). Highest abundances occur in summer in both shelf and slope regions.

9.3 Hyperiid amphipods

Parathemisto (about 5 mm) and *Primno* (usually to about 1 cm) are the dominant genera in our samples. *Hyperia* (1 cm), *Phronima* (2 cm), and *Hyperoche* (3 mm) also occur frequently. Hyperiids have prominent compound eyes, and most are strongly pigmented; they should therefore be readily detectable by visual predators. However, it is now recognized that hyperiid amphipods are rarely free-living but instead are highly specialized as "parasitoids" of gelatinous zooplankton: they exploit their larger gelatinous host species as a combination of "house," food collector, and direct prey. Seabirds with hyperiids in their guts have probably obtained them as highly nutritious by-catch; their gelatinous hosts would have been ingested at the same time (and were probably the target prey item) but more rapidly broken down by digestive fluids and hence less easily identified in the gut residue (Harrison 1984).

9.4 Large calanoid copepods

The most important copepods for seabirds off Vancouver Island appear to be *N. cristatus* (up to 10 mm body length) and *N. plumchrus* (to about 5.5 mm). Both species are endemic to the open subarctic North Pacific, and both are strong seasonal vertical migrators that overwinter as C5 copepodites at depths greater than 500 m (Miller and Clemons 1988). *Neocalanus* spp. are more abundant seaward of the continental shelf break than on the continental shelf (see Fig. 5) because of this seasonal depth requirement. There is also some evidence for an alongshore trend in average abundance (higher to the north). Fulton and LeBrasseur (1985) argued that the northward shift of the distributional limit of these species (usually located somewhere off Oregon) is a sensitive and significant indicator of El Niño conditions in the California Current system.

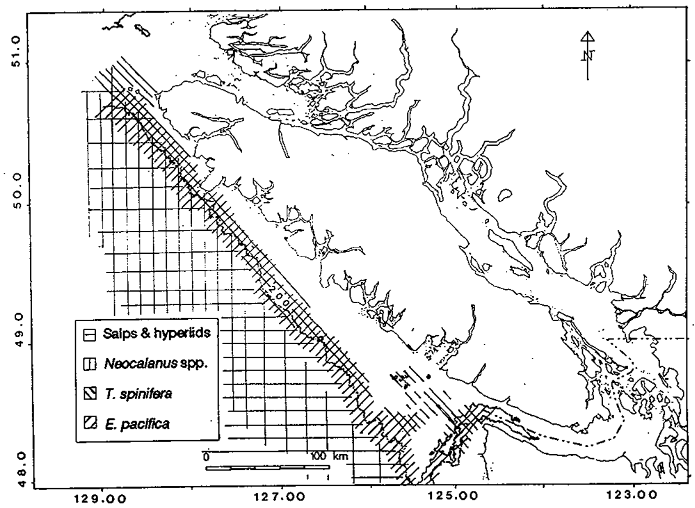
Neocalanus plumchrus and *N. cristatus* both have one generation per year, and their developmental cycles are strongly seasonal (Miller and Clemons 1988). Maturation, mating, and spawning of *Neocalanus* (mostly late winter to early spring) all take place at the overwintering depth. Young-of-the-year swim upward to 0–100 m, where they feed and grow. In contrast to the strong seasonal migration, diel vertical migration of the copepodites is weak or absent during the spring and summer growing season. Downward migration of the population of large and lipid-rich C5 copepodites begins in early summer; the majority have left the upper layer by mid-August. Availability and nutritional value to seabirds should be maximal in June and July when C4 and C5 stages dominate the surface layer populations.

Calanus marshallae is the major component of copepod biomass on the Vancouver Island continental shelf. Adults reach about 4 mm body length and are abundant in the upper 20–30 m from early spring through autumn. Early copepodites are nearly transparent, but C5 copepodites and adults accumulate orange lipid reserves. *Calanus* seems to be a minor component of the diets of local seabirds (Vermeer 1984) but is an important prey item for many planktivorous birds in the Bering Sea (G.L. Hunt, N.M. Harrison, and J. Piatt, unpubl. data).

9.5 Location of "best" feeding grounds for planktivorous seabirds

The zones within which the "most available" zooplankton taxa usually have their highest biomass are shown schematically in Figure 6. Overlapping zones of high biomass occur along the outer margin of the continental shelf for the key prey taxa (euphausiids, large calanoids, large gelatinous zooplankton plus their associated hyperiid amphipods). This suggests that the outer continental shelf and shelf break should be rewarding feeding grounds for planktivorous seabirds. This interpretation is supported by the observation of Morgan et al. (1991) that the highest seasonal abundances of many planktivorous birds occur at the outer edge of the shelf and over the shelf break. Highest densities of breeding colonies occur along the northern third of the Vancouver Island coast (K. Vermeer, pers. commun.). It is likely that this is caused partly by the alongshore trend in shelf width (and resulting proximity of the shelf break to suitable north island coastal nesting sites) and partly by a north–south trend in shelf break abundance of *Neocalanus* spp.

Figure 6
Regions of maximum abundance for the zooplankton taxa most heavily utilized by planktivorous seabirds



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Distribution, abundance, and habitat of prey fish on the west coast of Vancouver Island

Douglas E. Hay, Michael C. Healey, Daniel M. Ware, and Norman J. Wilimovsky

1. Abstract

The distribution, abundance, and habitat of the major fish species on the west coast of Vancouver Island are reviewed in the context of their availability to seabirds. A dominant feature of the ichthyofauna in the offshore region is the change in seasonal abundance: about half of the pelagic fish biomass is present only during the spring and summer upwelling season; in the spring, the dominant species migrate to more southern waters to spawn. In the near-shore environment, the availability of fish as prey depends upon seasonal migrations, particularly among the salmonids and herring. Longer-term changes in the abundance of several species, such as Pacific hake *Merluccius productus*, Pacific sardine *Sardinops sagax*, northern anchovy *Engraulis mordax mordax*, and Pacific herring *Clupea harengus pallasi*, could have a long-term impact on seabirds. The consequence of the long-term changes, as well as the more predictable seasonal changes, is that the most effective avian predators are probably opportunistic, relying on different prey as they become available. In addition to changes in seasonal abundance, vulnerability of intertidal and shallow subtidal fish species is, in part, dependent upon changes in the tidal heights relative to the natural photoperiod.

2. Résumé

La répartition, l'abondance et l'habitat des principales espèces de poissons de la côte ouest de l'île de Vancouver sont étudiés en fonction de l'accessibilité à ces espèces par les oiseaux de mer. L'une des principales caractéristiques de l'ichtyofaune de la zone extracôtière est la variabilité de son abondance saisonnière. Environ la moitié de la population de poissons pélagiques est présente seulement pendant la saison printanière et estivale de la remontée des eaux; au printemps, les espèces dominantes migrent vers des eaux plus méridionales pour frayer. Près du littoral, la quantité de poissons qui peuvent servir de proies varie en fonction de leurs migrations saisonnières, notamment dans le cas des salmonidés et du hareng. Des changements à long terme dans la population de plusieurs espèces comme le merlu du Pacifique *Merluccius productus*, la sardine du Pacifique *Sardinops sagax*, l'anchois du Pacifique *Engraulis mordax mordax* et le hareng du Pacifique *Clupea harengus pallasi* pourraient avoir des effets de longue durée sur les oiseaux de mer. En raison de ces changements à long terme ainsi que des variations saisonnières plus prévisibles, les oiseaux prédateurs les plus efficaces font probablement preuve d'opportunisme en comptant sur différentes proies à mesure qu'elles se présentent. En plus de varier selon les changements dans l'abondance saisonnière, la vulnérabilité des espèces de poissons intertidales et infratidales en eau peu profonde est en partie fonction des changements dans la hauteur des marées compte tenu de la photopériode naturelle.

3. Introduction

This paper describes the major fish species on the west coast of Vancouver Island as potential prey for seabirds. We begin with an overview of the offshore and near-shore fish environments. This is followed by three sections, each describing different groups of fish: migratory salmonids; offshore and near-shore pelagic species; and intertidal and shallow subtidal species. Although Hart (1973) listed about 200 fish species along the west coast of Vancouver Island, the number that are sufficiently abundant to provide a significant food resource for seabirds is much smaller.

Since the turn of the century, several important prey species have experienced particularly dramatic changes in numbers. These include the Pacific sardine or pilchard *Sardinops sagax*, the northern anchovy *Engraulis mordax*, and the Pacific herring *Clupea harengus pallasi*. The changes in these species, when combined with differences in cohort size of salmonids and natural fluctuations in the abundance of other species, have produced substantial temporal differences in the abundance and species composition of the community of prey fish.

In this paper, M.C. Healey prepared the section on salmonids; N.J. Wilimovsky wrote the section on intertidal fish; D.M. Ware wrote the sections on offshore fish and the ocean environment; and D.E. Hay contributed to the herring, other small pelagic fish, and discussion sections.

4. The fish environment

The west coast of Vancouver Island is at the northern end of the North America Coastal Upwelling Domain. Ware and McFarlane (1989) reviewed the dominant oceanographic features and associated biological productivity of this region. Based on oceanographic information and distributions of migratory pelagic fish, they concluded that the climatological boundaries of the Coastal Upwelling Domain extend from Baja California in the south (25–28°N) to the northern tip of Vancouver Island (50°50′N). Upwelling, which leads to cold water rising onto the continental margin, occurs primarily from May to September, in response to northwesterly winds. Winter is a season of downwelling in this region, driven by southeasterly winds. Annual transitions between downwelling and upwelling seasons occur in the spring and fall, with the seasonal reversal in the prevailing alongshore winds and currents. Winds inducing upwelling occur year-round off Baja California, where maximum upwelling takes place from March to June. In contrast, the intensity of upwelling off the west coast of Vancouver Island is greatest between June and August.

Thomson and Ware (1988) reviewed the seasonal and interannual variation in water properties and circulation off the west coast of Vancouver Island. This region is characterized by marked summer upwelling and a northward-flowing, buoyancy-driven coastal current that stretches along the inner continental shelf from Juan de Fuca Strait to Brooks Peninsula. Winds in this region are predominantly from the north in summer and the south in winter. Upwelling is particularly strong around capes and headlands where the continental shelf is narrow. There is a strong upwelling centre extending from the Scott Islands to Brooks Peninsula and another centre near Cape Flattery. The prevailing summer circulation over the continental margin of Vancouver Island is characterized by four main features:

(1) the poleward-flowing coastal current along the inner shelf;
(2) the equatorward-flowing shelf edge current that extends along the entire Pacific coast from Vancouver Island to California;
(3) the counterclockwise rotating Juan de Fuca Eddy situated over the Juan de Fuca Canyon; and
(4) the generally weak clockwise circulation over La Pérouse Bank (Fig. 1).

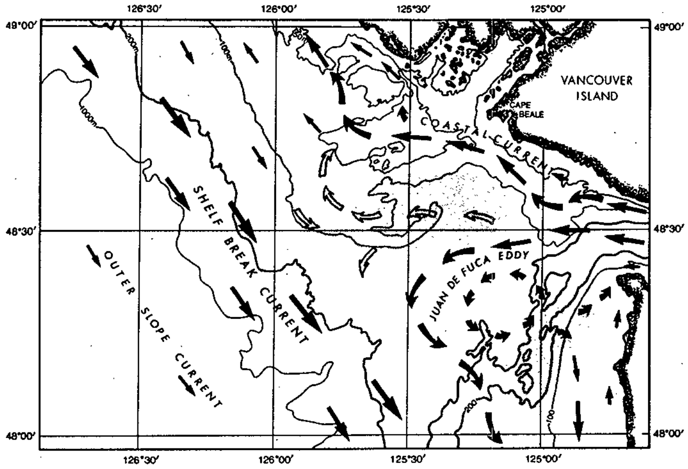
The transition from summer to winter conditions takes place sometime between October and November during the first major autumn storm. The "Fall Transition" is marked by a reversal in the prevailing winds, an accompanying reversal in the shelf break current, and a cessation of upwelling. During winter, the flow is typically to the northwest over the entire continental margin, and vigorous wind mixing leads to a deepening and destratification of the upper 100 m of the water column.

The west coast of Vancouver Island consists of five large coastal indentations (i.e., sounds) that are adjacent or connected to sheltered inlets. Within these indentations, shoreline can vary from beaches of mud, pebbles, cobble, and boulders to sheer rock cliffs. Inside waters can vary from well-mixed shallow estuarine waters to deep and stable silled inlets, with potentially anoxic bottom waters.

The most southern indentation, Barkley Sound, consists of a mixture of deep and shallow sheltered water, studded with islands and reefs and opening into three inlets (Alberni, Effingham, and Pipestem) (Fig. 2). Alberni Inlet receives drainage waters from three large lakes (Henderson, Sproat, and Great Central) that produce large sockeye salmon *Oncorhynchus nerka* runs. North of Barkley Sound, Clayoquot Sound also consists of a complex mixture of islands and reefs with adjacent inlets (Sydney, Shelter, and Herbert): the sound receives the drainage from Kennedy Lake, another large sockeye salmon producer. Nootka Sound, north of Clayoquot Sound, is mainly exposed open water opening to three sheltered inlets (Muchalat, Tlupana, and Tahsis). Tahsis Inlet is connected to Zeballos and Esperanza inlets in the north. Kyuquot Sound is the smallest of these indentations and consists mainly of deep water with few islands and reefs. Quatsino Sound in the north is relatively deep and leads to four large inlets (Neroutsos, Rupert, Holberg, and Winter Harbour).

Although fish are found throughout these waters, they are generally most abundant in the shallow, sheltered water — particularly those around islands and reefs. These conditions are most frequent in the southern indentations of Barkley and Clayoquot sounds, so that these areas support more inshore fish species than the deeper northern coastal indentations.

Figure 1
General summer circulation pattern on La Pérouse Bank and surrounding waters (from Thomson and Ware 1988)



5. Pacific salmon

Five species of Pacific salmon (*Oncorhynchus* spp.) occur as juveniles in marine habitats along the west coast of Vancouver Island. Three species (sockeye, pink *O. gorbuscha*, and chum *O. keta* salmon) are seasonal residents; coho *O. kisutch* and chinook *O. tshawytscha* salmon are present throughout the year.

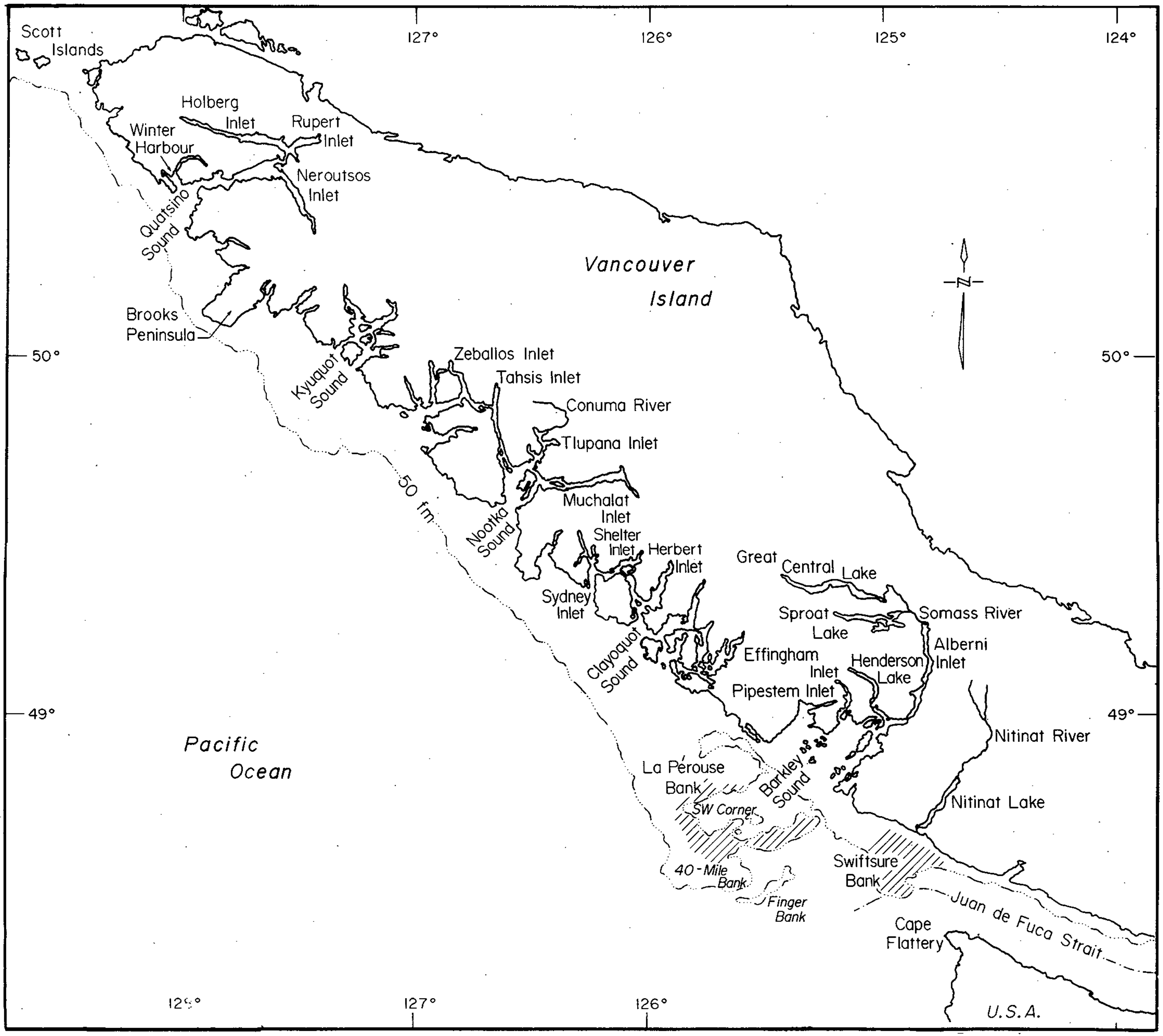
All five species are anadromous and spawn in autumn in river systems along the west coast of Vancouver Island. As most rivers with salmon runs discharge into deep bays or inlets along the west coast, the first marine habitats occupied by the salmon are sheltered and often estuarine in nature. During their marine lives, the salmon migrate through these sheltered marine waters to reach the open coast, where they assume a pelagic existence. Once on the open coast, all species disperse northward and, ultimately, seaward to varying degrees. Because each species makes different use of the sheltered waters and the open coast, it is useful to divide their early marine lives into sheltered water and open coastal phases.

5.1 Origin and abundance of juveniles

Juvenile salmon in marine waters originate from both local and distant sources. Local sources include wild spawning populations and hatcheries off the west coast of Vancouver Island. Juvenile production from wild spawning totals approximately 114 million, including 11 million sockeye salmon, 70 million chum salmon, 22 million pink salmon, 6 million coho salmon, and 5 million chinook salmon (adapted from values in Healey 1989). These estimates are, however, imprecise, and production can vary widely among years for all species, particularly for juvenile pink salmon runs from the Fraser River, which are low in odd years and high in even years. Three major west coast hatcheries are located on the Nitinat River, the Somass River, and the Conuma River (Fig. 2). The hatcheries increase the local production of juveniles to approximately 162 million (Department of Fisheries and Oceans 1988).

Mortality during the first few weeks of ocean residence is high, on the order of 3–9% per week, so that populations of juveniles entering the ocean are rapidly reduced (Parker 1966; Ricker 1976; Bax 1983; Healey 1989). Most mortality is believed to be due to predation (Parker 1971), some of which may be caused by marine birds (e.g., Nettleship et al. 1984; Vermeer et al. 1987).

Figure 2
The west coast of Vancouver Island, showing some of the major coastal indentations, river systems, offshore banks, and herring spawning sections. The dotted-dashed line indicates the 50-fathom (approx. 100-m) depth contours that are used to identify the banks mentioned in the text.



The population of juveniles on the west coast of Vancouver Island is augmented by unknown numbers of juveniles that migrate into the region from the Strait of Georgia, Puget Sound, and the Pacific coasts of Washington and Oregon (Pearcy 1984; Hartt and Dell 1986).

5.2 Juveniles in sheltered marine waters

5.2.1 Chum salmon

Chum salmon spawn in most river systems along the west coast of Vancouver Island. From March to May, chum salmon migrate to sea as fry, 35–40 mm in length (0.3 g), immediately after emerging from the spawning beds. After seaward migration, chum salmon fry spend their first few weeks of marine life in sheltered coastal inlets before migrating to the open coast. The timing of both entry to sheltered marine waters and subsequent migration to open coastal waters is illustrated by the chum salmon of Nitinat River. These salmon migrate to Nitinat Lake (an almost land-locked coastal inlet) during March, April, and May, are present in the lake until June, and then leave the lake for the open coast. This basic pattern is repeated in inlets and bays all along the coast. Chum salmon fry grow at about 0.5–0.75 mm/day, and those from Nitinat Lake are 50–60 mm in length at the time they leave the lake for the open coast.

5.2.2 Pink salmon

Pink salmon spawning rivers are mainly on the northwest coast of Vancouver Island. Like chum salmon, pink salmon migrate to sea immediately after emerging from their spawning nests in April or May as fry, 30–35 mm in length (0.2 g). There are no studies of seaward migration of pink salmon fry or their residence in different habitats during early marine life on the west coast of Vancouver Island. Studies elsewhere, however, indicate that the time at which pink salmon fry enter the ocean and the habitats they occupy during their first few weeks of ocean residence are similar to those of chum salmon (Parker 1965, 1966; Healey 1967, 1980). Pink salmon grow slightly faster than chum salmon, about 0.75–1.0 mm/day, so that their smaller size as fry is made up over the first few weeks of ocean life.

5.2.3 Sockeye salmon

Sockeye salmon are produced mainly from the central west coast of Vancouver Island, especially from the rivers tributary to Alberni Inlet (Fig. 2). Sockeye salmon typically remain one or two years in fresh water before migrating to sea as smolts, 60–100 mm in length, in late April or early May (Hyatt et al. 1984; Healey 1986, 1989). Unlike chum and pink salmon, sockeye salmon do not linger in sheltered inlets but migrate rapidly towards the open coast at a speed of about 5 km/day. Sockeye from the head of Alberni Inlet traverse the 35-km-long inlet in about seven days, then move west diagonally across Barkley Sound to Amphitrite Point and exit the sound by mid-June (Healey 1988). Smolts from Alberni Inlet rivers grow at about 1 mm/day and are about 90–100 mm long when they leave Barkley Sound (C. Groot, Department of Fisheries and Oceans, Nanaimo, pers. commun.).

5.2.4 Coho salmon

Coho salmon are produced in river systems all along the west coast of Vancouver Island. Coho salmon normally spend one or two years in fresh water before migrating to sea in May at 80–100 mm in length. Like sockeye salmon, coho salmon appear to spend little time in sheltered coastal waters but move quickly out of habitats such as Barkley Sound and Nitinat Lake (Healey 1982; Beacham 1990). During their first summer at sea, coho grow at 1.0–1.5 mm/day (Healey 1980, 1989).

5.2.5 Chinook salmon

Chinook salmon spawning rivers are distributed all along the west coast of Vancouver Island. Most chinook salmon from Vancouver Island rivers migrate to sea immediately on emergence from the spawning nest, when 40–45 mm in length (0.4 g). These chinook salmon utilize estuarine habitats as nursery areas for 6–8 weeks, after which they disperse to sheltered marine areas (Healey 1980, 1982). The chinook salmon that do not migrate to sea reside in their natal river for 6–8 weeks and migrate to sea in June when 60–80 mm in length (2–4 g). These June migrants occupy the estuarine nurseries for a few days to two weeks, after which they disperse to sheltered marine nurseries. A few chinook salmon remain a full year in their natal river and migrate to sea as yearling smolts, 90–120 mm in length (8–15 g). When they do go to sea, they disperse rapidly from sheltered marine areas to the open coast, like sockeye and coho salmon.

5.3 Juveniles on the open coast

Little is known about the behaviour of juveniles once they leave sheltered marine waters for the open coast. Hartt and Dell (1986) captured small numbers of all five species in purse seine nets within 30 km of shore along the west coast of Vancouver Island between 1964 and 1986. Catches were best off the north tip of Vancouver Island, where chum and pink salmon were abundant. Chum, pink, and sockeye salmon were captured in all months sampled (June through October). Catches of chum salmon were greatest in July and much lower in other months. Catches of pink salmon were greatest in July, remained high in August, and were lower in September and October. Sockeye salmon catches were highest in June and July, lower in August, and lower still in September and October. Coho salmon catches were highest in June and July and lower in August and September. Chinook salmon catch was high only in June. In relative terms, pink salmon catches were highest overall, followed, in descending order, by chum, coho, sockeye, and chinook salmon. The ordering of the species in the purse seine catches reported by Hartt and Dell (1986), therefore, is not the same as the relative abundance of locally produced juveniles estimated from spawning escapements above. In particular, pink salmon were overrepresented and sockeye salmon under-represented in the catches relative to estimated production.

The high catches of coho and chinook salmon early in the summer contrast with the results of more recent sampling by hook and line, which suggest that young coho and chinook salmon do not move onto the continental shelf until late autumn (Olsen et al. 1988). Sampling of coho and chinook salmon in sheltered waters further confuses the picture for these species. Catches of chinook salmon in sheltered waters remain high throughout the summer months, whereas catches of coho salmon decline early in summer; this suggests that chinook salmon linger in the sheltered waters, whereas coho salmon migrate rapidly to open waters (Healey 1982, 1988; Beacham 1990).

The seasonal pattern of catches reported by Hartt and Dell (1986) suggests that sockeye salmon do not linger on the west coast of Vancouver Island but move quickly north and away from Vancouver Island waters. Chum and, particularly, pink salmon, however, appear to linger in Vancouver Island waters. The high numbers caught at the north end of the island suggest that this may be a staging area for these species before they continue their northward migration.

The origins of the coho and chinook salmon captured by Hartt and Dell (1986) are unknown. Young-of-the-year coho and chinook salmon captured by hook and line off southwest Vancouver Island in recent years, however, are almost all from U.S. hatcheries, if tag returns are representative of the origins of these fish (Olsen et al. 1988; MCH, unpubl. data). No tagged smolts from either Robertson Creek or Nitinat River hatcheries have been captured off southwest Vancouver Island; this suggests that the juveniles from these hatcheries do not occupy nearby coastal nursery areas when they move out of sheltered waters.

Olsen et al. (1988) presented information on the sizes of coho and chinook salmon captured off southwest Vancouver Island in the fall of 1988. Young-of-the-year coho salmon ranged in size from 20 cm to somewhat larger than 40 cm (salmon larger than 40 cm were not sampled in this study) and averaged about 33 cm during September to November. Young-of-the-year chinook salmon were captured infrequently, but they also ranged from 20 to 40 cm and averaged about 29 cm. Fish-eating marine birds in the eastern North Pacific Ocean fed upon fishes ranging from 2.5 to 23 cm in length (Vermeer et al. 1987). Thus, by early autumn, these species had outgrown the prey sizes typically taken by marine birds.

6. Pelagic and offshore species

In summer, the continental shelf off the west coast of Vancouver Island is dominated by eight species of pelagic fish: Pacific hake *Merluccius productus*, spiny dogfish *Squalus acanthias*, Pacific herring, juvenile black rockfish *Sebastes melanops*, juvenile sablefish *Anoplopoma fimbria*, coho salmon, chinook salmon, eulachon *Thaleichthys pacificus*, and Pacific sandlance *Ammodytes hexapterus*. Historically, anchovies and sardines were very abundant; currently, however, sardines are absent, and anchovies occur only at relatively low levels in some of the inlets and sounds along the west coast of Vancouver Island. Pacific hake is a migratory species that currently makes up about 50% of the summer biomass of fish on the continental shelf. Pacific hake undergo extensive annual migrations (1600–2100 km) between summer feeding grounds off Washington and British Columbia and winter spawning grounds off southern California. Most of the hake and dogfish are too large to be eaten by seabirds, but, as feeders on planktonic euphausiids, they could be potential competitors of planktivorous seabirds. The principal pelagic fish that appear to fall prey to seabirds are herring, smelt, Pacific sandlance, and Pacific saury *Cololabis saira* (Vermeer 1979, 1982, this volume; Carter 1984; Vermeer and Westrheim 1984). The juveniles of some of the demersal sablefish and rockfish species are also eaten (Vermeer 1979; Vermeer and Westrheim 1984).

6.1 Pacific herring

The principal herring stocks along the west coast of Vancouver Island spawn in Barkley, Clayoquot, and Nootka sounds in the early spring (Hay and Kronlund 1987). In general, herring spend the first six months of life in shallow inshore waters (Hourston 1958). Between August and October, many begin moving seaward to the offshore banks, although some herring remain resident in inshore waters for some or all of their lives. The young herring that migrate to sea may remain there for the next two years until they join the spawning stocks as mature adults, usually at age three. After spawning, adult herring return to the offshore banks to feed and remain there until the following spring, when they migrate inshore to spawn again.

The Canadian Department of Fisheries and Oceans has conducted offshore herring surveys around La Pérouse Bank off Barkley Sound intermittently since 1969. These surveys showed that herring concentrate in the spring (March–May) on the 100-m edge on offshore banks: specifically at SW Corner, 40-Mile Bank, Finger Bank, and the southeast edge of Swiftsure Bank (Fig. 2). Dense aggregations at these locations persist throughout summer (June–August) and fall (September–November). However, by September and October, some herring leave these areas and disperse into deeper waters between the banks and the shelf break. Herring are most widely dispersed on the continental shelf in the fall. In winter (December–February), herring concentrate at SW Corner, 40-Mile Bank, and Swiftsure Bank; by February, they concentrate in prespawning aggregations in Barkley Sound and other inlets. Consumption of herring spawn by seabirds was confirmed in 1988 by observation and stomach analyses (Haegele and Schweigert 1989). Most of the spawn was consumed by gulls, although scoters, ducks, crows, and Canada Geese *Branta canadensis* were also observed feeding upon spawn. In 1988, the maximal estimates of consumption of herring eggs by birds in Barkley Sound did not exceed 300 t, which is small compared with the estimated spawning biomass of 7800 t.

There is limited distributional information on young-of-the-year (0+) herring, but, based on recent studies in the Strait of Georgia (C. Haegele, pers. commun.), nearly all are found within 2 km of the shore early in the summer. Surveys and analysis of offshore predator stomachs collected in August between 1986 and 1990 indicate that young-of-the-year herring (<15 cm in length) tend to be distributed in Barkley Sound and the shallow waters immediately adjacent to the sound later in the summer, with some near the 100-m isobath along the eastern side of La Pérouse Bank.

Stomach samples collected in summer around La Pérouse Bank since 1985 indicate that all age-groups of herring tend to feed on euphausiids. They also appear to feed intermittently, presumably as euphausiids become available near the surface. Dense aggregations of euphausiids are occasionally found near the surface in summer on 40-Mile Bank. Ware (unpubl. data) observed a euphausiid "swarm" at this location on 16 August 1988. The swarm was attended by large numbers of seabirds, herring, dogfish, and 8–10 humpback whales *Megaptera novaeangliae*. The amount of biological activity in such a small location on the bank was truly striking. The herring and seabirds appeared to be feeding actively upon euphausiids, whereas the dogfish and whales appeared to be eating both herring and euphausiids. All this activity occurred in the same vicinity on 40-Mile Bank where herring and whales had been spotted 3–4 days earlier.

6.2 Eulachon

The eulachon is a small anadromous species of smelt. It spawns in the lower reaches of large rivers on the British Columbia coast, particularly the Fraser. Most eulachon on the west coast of Vancouver Island probably originate in the Fraser River. Spawning occurs in the spring months, mainly mid-March to mid-May. Eulachon larvae enter the sea in the late spring and can be found on the west coast of Vancouver Island by midsummer. After 2–3 years, most fish reach an average size of about 20 cm, when they mature sexually. They seem to have been less abundant since 1970 than during the 1950s (Samis 1977).

Concentrations of eulachons occur at various locations along the west coast of Vancouver Island. Midwater trawl surveys since 1985 have encountered them scattered along the landward sides of the continental shelf and in various inlets and sounds. Eulachon have been observed as part of extensive schools of mixed species (also including young herring and anchovy) in Barkley Sound and in Sydney and Shelter inlets. Eulachon are also encountered frequently on Swiftsure Bank. Because eulachon tend to be scarce offshore relative to hake, herring, and dogfish, little is known about this phase of their life history.

6.3 Northern anchovy

The northern anchovy extends from Baja California, Mexico, to southern British Columbia. Anchovies are abundant off Oregon, where their biomass has been estimated at various times as between 0.5 and 1.0 million tonnes (Richardson 1981). In southern British Columbia, anchovies are found mainly in inside waters. There they are short-lived (maximum 6–7 years) and small (maximum 170 mm for females, 150 mm for males) (Pike 1951). Spawning occurs from June to August.

In the 1940s, anchovies were sufficiently abundant to support small purse seine fisheries with annual catches of a few thousand tonnes. They declined in the late 1950s and later years, but substantial quantities have been reported recently (1986). In the summer, anchovy may occur in mixed schools with eulachon and juvenile herring. Hay (unpubl. data) counted approximately 80 and 110 of these schools in Barkley and Clayoquot sounds, respectively. Total biomass of these schools was estimated at between 36 000 and 180 000 t.

6.4 Capelin

Southern British Columbia is near the southern edge of the distribution of capelin *Mallotus villosus* (Jangaard 1974), and consequently capelin are not locally abundant. Capelin warrant mention here because they are one of the few fish in southern British Columbia that spawn in the fall (September and October), in intertidal sandy areas during periods of spring tides on the full moon. They may be available to seabird predators at this time.

6.5 Pacific sandlance

The life history of Pacific sandlance was reviewed by Field (1988). In southern British Columbia, sandlance spawn in January and February. They live in shallow near-shore areas at depths less than 100 m. Postlarval sandlance were observed in the eddy area off the lower west coast of Vancouver Island in August 1986. They are also observed on Swiftsure Bank, where they frequently form a fairly dense scattering layer near the surface. Sandlance are abundant from spring to late summer but are relatively uncommon during the rest of the year, when they are believed to be buried in the sand (Field 1988). This life history pattern would explain the change in occurrence of sandlance in the diets of offshore Pacific cod *Gadus macrocephalus* studied by Westrheim and Harling (1983). Between 1950 and 1980, they found that sandlance were the principal prey of Pacific cod during the first two quarters of the year, became considerably less important in the cod diet in the third quarter, and were absent in the fourth quarter. Sandlance often form large aggregations near the surface during the day and remain buried in the sand at night (Field 1988). Sandlance feed mainly on calanoid copepods and, in turn, are fed upon by a wide variety of seabirds, fish, and marine mammals.

6.6 Pacific hake

Migratory Pacific hake are too large to be eaten by seabirds but are worth mentioning because they may compete with seabirds for food and because the offal from the fishery is an abundant and likely important source of food. This waste product could affect the distribution patterns and even the survival of juvenile birds, such as first-year California Gulls *Larus californicus*. As many as 15 700 California gulls have been observed around a single factory ship (Vermeer et al. 1989).

Pacific hake is currently the most abundant species in the Coastal Upwelling Domain. The hake stock complex in this region consists of a large migratory component and a comparatively small resident component. Migratory hake spawn primarily in winter off central and southern California. Juvenile hake (1–3 years old) are concentrated near the spawning area. After spawning, schools of adult hake migrate poleward at speeds of about 17 km/day and arrive off the southern west coast of Vancouver Island in late May to early June. Only the largest, and therefore oldest, individuals in the migratory stock enter Canadian waters. About 200 000–300 000 t of hake (about 25% of the migratory stock) spend 4–5 months feeding on euphausiids and herring in the La Pérouse Bank area and along the outer edge of the continental shelf as far north as Queen Charlotte Sound (Ware and McFarlane 1986). In recent years, the main body of hake has been found in the offshore basins between La Pérouse Bank and the west coast of Vancouver Island. In late summer (August), hake begin moving to the shelf break to feed. They remain there until the shift in wind direction and currents that mark the Fall Transition. Upon completing the annual migration, hake will have travelled some 4200 km in 239 days!

Small resident (i.e., nonmigratory) stocks of hake occur in the Strait of Georgia and in many of the large inlets along the west coast of Vancouver Island. These smaller hake populations are completely self-sustaining and complete their life cycle in Canadian waters.

Table 1
Fish frequently inhabiting areas on the west coast of Vancouver Island

Area	Family	Species
High rock intertidal areas	Cottidae	Sharpnose sculpin *Clinocottus acuticeps*
		Calico sculpin *Clinocottus embryum*
		Tidepool sculpin *Oligocottus maculosus*
	Stichaeidae	High cockscomb *Anoplarchus purpurescens*
		Black prickleback *Xiphister atropurpureus*
Near-shore open water column	Osmeridae	Smelts (2 species)
	Aulorhynchidae	Tube-snouts (1 species)
	Scorpaenidae	Rockfish (at least 5 species)
	Hexagrammidae	Greenlings (4 species)
	Embiotocidae	Surfperches (at least 4 species)
	Ammodytidae	Sandlances (1 species)

Euphausiids are the most important food item off the west coast of Vancouver Island. They provide more than 80% of the diet for the roughly 342 000 t of fish that spend the summer feeding in the fertile waters off the west coast of the island. Preliminary calculations indicate that hake eat some 216 000 t of euphausiids during the upwelling season (May–October), whereas dogfish and herring stocks eat an additional 148 000 t.

7. Intertidal fish

The abundance of intertidal fish has been examined at a few locations in the northeast Pacific Ocean. Although over 35 species inhabit the intertidal zone, many are seasonal in occurrence, and only about five species occur commonly in the higher intertidal area (Table 1). Winter populations are lower than summer populations. The available information was summarized in a previous report on fish as prey for seabirds in the Strait of Georgia (Hay et al. 1989). These data may reflect the carrying capacity of individual intertidal pools, as there is evidence that a "floating population" of most species frequents the subtidal zone (the region just below the intertidal zone). The number and abundance of fish appear somewhat greater in the subtidal zone than in the intertidal zone, but here again they are primarily inhabitants of rocky crevices and seaweed. Relatively few (six) subtidal species groups range in the water column where they might be more available to birds (Table 1).

Because of the accessibility of the intertidal region, this environment has received considerable study. Nevertheless, our knowledge of the fish is largely limited to daylight, summer investigations; night and winter data are limited, as are high-tide observations at all seasons of the year.

One of us (NJW) observed (with binoculars) mammals and birds foraging in the intertidal zone of Barkley Sound. Black bears *Ursus americanus* appear as casual browsers of the intertidal zone but have not been observed to extract fish from tide pools. Mink *Mustela vison*, which move extensively across the intertidal zone, appear only to feed subtidally, diving to take midshipman *Porichthys notatus*. In the summer, the midshipman seems to be the dominant food of mink. With the exception of the Great Blue Heron *Ardea herodias*, the birds observed foraging in the intertidal zone (crows, gulls, sandpipers, eagles, and oystercatchers) appeared to feed only on invertebrates and seaweeds. Herons appear to actively seek out fish.

Near-shore summer flocks of diving birds likely feed on fish, the most abundant in the inshore area being herring, salmon, and tube-snouts (*Aulorhynchus flavidus*). The primary fish fauna of kelp beds (rockfish, surfperch, and clingfish) seem less exploited.

8. Discussion

We have not included a specific discussion of shallow subtidal fish in this paper, for two reasons. First, most of the available information was presented in a previous paper on the fish of the Strait of Georgia (Hay et al. 1989). Second, there is little evidence that such species contribute to the diets of seabirds.

The descriptions of the fish as prey species indicate that abundance can vary within and between years. In general, both the abundance and vulnerability of fish, as prey for seabirds, increase in the spring and early summer months.

Juvenile salmon are present in marine waters off the west coast of Vancouver Island during all months of the year. They are abundant only in the spring and early summer, when the transient species (i.e., sockeye, pink, and chum) are present. Juvenile salmon are vulnerable to predation by mergansers when they are concentrated near their natal rivers from March to May (Vermeer, this volume) and are of a suitable size to be preyed upon. Later, when they have migrated to the waters of the open coast, they are less abundant, are more dispersed, and have grown to sizes less attractive to marine birds. Juvenile chum, coho, and sockeye salmon have been recorded in the diets of Rhinoceros Auklets *Cerorhinca monocerata* from Triangle, Pine, and Lucy islands on the British Columbia coast but were only a minor diet item (Vermeer and Westrheim 1984). Fish-eating birds sampled over La Pérouse and Swiftsure banks were found to have eaten mainly herring and sandlance. No juvenile salmon were found in these birds, but the sample size was small (Vermeer, this volume).

As in the Strait of Georgia, herring may be the single most important prey for many seabird species. Most predation would occur on the juvenile stages, because most of the older age classes migrate farther out to sea and are found in deeper water. Sandlance are important prey species throughout their lives. Most intertidal fish are small enough at all life stages to constitute prey for birds. Although the biomass of intertidal fish is lower than that of other species (herring, salmonids, and sandlance), the availability of intertidal fish during midwinter may make them a particularly important prey species.

Fish may become available as prey as by-products of commercial fishery operations during the relatively short fishing season. Young salmonids, particularly small (<30 cm) coho salmon, too small to legally keep in the commercial and recreational fisheries, may be taken by seabirds when they are released from the vessels. Commercial fisheries for herring in March usually result in a small (<1%) loss that may be available to seabirds. Trawling operations, some with partial processing at sea, result in offal from commercially fished species and discards of species that are not commercially valuable. The offal and discards attract thousands of seabirds, particularly California Gulls (Vermeer et al. 1989).

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Invertebrate fisheries and their possible conflicts with marine birds

Neil Bourne

1. Abstract

Marine invertebrate resources in British Columbia support valuable commercial fisheries and are also used in the recreational fishery. In 1989, the landed weight of marine invertebrates in commercial fisheries in British Columbia was 19 324 t, with a value of $40.8 million. Many of these fisheries occur along the west coast of Vancouver Island. A brief description of the habitat of marine invertebrates in commercial fisheries along the west coast of Vancouver Island is presented, along with a summary of the fisheries. Possible conflicts with marine birds are also identified. With the exception of wintering sea ducks, predation by marine birds on these commercially important invertebrates is probably minor. Predation by wintering waterfowl on bivalves can be important, particularly in areas where bivalves are cultured. The activities of vessels and commercial harvesters in invertebrate fisheries may disturb seabird colonies.

2. Résumé

Les invertébrés marins de la Colombie-Britannique font vivre d'importantes pêcheries commerciales et servent aussi pour la pêche sportive. En 1989, le poids au débarquement des invertébrés marins provenant des pêcheries commerciales de la Colombie-Britannique s'élevait à 19 324 t, et leur valeur atteignait 40,8 millions de dollars. Bon nombre de ces pêcheries se trouvent sur la côte ouest de l'île de Vancouver. Une liste des pêcheries ainsi qu'une brève description de l'habitat des invertébrés marins liés à la pêche commerciale le long de la côte ouest de l'île sont présentées. En outre, les conflits possibles avec les oiseaux de mer sont signalés. Sauf dans le cas des canards de mer qui hivernent, la quantité de ces invertébrés d'une importante valeur commerciale dont se nourrissent les oiseaux de mer est probablement assez faible. Le nombre de bivalves pris par la sauvagine qui hiverne sur la côte peut être considérable, notamment dans les zones de culture de ces lamellibranches. Les activités des bateaux et des exploitants pêcheurs commerciaux dans les pêcheries d'invertébrés peuvent perturber les colonies d'oiseaux de mer.

3. Introduction

British Columbia's coastal waters have a rich invertebrate fauna, but relatively few species are utilized in commercial fisheries (Quayle and Bourne 1972; Ketchen et al. 1983; Jamieson and Francis 1986; Quayle 1988). At present, about 30 species representing three phyla—Echinodermata, Arthropoda, and Mollusca—are used. In 1989, the total landed weight from invertebrate fisheries in British Columbia was 19 324 t, with a value of about $40.8 million. Of this total, 3871 t were echinoderms (valued at $3.1 million), 3886 t were arthropods ($13.3 million), and 11 568 t were molluscs ($24.4 million). These landings are not large compared with total fishery landings for the coast, but invertebrate fisheries are of economic importance to many coastal communities. Invertebrate resources are also used extensively in the recreational fishery (Bourne et al. 1987).

The west coast of Vancouver Island is an increasingly important area for marine invertebrate fisheries because of the rising market value of the products and improved access to many formerly isolated localities. This paper reports on invertebrate fisheries along the west coast of Vancouver Island and the relationship between these fisheries and marine birds. Emphasis is placed on molluscs, particularly bivalves, because they support large commercial fisheries along the west coast and are known to be important in the diet of many marine birds.

The west coast of Vancouver Island, as defined here, extends from Race Rocks in Juan de Fuca Strait to Cape Scott and includes Department of Fisheries and Oceans statistical areas 20–27, inclusive (Fig. 1).

4. Echinoderms

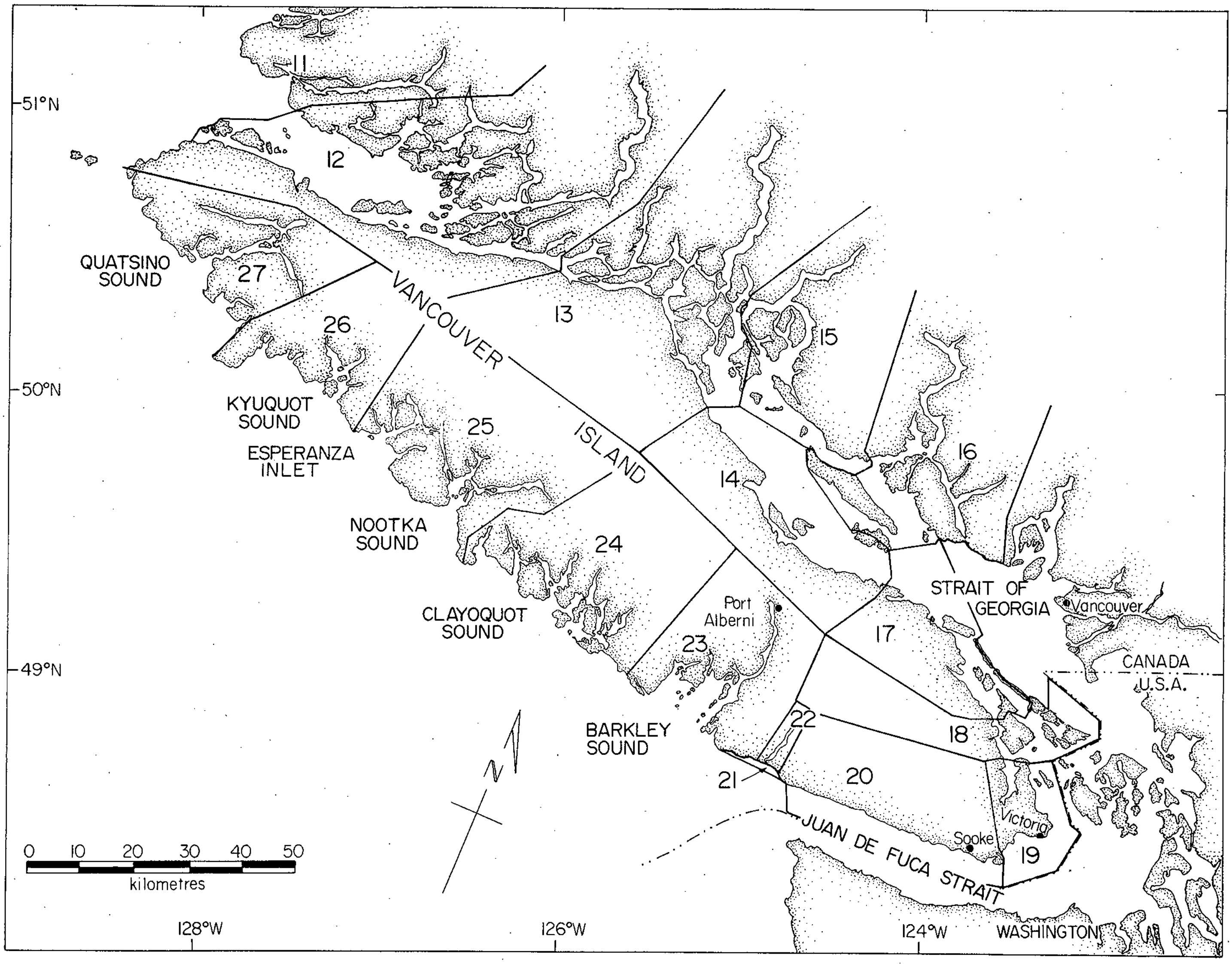
Three species of echinoderms are harvested in commercial fisheries in British Columbia: red sea urchin *Strongylocentrotus franciscanus*, green sea urchin *S. droebachiensis*, and sea cucumber *Parastichopus californicus*. Applications have been made to harvest the purple sea urchin *S. purpuratus*, but to date no landings have occurred. Only subtidal stocks of these three species are fished commercially, and they are harvested by diving.

4.1 Red sea urchins

Red sea urchins are the main echinoderms landed in British Columbia. They are found in a wide range of rock habitats in exposed and protected areas along the west coast of Vancouver Island, at depths to 100 m (Jamieson and Francis 1986). They are herbivores and feed on both attached marine plants and drifting kelp.

The fishery began in 1970; for the next decade, landings were sporadic but gradually increased. In 1988 and 1989, total British Columbia landings of red sea urchins were 1674 t and 2409 t, respectively, of which 17% and 15% came from the west coast of Vancouver Island. Most landings on the west coast were from area 24.

Figure 1
Map of Vancouver Island showing the location of some places mentioned in the text and the Department of Fisheries and Oceans statistical areas



4.2 Green sea urchins

Green sea urchins also have a wide distribution along the west coast of Vancouver Island but tend to occur in quieter waters and on softer substrates than red sea urchins, at depths up to 100 m. They are herbivores and eat both attached marine plants and detritus.

The fishery began in the late 1980s. Landings for the coast were 347 t and 519 t in 1988 and 1989, respectively, but only minor amounts were from the west coast, mostly area 24.

4.3 Sea cucumbers

Sea cucumbers have a wide distribution along the west coast of Vancouver Island, occurring to depths of 90 m (Jamieson and Francis 1986). They occur in areas protected from strong wave action and are most common on bedrock, although they also occur on gravel, sand, or mud substrates. The animals feed on microorganisms associated with sediment particles and detritus.

The fishery began in the late 1970s and has increased steadily since then. In 1988 and 1989, landings for the coast totalled 1358 t and 943 t, respectively, of which 38% and 23% were from the west coast of the island. The major west coast fishing area is area 25, but significant landings were also made in areas 23, 26, and 27.

5. Crustaceans

Fisheries for crustaceans can be divided into four groups: crabs, shrimp (including prawns), goose barnacles, and euphausiids.

5.1 Crabs

Commercial harvest of five crab species has been recorded in British Columbia, but almost the entire landings are of one species, the Dungeness crab *Cancer magister*.

Dungeness crabs occur along most of the west coast of Vancouver Island, from the intertidal area to depths of 180 m (Jamieson and Francis 1986). They are most abundant on sand substrates but may also be found on mud and gravel areas. They are omnivorous and prey on a wide variety of live animals and detritus.

The fishery is by trap. In 1988 and 1989, landings for British Columbia totalled 1406 t and 1226 t, respectively; almost 25% of the catch was from the west coast of Vancouver

Island. The most important fishing area on the west coast is area 24, in Clayoquot Sound and off Long Beach.

Minor fisheries for other crab species occur: rock crab *C. productus*, golden king crab *Lithodes aequispina*, red king crab *Paralithodes camtschatica*, and, recently, an experimental fishery for tanner crab *Chionoecetes bairdi* off the west coast. Landings of these species have been small.

5.2 Shrimp

About 85 species of shrimp occur in British Columbia waters, but only six are harvested commercially: sidestripe *Pandalopsis dispar*, pink *Pandalus borealis*, smooth pink *P. jordani*, coonstripe *P. danae*, humpback *P. hypsinotus*, and prawn *P. platyceros* (Butler 1980). Only the smooth pink shrimp, coonstripe shrimp, and prawn are important fisheries off the west coast of Vancouver Island.

Smooth pink shrimps are the target species for the trawl fishery off the west coast of Vancouver Island. They are found on mud bottom to depths of 200 m. The fishery has been sporadic and relies on the strength of incoming year classes. In 1988 and 1989, landings of shrimp (excluding prawns) for the British Columbia coast totalled 2211 t and 1823 t, respectively. Approximately 88% of these landings were from the west coast, primarily area 24.

Coonstripe shrimp occur on sandy, gravel, and rocky bottom, generally in areas of high tidal flow. The only commercial fishery in British Columbia is a small trap fishery in Sooke Harbour (area 20), where landings range from 5 to 50 t.

Prawns occur along the west coast of Vancouver Island usually on rocky bottom, at depths up to 200 m. Fishing is mostly by trap, and most fisheries occur in inlets along the coast of British Columbia. In 1988 and 1989, total prawn landings for the coast were 505 t and 655 t, respectively. Only 14% and 8% of the catches, respectively, were from the west coast. Fisheries in this area were mostly in areas 23, 25, and 26.

5.3 Goose barnacles

One species of barnacle, the goose barnacle *Pollicipes polymerus*, is harvested in British Columbia, almost exclusively on the west coast of Vancouver Island. The species occurs throughout British Columbia on the exposed outer coast, from the lower part of the intertidal area to subtidal depths.

A small intertidal fishery for this species has existed since the early 1980s. Animals are chiselled off rocks and graded for live shipment to markets. Landings are small—43 t and 27 t in 1988 and 1989, respectively. In 1989, the catch was entirely from the west coast of Vancouver Island, mostly from areas 23, 24, and 26.

5.4 Euphausiids

About 23 species of euphausiids occur in British Columbia waters. They are planktonic and occur to depths of 600 m. A small commercial fishery, mainly for *Euphausia pacifica*, exists in the Strait of Georgia.

6. Molluscs

Molluscs from three classes are harvested in commercial fisheries in British Columbia: Cephalopoda, Gastropoda, and Bivalvia.

6.1 Cephalopods

6.1.1 Octopus

Three species of octopus occur in waters off the west coast of Vancouver Island, but only one, the giant Pacific octopus *Octopus dofleini*, is of commercial interest (Jamieson and Francis 1986). The giant octopus occurs to depths of 50 m, generally on rocky substrates. Planktonic larvae are found in the upper surface waters for about two months before settling in inshore areas. Growth is rapid, and animals over 25 kg have been recorded (Hartwick 1973; Hartwick et al. 1981).

The fishery is small, and landings were generally about 55 t until 1987–89, when they increased to approximately 170 t. Much of the catch is taken as a by-catch in shrimp and groundfish trawling fisheries and in the crab and prawn trap fisheries. A dive fishery for octopus, mostly in the Strait of Georgia, has accounted for the recent increase in landings.

Octopus landings from the west coast of Vancouver Island have never been large and were 17% and 14% of the total catch in 1988 and 1989, respectively. Most of the catch was from area 24.

6.1.2 Squid

Seventeen species of squid have been recorded in British Columbia waters, but only four are of commercial interest: opal *Loligo opalescens*, red *Berryteuthis magister*, nail *Onychoteuthis borealijaponica*, and flying *Ommastrephes bartrami*. Squid probably form a significant part of the total biomass in the northeast Pacific Ocean (Jefferts 1986), but landings in British Columbia are small.

Opal squid occur off the west coast of Vancouver Island to depths of 250 m (Jamieson and Francis 1986). Larvae are planktonic in surface waters until they attain a mantle length of 4 cm, when they move closer to the bottom. At a mantle length of about 8 cm, they begin to school with other individuals.

Little is known about red squid. They occur in depths to 4600 m and appear to spend most of their lives on or near the bottom but occasionally rise to the surface.

Nail squid occur in coastal waters off the west coast of Vancouver Island in depths to 400 m during the day but come to the surface at night. Occasional reports are received of large concentrations of this species in surface waters off the west coast.

Flying squid are large, with a mantle length to 1 m. This tropical to subtropical species occurs in waters at or above 15°C, rarely within 50 km of the shore. An experimental sunken gill-net fishery was tested off the west coast of Vancouver Island in the 1980s. Although large quantities of flying squid were caught, a serious problem arose with the by-catch of marine birds and mammals (Jamieson and Heritage 1987). The fishery is still maintained by some foreign fleets outside Canadian territorial waters.

Most of the British Columbia squid catch consists of opal squid, taken by small seines. In 1988, no landings occurred; in 1989, only 35 t were landed. Most of the catch (74% in 1989) came from Barkley Sound.

6.2 Gastropods

Gastropods comprise the majority of marine molluscs in British Columbia (Bernard 1970), but only one species, the northern abalone *Haliotis kamtschatkana*, is harvested commercially.

6.2.1 Abalone

Northern abalone occur along the west coast of Vancouver Island from the lowest part of the intertidal area to depths of 15 m, but distribution is sporadic. Abalone are herbivores, feeding on surface algae and other plants. Growth is slow, requiring 6–10 years to attain a shell length of 100 mm, the minimum legal size limit in the commercial fishery (Sloan and Breen 1988).

The commercial fishery for abalone is on subtidal stock by scuba divers. Landings increased in the mid-1970s as the fishery developed but declined to present levels of about 50 t per year because of management restrictions. Since the early 1970s, most of the catch has come from the north coast district (Sloan and Breen 1988). In 1988 and 1989, abalone landings from the west coast of Vancouver Island amounted to only 6% and 3%, respectively, of the total British Columbia landings.

6.3 Bivalves

Bivalves comprise the major portion of landings in invertebrate fisheries in British Columbia. In 1989, 61% of the landed weight and 54% of the value of commercial invertebrate fisheries in British Columbia were bivalves.

Four species of clams are harvested in intertidal clam fisheries—razor *Siliqua patula*, butter *Saxidomus giganteus*, littleneck *Protothaca staminea*, and manila *Tapes philippinarum*—along with minor landings of cockles *Clinocardium nuttallii* and soft-shell clams *Mya arenaria*. Three species of clams are harvested in subtidal fisheries: geoducks *Panope abrupta* and two species of horse clams—*Tresus capax* and *T. nuttallii*. One species of oyster, the Pacific oyster *Crassostrea gigas*, supports a valuable industry. Small quantities of blue mussels *Mytilus edulis* and three species of scallops—pink *Chlamys rubida*, spiny *C. hastata*, and weathervane *Patinopecten caurinus*—are also landed.

Bivalves, particularly intertidal clams and oysters, are also harvested in the recreational fishery (Bourne et al. 1987). Species harvested are generally the same as in the commercial fishery. The extent of recreational landings along the west coast of Vancouver Island is unknown.

6.3.1 Intertidal clams

A small population of razor clams occurs on the west coast of Vancouver Island from Pachena Beach to Tofino. Commercial landings from this area have never been large, and the clams have been harvested only in the recreational fishery in the last 20 years.

The other three species of intertidal clams are found on beaches in protected waters and are common along the west coast of Vancouver Island. Butter clams occur mainly in the lower third of the intertidal zone to depths of 10 m. They are found in substrates with different proportions of sand, broken shells, mud, and gravel. Littleneck clams are most abundant from about the mid-intertidal beach to the 1-m intertidal level but are found to depths of 10 m. They occur with butter clams but are more common in firmer substrates. The manila clam was accidentally imported into British Columbia along with Pacific oyster seed from Japan (Bourne 1978). It was probably introduced into the Barkley Sound area with Pacific oyster seed and spread rapidly along the west coast of Vancouver Island to Quatsino Sound (Bourne 1982). Manila clams occur from the 1-m intertidal level to well above the mid-intertidal area, generally on sand/gravel beaches.

A fishery for intertidal clams has existed in British Columbia for about 100 years (Quayle and Bourne 1972). For many years, the most important species harvested was the butter clam, which was usually canned. In the mid-1970s, market demand changed to littleneck and manila clams. Since then, landings of both littleneck and manila clams, particularly the latter, have increased, and they are now the dominant species landed.

The west coast of Vancouver Island has always been an important area in the intertidal clam fishery. In 1988 and 1989, only small landings of butter clams were made on the west coast, mostly in area 26. In the same years, harvest of littleneck clams along the west coast was 10–13% of the total landings and occurred mostly in area 24. Manila clam landings from the west coast amounted to almost 25% of the total landings; in 1988, they were mostly in areas 24, 25, and 26; in 1989, they were mostly in areas 23, 24, and 25, but significant landings were also made in areas 26 and 27.

6.3.2 Subtidal clams

Geoducks are found from the lower intertidal zone to depths of at least 120 m (Bernard 1983). On the west coast of Vancouver Island, they occur in moderately exposed to sheltered conditions in fine mud to sand/gravel substrates. The two species of horse clams are also widely dispersed along the west coast. They occur in the lower third of the intertidal zone to depths of 10 m. *Tresus capax* occurs in mud/sand/gravel substrates, *T. nuttallii* in sand substrates.

Commercial diving for geoducks and horse clams is a recent activity (Harbo et al. 1986). Horse clams have been harvested intertidally (Quayle and Bourne 1972), but the fishery has been for subtidal stocks more recently.

The west coast of Vancouver Island has been an important area for the commercial geoduck and horse clam fisheries, particularly area 24. In 1988 and 1989, 35% and 37%, respectively, of the total geoduck landings were from this area. In 1988, most landings were from area 24, but significant landings were also made in areas 23, 25, 26, and 27. In 1989, most landings were again from area 24, but areas 23 and 27 were also important. This harvest pattern is partly due to management policies.

6.3.3 Oysters

Three species of oysters have been harvested commercially in British Columbia: native *Ostrea lurida*, eastern *Crassostrea virginica*, and Pacific (Quayle 1988). However, Pacific oysters are the only species used in the present British Columbia oyster industry. They were first imported from Japan in 1912, and numerous importations of juveniles were made subsequently until about 1970 (Bourne 1978; Quayle 1988).

The Pacific oyster industry is essentially a culture industry centred in the Strait of Georgia (Quayle 1988), but culture activities occur along the entire west coast of Vancouver Island. Most production is from intertidal bottom culture.

6.3.4 Mussels

Blue mussels are circumboreal and ubiquitous along the west coast of Vancouver Island in a wide variety of habitats, generally in the upper half of the intertidal area (Bernard 1983).

Attempts have been made to harvest wild populations of blue mussels, but they have been unsuccessful because of poor quality and low prices. Recently, there have been attempts to culture mussels, particularly in the Barkley Sound area, but production has been small.

6.3.5 Scallops

At present, only two species of scallops are harvested commercially—pink and spiny (Bernard 1983; Bourne 1991). Both species occur off the west coast of Vancouver Island, pink scallops from 5 to 200 m mostly on mud bottom, spiny scallops from 5 to 150 m on rock bottom in areas of strong current.

The fishery for pink and spiny scallops is small. Some harvest is by trawls, but most is by divers. In the last two years, an increasing amount of the catch has come from the west coast of Vancouver Island, mainly area 20.

7. Interactions with marine birds

7.1 Predation on commercially important invertebrate resources

Marine invertebrates are eaten by many species of birds and can form a significant portion of their diet (Cottam 1939; Hartwick 1976; Vermeer and Levings 1977; Vermeer 1981, 1982a, 1982b, 1983; Vermeer and Bourne 1984; Bourne 1984, 1989; Vermeer and Ydenberg 1989; Vermeer et al. 1989). The west coast of Vancouver Island is an important area during seasonal peaks in bird abundance, and significant predation of marine invertebrate resources can occur. The area is part of the Pacific flyway, and large numbers of birds utilize the intertidal and near-shore area during spring and fall migrations (Vermeer et al. 1983; Campbell et al. 1990). In addition to supporting many seabird breeding colonies, the west coast is also an important wintering area for many species of ducks and gulls (Vermeer et al. 1983).

Information on the extent of bird predation on commercially important marine invertebrate resources on the west coast of Vancouver Island is limited. Only predation of recruits or adults of commercially important marine invertebrates can be considered, as the extent of predation on larval forms or early juveniles is unknown.

7.1.1 Echinoderms

Sea urchins are not commonly eaten by marine birds, as the birds probably do not target on them. Small sea urchins may be taken incidentally by ducks, and adults may be eaten occasionally by oystercatchers and gulls.

Birds are not known to be serious predators of sea cucumbers in British Columbia. Small sea cucumbers may be eaten occasionally by oystercatchers and ducks, but it is not known if they include species of commercial importance. Gulls may eat adult sea cucumbers.

7.1.2 Crustaceans

Birds are important predators of crustaceans, although the extent of predation on commercially important species on the west coast of Vancouver Island is unknown.

Crabs form an important part of the diet of many species of ducks, gulls, and Great Blue Herons *Ardea herodias* (Cottam 1939; Palmer 1978), but whether these birds prey extensively on Dungeness crabs is unknown. It is unlikely that marine birds feed extensively on adult Dungeness crabs (other than scavenged corpses), but Great Blue Herons and Glaucous-winged Gulls *Larus glaucescens* have been observed feeding on juvenile Dungeness crabs in shallow waters (V. Gallucci and D. Armstrong, pers. commun.). Ducks also prey on crabs but probably target on other species, particularly *Hemigrapsus* spp.

Jamieson and Phillips (1989) reported that Dungeness crab larvae can be concentrated in waters off the west coast of Vancouver Island, where they may be prey for a variety of seabirds, including storm-petrels (*Oceanodroma* spp.), shearwaters (*Puffinus* spp.), Northern Fulmars *Fulmarus glacialis*, and many species of alcids.

Marine birds are not considered to be serious predators of major shrimp or prawn stocks off the west coast of Vancouver Island. These species occur at considerable depths, are probably out of range of serious predation by birds, and are generally secretive during daylight hours. Seabird predation on the coonstripe shrimp, which occurs at shallower depths in inshore areas, may be more significant. However, this fishery is not large in British Columbia.

Glaucous-winged Gulls prey to a limited extent on goose barnacles (Vermeer 1982b).

Marine birds are known to feed extensively on euphausiids (Palmer 1978; Nelson 1979). Cassin's Auklets *Ptychoramphus aleuticus* feed extensively on euphausiids along the west coast of Vancouver Island (Vermeer 1984, this volume). Bonaparte's *Larus philadelphia* and Mew *L. canus* gulls feed on euphausiids in areas of tidal upwelling (Vermeer et al. 1987). No commercial fishery exists for euphausiids off the west coast; if one developed, however, there could be a conflict between it and marine birds.

7.1.3 Molluscs

Marine birds are known to prey on all three classes of molluscs harvested in commercial fisheries—cephalopods, gastropods, and bivalves—and at times may be serious predators (Bourne 1989).

7.1.3.1 Cephalopods. Octopus are eaten by seabirds (Hatch 1984); however, they were not considered serious predators in the Strait of Georgia (Bourne 1989) and are probably not serious predators on the west coast of Vancouver Island. Squid are an important item in the diet of many seabirds (Nelson 1979; Schneider and Hunt 1984). Establishment of a large squid fishery does not appear likely in the near future. The sunken drift net fishery for flying squid represents a major threat to marine birds; as long as it is maintained by foreign fleets outside Canadian territorial waters, it will undoubtedly continue to cause serious mortalities to marine birds.

7.1.3.2 Gastropods. Gastropods form an important part of the diet of many marine birds, particularly diving ducks (Cottam 1939; Vermeer 1982a, 1983; Vermeer and Bourne 1984; Bourne 1984, 1989). However, the species of gastropods identified have been small and are of no commercial importance. Cormorants (*Phalacrocorax* spp.) and Glaucous-winged Gulls have been reported feeding on abalone (Vermeer 1982b; Bourne 1989), but the extent of predation is probably minor. It is doubtful if marine birds are significant predators of abalone on the west coast of Vancouver Island because of the cryptic behaviour of abalone and their firm adherence to rocks. Predation by birds such as gulls would occur mostly on intertidal stocks, which are small (Sloan and Breen 1988).

7.1.3.3 Bivalves. Bivalves are an important part of the diet of many species of marine birds, including ducks, gulls, and oystercatchers (Bourne 1989). Glaucous-winged Gulls feed on cockles, manila clams, and mussels (Vermeer 1982b; Bourne 1989); in Washington, they have been observed feeding on razor clams (D. Simons, pers. commun.). Both cockles and manila clams are buried at shallow depths in the substrate and are likely easy prey for gulls. Glaucous-winged Gulls are probably significant predators of cockles, particularly in areas where they concentrate or near nesting colonies, and may take large numbers of manila clams in isolated locations. However, overall, Glaucous-winged Gulls are not considered serious predators of commercially important bivalves on the west coast of Vancouver Island.

Shorebirds, including oystercatchers, have been reported as predators of bivalves (Hartwick 1974; Goss-Custard 1984; Baird et al. 1985) and may be important predators on juvenile stages of commercially important bivalves. They have been observed feeding on small razor clams on Washington state beaches (D. Simons, pers. commun.). The extent of predation by shorebirds on commercially important bivalves on the west coast of Vancouver Island is unknown but is probably small, because of the seasonal nature of shorebird numbers.

Wintering flocks of ducks feed on bivalves and can be serious predators of commercially important bivalves (Bourne 1989). Species that feed on bivalves include Bufflehead *Bucephala albeola*, Barrow's Goldeneye *B. islandica*, Common Goldeneye *B. clangula*, Greater Scaup *Aythya marila*, Oldsquaw *Clangula hyemalis*, Harlequin Duck *Histrionicus histrionicus*, and White-winged *Melanitta fusca*, Surf *M. perspicillata*, and Black *M. nigra* scoters.

The most commonly eaten bivalve is the blue mussel. Bufflehead, Common and Barrow's goldeneyes, Greater Scaup, Oldsquaw, and Harlequin Ducks do not appear to feed extensively on buried clams. However, White-winged and Surf scoters do feed on littleneck and manila clams (Bourne 1984; Vermeer and Bourne 1984). Horse clams are rarely eaten, and geoducks have not been reported in the gut contents of ducks, probably because they are deep in the substrate. Greater Scaups and American Black Oystercatchers *Haematopus bachmani* have been reported eating oysters, but they are probably not serious predators except in special circumstances (Butler and Kirbyson 1979; Bourne 1984). Heavy predation would occur only in areas where there are large numbers of small single oysters, and this is rarely the situation on the west coast of Vancouver Island. Scallops have not been recorded in the gut contents of seabirds off the west coast.

Ducks, particularly large wintering flocks of scoters and goldeneyes, can be important predators of bivalves. Large numbers of Surf and White-winged scoters and goldeneyes are one of the major factors preventing development of a large mussel culture industry in British Columbia (Bourne 1989). Bourne (1989) estimated that a flock of 200 scoters could consume 5.3–15.9 t of littleneck and/or manila clams in a six-month period in the Strait of Georgia.

7.2 Other potential areas of conflict

A possible area of conflict between invertebrate fisheries and marine birds is the effect these fisheries have on marine birds. Marine birds are occasionally caught in fishing gear, such as trawls, but mortalities from this source are small. Concern has been expressed that commercial goose barnacle harvesters may cause disturbance to marine birds at nesting colonies, and harvest in these areas should be avoided (R. Harbo, pers. commun.).

Another possible area of conflict between marine bird populations and commercial harvest of invertebrates is aquaculture. In the immediate future, invertebrate aquaculture will probably be confined to the culture of bivalves (Bourne 1988).

In past years, only Pacific oysters were cultured on the west coast of Vancouver Island, and only in Barkley and Clayoquot sounds. Now, attempts are being made to culture oysters as far north as Quatsino Sound. Attempts are also being made to culture blue mussels, manila clams, and Japanese scallops *Patinopecten yessoensis* in various west coast locations.

Aquaculture activities concentrate prey species and hence attract predators, particularly diving ducks, where bivalves are cultured. Methods have been devised to protect some bivalves under culture—for example, protective nets around mussel culture operations and over manila clam culture areas. However, this adds to costs, and new and less expensive methods to protect bivalve crops from bird predation will have to be found.

Bivalve aquaculture activities will probably continue to expand gradually along the west coast of Vancouver Island. Every precaution must be taken to reduce the risk of conflict between these operations and seabird populations.

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Factors affecting the distribution of kelp and its importance as a food source

Robert E. DeWreede

1. Abstract

Kelp beds form a major habitat in many near-shore marine sites in British Columbia. The abundance and distribution of kelps are determined in part by such factors as salinity, light, and temperature and by herbivores, such as sea urchins and limpets. Sea otters *Enhydra lutris* influence kelp distribution by consuming urchins. Together these factors determine the age (and hence size and stage) and structure of kelp stands. Birds are predators of organisms that live in kelp beds, but almost nothing is known of kelp–bird interactions in British Columbia. The sensitivity of some kelps to temperature and the possibility of increasing seawater temperature hold unknown consequences for both kelps and birds associated with kelps.

2. Résumé

Les lits de varech constituent un important habitat dans bon nombre de zones littorales de la Colombie-Britannique. L'abondance et la répartition du varech sont déterminées en partie par des facteurs comme la salinité, la lumière, la température et certains herbivores comme les oursins et les patelles. Les loutres de mer *Enhydra lutris* influent sur la répartition du varech parce qu'elles se nourrissent d'oursins. L'ensemble de ces facteurs détermine l'âge (et donc la dimension et le stade) ainsi que la composition des lits de varech. Les oiseaux se nourrissent d'organismes qui vivent dans ces lits, mais on ne sait presque rien des interactions entre les oiseaux et le varech en Colombie-Britannique. Les conséquences pour le varech et les oiseaux qui y trouvent leur nourriture de la sensibilité de certains varechs à la température et de l'élévation possible de la température de l'eau de mer sont inconnues.

3. Introduction

The term "kelp" is a colloquialism used to denote various large seaweeds, and "kelp beds" refers to the collection of these algae in a given location. In British Columbia and adjacent coastal waters, kelp beds exist within fairly well defined physical and biological limits. Such physical variables as temperature, salinity, light, nutrients, and wave action, and their interactions and seasonal fluctuations, are important determinants of the distribution and abundance of the genera and species that comprise the kelp bed. Herbivores such as sea urchins, limpets, and chitons are important biological influences; otters, in their role as predators of urchins, also have an impact.

The purpose of this paper is to review the factors that govern the distribution and abundance of kelp and focus on kelp as a food source for a variety of organisms, including marine birds.

4. Life history of main kelp genera

The kelps, all members of the Laminariales and Phaeophyta, have identical life histories. The large visible plants are the diploid sporophytes. At maturity, spores may form in patches on the blades, as in *Nereocystis* and *Laminaria*, or on specialized structures called sporophylls, as in *Alaria* and *Pterygophora*. Released following meiosis, the haploid spores form microscopic male and female gametophytes, and the resulting gametes undergo sexual fusion. The resulting diploid zygote then forms the sporophyte.

The dominant genera in British Columbia kelp beds are *Macrocystis, Nereocystis, Pterygophora, Eisenia, Laminaria,* and *Alaria*; other less common genera are *Agarum* and the more intertidal kelps, *Hedophyllum* and *Egregia*. All of these kelps, except *Hedophyllum*, have the same basic structure—a holdfast, stipe, and various blades and/or sporophylls; *Hedophyllum* lacks a stipe. In general, the kelps grow most rapidly in the spring months, with the annuals such as *Nereocystis* dying back in the late winter. Other kelps (e.g., *Laminaria setchellii*) may retain the stipe as a perennial structure and renew the blades every year. Still others, such as *Pterygophora*, may live for 10–20 years, losing only a relatively small apical blade every year.

5. Physical factors affecting kelp distribution

5.1 Temperature

The critical upper temperature for the survival of many kelps is about 15°C; higher temperatures for more than a few days can have adverse effects on both sexual reproduction of the gametophyte and vegetative growth of the sporophyte. In the Barkley Sound area, Druehl et al. (1987) monitored temperature for 18 months and found that, at 4 m depth, the maximum temperature of 14°C occurred in July and the minimum of 8–9°C in February.

Work on *Egregia menziesii*, a kelp growing in the low intertidal area in local west coast waters, has shown that a temperature range of 7–15°C has little effect on net photosynthesis of the sporophyte (Gordon and DeWreede 1978). However, experiments on the development of gametophytes into new sporophytes indicate that spores of *E. menziesii* are generally not viable at 15°C; this viability is altered by salinity as well (see below). For another kelp, *Laminaria hyperborea*, which occurs in the North Atlantic, Kain (1964) found that gametophytes were able to survive to about 17°C for 11–14 days before a precipitous decline in survival occurred, at 20°C, no maturation of gametophytes occurred. Ueda (1929) found that gametophytes of *Laminaria religiosa* became fertile only below 12°C, and Meyers (1928) observed that antherozoids of *Egregia menziesii* were released only below 16°C. Kemp and Cole (1961) stated that *Nereocystis leutkeana* gametophytes would grow at temperatures to 14°C but became reproductive only at 9°C or below.

Some waters in British Columbia, such as the Strait of Georgia, have temperature (above 15°C) (and salinity, see below) conditions that prevent the growth of some kelps that flourish in cooler, more oceanic waters found off the west coast of Vancouver Island. Freeland (this volume) showed that a long-term warming of about 0.9°C has occurred along the British Columbia coast this century. Because of the sensitivity of kelp to temperature, possible global warming may affect both kelp and its associated community.

5.2 Salinity

Salinity measurements vary seasonally and can change rapidly. For example, Druehl et al. (1987) found salinities in Barkley Sound of 32‰ in late November and again in May and a low of 27‰ in December. The seasonal pattern at 4 m depth was less distinct for salinity than for temperature. However, kelps respond to salinity changes, and such changes may be responsible in part for their distribution and abundance.

For *Egregia menziesii*, net photosynthesis decreases with decreasing salinity (Gordon and DeWreede 1978), especially below 32‰. Not unexpectedly, there is also a trend towards smaller sporophyte sizes owing to reduced growth rates with decreasing salinity; as well, spores generally do not germinate at 17‰.

In a study of standing crop and productivity of *Nereocystis* at Malcolm Island, British Columbia, Foreman (1984) pointed out that high densities of *Nereocystis* were correlated with record low mean annual temperatures of 8°C and salinities of 31.0‰; as the temperature and salinity increased from these lows, the standing crop decreased.

5.3 Light

Light follows a marked seasonal regime in British Columbia if average readings are used, but each month's data have a high standard deviation. Maxima of approximately 42 E/m^2 per day occur from May to August, and lows of 9 E/m^2 per day from December to February (Druehl et al. 1987). Kelps, being photosynthetic organisms, require light; however, the extent to which their distribution is affected by light and whether intensity or spectral distribution of light is more important remain undetermined.

Many seaweeds cannot exist below the 1% level of light, which, depending on the water type, may occur from 150 m to depths as shallow as 4–5 m. In addition to intensity changes with depth, spectral quality is also altered, with colours above 600 nm and below 400 nm (red/infrared and violet/ultraviolet) being screened out in shallower depths (Saffo 1987).

Light undoubtedly affects kelp distribution at depth, but it is also apparent that biological factors such as grazing by sea urchins often limit the lower distribution of kelps in British Columbia and contiguous parts of the west coast.

5.4 Wave exposure

Wave exposure and related factors are other determinants of kelp distribution and abundance. For example, the intertidal plant *Postelsia* occurs only on wave-swept platforms. The impact of waves on subtidal kelps is less obvious and may function less to determine presence/absence than to shape population structure such as age distribution. In both types of habitats, however, the effect of waves may be either direct, by ripping plants away as a result of the force of the waves, or indirect, by affecting the numbers of herbivores present.

Denny et al. (1989) showed that a 1-mm razor cut in the stipe of *Postelsia* resulted in 100% loss of the 30 plants so treated within 24 hours. If herbivore damage results in similar mortality, their impact, even if grazing only a part of the stipe, must be great. However, it is likely that it is not possible for most herbivores to feed in high wave impact environments, and hence *Postelsia* may suffer little from this problem. In a paper examining the impact of storm waves on *Macrocystis pyrifera*, Seymour et al. (1989) found that water motion greatly affected survivorship of this species and concluded that breaking waves are an important factor in determining the inner boundary of *Macrocystis* stands. Individual kelps can often withstand substantial wave impact, whereas entangled plants are unable to do so (Denny et al. 1989; Seymour et al. 1989).

5.5 Substratum

All kelps grow attached to a solid substratum, primarily rock. However, they readily attach to other anchored structures such as ropes and jetties. In all cases, their survival is determined by how well they can gain attachment and the permanence of the substratum. Each spring, numerous small kelps are swept into the intertidal zone because of their attachment (as spores) to small pebbles.

6. Interactions among kelp bed inhabitants

6.1 Herbivory

Many organisms eat kelps. Some (e.g., sea urchins) consume only selected species, whereas others (e.g., chitons and limpets) select specific life history stages, such as the very young (and small) sporophytes or microscopic gametophytes. Studies by Leighton (1966), Vadas (1977), Duggins (1981), and others have documented that urchins display a preference among different species of kelps, with *Nereocystis* being the most preferred (Vadas 1977) and *Agarum* the least, among the genera offered. Leighton (1966) showed that within a kelp species, the sporophylls (areas of the plant containing the spore-bearing structures) were most preferred by urchins, the nonreproductive parts of the blade next, followed by the stipe and the holdfast. This preference is thus the reverse of the sequence in which an urchin would encounter a kelp. Despite research on the topic, the basis for these choices is not yet clear; suggestions have included selection for high caloric values, protein content, and avoidance of toxic or irritating chemicals.

The choice made by invertebrates such as limpets and chitons (which feed with a radula) is very likely based on such factors as the chemicals contained by the food, nutritional requirements, and ability of the radula to remove the food from the substratum. Research by Padilla (1985) indicates that choice based on thallus hardness may be counterintuitive, as studies on the limpets *Acmaea mitra* and *Notoacmaea scutum* indicated that it requires less force for them to remove thallus pieces from a crustose coralline algae (*Pseudolithophyllum*) than from more fleshy species such as *Hedophyllum* (a kelp) and *Iridaea* (a bladed red algae).

Direct experimental evidence of the basis of food choice is lacking, but experiments have been done to test the effect of adding and removing these herbivores to and from algal communities. Duggins and Dethier (1985) examined the effect of increasing and decreasing the density of the chiton, *Katharina tunicata*, on algal communities. The low intertidal algal community initially consisted of *Hedophyllum* and some understory algae; there was no change in the control sites throughout the four- to five-year study. In sites where *Katharina* was removed, there was an increase in abundance and diversity of the algae after three years. In sites with *Katharina* added, algal abundance and diversity both decreased. An important mechanism undoubtedly was the selective grazing on small gametophytes and sporophytes in the *Katharina* addition experiments and an increased dominance of the dominant algal species in the exclusion experiments. When, after three years, the dominant kelps were removed in the *Katharina* addition sites, there was another increase in diversity and abundance compared with nonremoval sites.

6.2 Predation

Predation is another important mechanism affecting the species diversity of kelps; the effects of predators on herbivores in turn affect the competitive interactions among algae. One example of this is the effect that sea otters *Enhydra lutris* have on kelp communities as these animals return to sites from which they had been hunted to extinction (Duggins 1980; Estes and Steinberg 1988). The otters prey on sea urchins and other invertebrates. The sea urchins consume many algae (as discussed above) and, in some cases, do so selectively. As the urchins disappear, an influx of many algae occurs, especially the kelp *Pterygophora*. In sites where the urchins had previously kept the algae to a coralline algal pavement, algal diversity will increase. In those sites where the urchins ameliorated the competitive interactions among the algae and thus allowed subdominants to exist, theory predicts that the diversity will decrease as the urchins disappear.

6.3 Competition

Competition is frequently cited as an important determinant of the abundance and diversity of marine algae. However, proving that competition is occurring or has occurred is extremely difficult (Connell 1980). By definition, interspecific competition involves the attempt by two species to obtain a common limiting resource, resulting in a reduction in fitness of both competitors, although not usually to the same extent (Begon and Mortimer 1981). In the shallow marine subtidal environment, space and/or light are often postulated to be the limiting resources, and there is some evidence to support this contention; however, the necessary decrease in fitness (and thus solid evidence for competitive interactions) has, to my knowledge, not been shown for algae.

Various experiments have been performed in an attempt to show that algae compete. Often these experiments take the form of removing a possible competitor and then monitoring the effects on the other assumed competitor. For example, Hruby (1976) examined whether competition between *Laminaria saccharina* and *Iridaea splendens* (as *I. cordata*) was limiting the extension of *Iridaea* lower into the subtidal zone. Hruby (1976) cleared *L. saccharina* from selected sites and removed kelp recruits from these sites monthly; appropriate controls were placed in both uncleared kelp sites and the adjacent *Iridaea* zone. He found that *Iridaea* was able to grow in the cleared sites but was unable to do so in the control (no clearing) site. Hruby (1976) concluded that competition between the two species resulted in limiting the lower extent of the *Iridaea*, but he acknowledged that the limiting resource had not been identified (but speculated it might be light) and did not test for a reduction in fitness of either species. An alternative explanation for this phenomenon might be that the kelps facilitate the presence of herbivores, which in turn graze the *Iridaea*.

Table 1
Birds of kelp forests (modified from Foster and Schiel 1985)

Surface canopy	Midwater and bottom	Seaward fringe
Bonaparte's Gull	Pelagic Cormorant	Common Loon
Larus philadelphia	*Phalacrocorax pelagicus*	*Gavia immer*
Great Blue Heron	Brandt's Cormorant	Western Grebe
Ardea herodias	*Phalacrocorax penicillatus*	*Aechmophorus occidentalis*
Wandering Tattler	Horned Grebe	Brandt's Cormorant
Heteroscelus incanus	*Podiceps auritus*	*Phalacrocorax penicillatus*
Red-necked Phalarope		Pelagic Cormorant
Phalaropus lobatus		*Phalacrocorax pelagicus*
Red Phalarope		Surf Scoter
Phalaropus fulicaria		*Melanitta perspicillata*
		White-winged Scoter
		Melanitta fusca
		Pigeon Guillemot
		Cepphus columba
		Common Murre
		Uria aalge

Pearse and Hines (1979) tested the hypothesis that light reduction by overstory kelps (*Macrocystis*) was responsible for the limited occurrence of other algae in the understory. They found that the *Macrocystis* overstory reduced the surface light intensity by 96% and that, upon removal of this species, kelps such as *Pterygophora californica* and *Laminaria dentigera* and foliose red algae were able to establish themselves.

Studies of intraspecific competition have similar problems in definitively showing the existence of competition. As well, authors of such studies as have been done with algae often take pains to point out that generalities made about this process for terrestrial plants do not necessarily hold for algae. Dean et al. (1989) briefly reviewed the literature on intraspecific competition and concluded from their own experiments that the survival of *Macrocystis pyrifera* juveniles was inversely related to density of recruits and followed the dominance and suppression model. However, they noted that there is little evidence for such inverse density-dependent survival in other algae and attributed their results to the competition for light in kelp forests, which may not occur to nearly the same extent in sites where *Macrocystis* does not grow.

6.4 Bird use of kelp forests

Few specifics are known about the ways in which birds utilize kelp forests in British Columbia. In this section, I summarize pertinent data from Foster and Schiel (1985), who reported on the occurrence of birds in California kelp beds, relating their findings to those birds that also occur in British Columbia (R.W. Butler, pers. commun.).

Foster and Schiel (1985) divided the California kelp forest into three habitats: the surface canopy, midwater and bottom, and the seaward fringe. Birds found in these habitats are listed in Table 1.

Birds (e.g., Bonaparte's Gulls *Larus philadelphia* and phalaropes) perch on kelp fronds in the surface canopy, where they scavenge on invertebrates. Great Blue Herons *Ardea herodias* hunt for small fish beneath the canopy. The midwater and bottom portions of kelp beds are frequently visited by cormorants, feeding mostly on fish (Hubbs et al. 1970) such as kelp perch *Brachyistius franatus*, and by Horned Grebes *Podiceps auritus*, which hunt for mysid shrimp. The seaward fringe of the kelp is visited by loons, grebes, cormorants, scoters, Pigeon Guillemots *Cepphus columba*, and Common Murres *Uria aalge*, which forage opportunistically.

When kelp dies, some fronds float into the open ocean, and others wash up on beaches. Rafts of free-floating kelp frequently attract phalaropes (Haney 1986). Beached kelp and other algae harbour insects and crustaceans, which may in turn attract Sanderlings *Calidris alba*, Black Turnstones *Arenaria melanocephala*, and Western Sandpipers *Calidris mauri* (R.W. Butler, pers. commun.).

In British Columbia, American Black Oystercatchers *Haematopus bachmani* forage in the low intertidal zone. These birds feed on shellfish and limpets and thus may influence the distribution and abundance of such low intertidal kelps as *Hedophyllum* and *Egregia*.

Based on the few data available, birds associated with kelp beds usually feed on organisms attracted to the kelp, but not on the kelp itself. However, the degree of interdependence between birds and kelp beds is poorly understood.

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The diet of birds as a tool for monitoring the biological environment

Kees Vermeer

1. Abstract

A review of the diet of marine birds in nesting colonies, in estuaries, in inlets, and over offshore banks along the west coast of Vancouver Island indicates that little is known of the diet of most nesting seabirds, except for the major nesting species, such as Glaucous-winged Gulls *Larus glaucescens*, Cassin's Auklets *Ptychoramphus aleuticus*, Rhinoceros Auklets *Cerorhinca monocerata*, and Tufted Puffins *Fratercula cirrhata*. The diet of Common Mergansers *Mergus merganser* in estuaries and that of Marbled Murrelets *Brachyramphus marmoratus* and Mallards *Anas platyrhynchos* in inlets are known to some extent, but that of all other species needs much more investigation. An analysis of the diet of a small sample of pelagic birds over offshore banks revealed that they foraged on the same main food categories as elsewhere in the North Pacific, although there were geographic differences in prey species. Herring spawn constitutes a major food source for piscivorous and nonpiscivorous birds and attracts many tens of thousands of diving ducks and gulls to spawning locations on the west coast of Vancouver Island in March.

It is necessary to monitor long-term changes in the diets of nesting seabirds together with changes in their populations and reproductive success, and the best location for such monitoring appears to be Triangle Island, an offshore island with a unique community of both planktivorous and piscivorous seabirds. Monitoring of the diets is providing biologists with an important tool to determine the effects of yearly physical variation in surface waters as well as those of major irregularities, such as El Niños and global warming, on both prey and seabirds.

It is also necessary to monitor pollutants from mines and pulp and paper mills in tissues of both estuarine and marine birds and their prey. Estuarine and marine birds occupy the highest levels of the food web, and magnification of toxic chemicals through prey organisms in this web makes those birds vulnerable to environmental contaminants. Examples of birds contaminated with arsenic and copper down-inlet from a copper mine and with dibenzodioxins downstream from a paper mill on the west coast of Vancouver Island are given.

2. Résumé

Une étude du régime des oiseaux de mer dans les colonies d'oiseaux nicheurs, les estuaires, les bras de mer et les bancs du large de la côte ouest de l'île de Vancouver révèle qu'on ne sait pas grand-chose du régime de la plupart des oiseaux de mer nicheurs sauf dans le cas des principales espèces, comme le Goéland à ailes grises *Larus glaucescens*, l'Alque de Cassin *Ptychoramphus aleuticus*, le Macareux rhinocéros *Cerorhinca monocerata* et le Macareux huppé *Fratercula cirrhata*. Le régime du Grand Bec-scie *Mergus merganser* dans les estuaires ainsi que celui de l'Alque marbrée *Brachyramphus marmoratus* et du Canard colvert *Anas platyrhynchos* dans les bras de mer sont connus dans une certaine mesure, mais il faut effectuer beaucoup plus de recherches dans le cas de toutes les autres espèces. L'analyse du régime d'un petit échantillon d'oiseaux pélagiques au-dessus des bancs du large a permis de constater qu'ils avaient absorbé les mêmes catégories principales de nourriture qui existent ailleurs dans le Pacifique Nord, mais que les espèces proies présentaient des différences géographiques. La rogue de hareng constitue une importante source de nourriture pour les oiseaux piscivores et non piscivores, et, en mars, elle attire des dizaines de milliers de canards plongeurs et de goélands dans les frayères de la côte ouest de l'île de Vancouver.

Il est nécessaire de surveiller les changements à long terme dans le régime des oiseaux de mer nicheurs de même que les changements dans leurs populations et le succès de leur reproduction; pour ce faire, le meilleur endroit semble être l'île Triangle, au large des côtes, où vit une communauté unique d'oiseaux de mer planctonivores et piscivores. La surveillance du régime de ces oiseaux constitue pour les biologistes un bon moyen de déterminer les effets de la variation physique annuelle des eaux de surface de même que ceux des principales conditions anormales, produites par exemple par El Niño et le réchauffement de la planète, sur les proies et les oiseaux de mer.

Il est également nécessaire de surveiller les polluants présents dans les tissus des oiseaux de mer et estuariens ainsi que dans leurs proies et qui proviennent des mines et des usines de pâtes et papiers. Ces oiseaux occupent les échelons les plus élevés du réseau trophique, et l'amplification des effets des produits chimiques toxiques par les organismes proies de ce réseau les rend vulnérables aux polluants du milieu. Des exemples d'oiseaux contaminés par l'arsenic et le cuivre dans un bras de mer en aval d'une mine de cuivre de même que par les dibenzodioxines en aval d'une usine de papiers sur la côte ouest de l'île de Vancouver sont présentés.

3. Introduction

Marine birds are defined here as birds that nest along the coast and obtain most of their food from marine waters on the west coast of Vancouver Island. The chief nesting species are the Fork-tailed Storm-Petrel *Oceanodroma furcata*, Leach's Storm-Petrel *O. leucorhoa*, Pelagic Cormorant *Phalacrocorax pelagicus*, Glaucous-winged Gull *Larus glaucescens*, Common Murre *Uria aalge*, Pigeon Guillemot *Cepphus columba*, Marbled Murrelet *Brachyramphus marmoratus*, Cassin's Auklet *Ptychoramphus aleuticus*, Rhinoceros Auklet *Cerorhinca monocerata*, and Tufted Puffin *Fratercula cirrhata*. A small number of Brandt's Cormorants *Phalacrocorax penicillatus*, Thick-billed Murres *Uria lomvia*, and perhaps also Horned Puffins *Fratercula corniculata* nest on the west coast.

The nesting season diets of Cassin's Auklet (Vermeer 1981a, 1984, 1985), Glaucous-winged Gull (Vermeer 1982a), Marbled Murrelet (Carter 1984), Rhinoceros Auklet, and Tufted Puffin (Vermeer 1979; Vermeer and Westrheim 1984) have been investigated in detail, but only anecdotal dietary information exists for Pelagic Cormorants, Common Murres, Pigeon Guillemots, and Fork-tailed and Leach's storm-petrels. The diet of the two storm-petrel species has been studied at Hippa Island on the west coast of the Queen Charlotte Islands (Vermeer and Devito 1988). Because storm-petrels forage far out at sea, the diet at Hippa Island probably does not differ much from that of storm-petrels nesting along Vancouver Island. For those reasons, the diet of the two species at Hippa Island is included in this review.

The diets of several marine bird species over offshore banks during the nonbreeding season and that of both marine and estuarine birds (grebes and ducks) in inlets on the west coast of Vancouver Island have been cursorily examined and are reported here. Where there are insufficient data on the birds' food habits on the west coast, I have briefly referred to studies on diet elsewhere from the northeastern coast of the Pacific Ocean. The diet of marine and estuarine birds in the Strait of Georgia, on the east coast of Vancouver Island, is better known than that on the west coast. Because birds feeding on the east and west coasts may use the same food categories, the reader is referred to a review on the subject by Vermeer and Ydenberg (1989).

4. Diet during the nesting season

4.1 Fork-tailed and Leach's storm-petrels

Leach's Storm-Petrels forage mainly over the open ocean and the shelf break, whereas Fork-tailed Storm-Petrels feed over the shelf break, the shelf, and also the open ocean (Vermeer and Rankin 1984; Vermeer, Morgan, and Smith, this volume). Both storm-petrels catch food near the water surface; at Hippa Island, they feed their nestlings fish, amphipods, copepods, isopods, shrimp, squid, and octopus (Vermeer and Devito 1988). The fish consist of myctophids, such as *Protomyctophum thompsoni*, *Tarletonbeania crenularis*, *Stenobrachius leucopsoris*, and *Symbolophorus californiense*; deep-water species, such as *Melamphaes lugubris* and *Bathylagus* spp.; and others occurring nearer to the surface, such as rockfish (*Sebastes* spp.), greenlings (*Hexagrammos* spp.), and sablefish (*Anoplopoma fimbria*). Many of those fish, which migrate to the water surface at night, have photophores and are luminescent, possibly making them visible to the birds. For these reasons as well as the timing of the storm-petrels' arrival at the colony throughout the night (Vermeer et al. 1988), it is likely that those fish are caught by the birds during and after dusk. The most important nonfish prey of Fork-tailed and Leach's storm-petrels is the bathypelagic amphipod, *Paracallisoma coecus*; it may migrate to the surface at night, where storm-petrels acquire it. Leach's Storm-Petrels also feed their young *Velella velella*, a jellyfish of the open ocean.

4.2 Glaucous-winged Gull

The Glaucous-winged Gull forages opportunistically, and its diet reflects prey abundance and accessibility. On the west coast of Vancouver Island, the gulls' diet consists of intertidal invertebrates, such as bivalves, gastropods, chitons, barnacles, crabs, and seastars, and fish, such as Pacific herring *Clupea harengus pallasi*, Pacific sandlance *Ammodytes hexapterus*, Pacific sauries *Cololabis saira*, and salmon (*Onchorhynchus* spp.) (Vermeer 1982a). Of the invertebrates, gooseneck barnacles *Pollicipes polymerus* and sea mussels *Mytilus californianus* are eaten chiefly by adult gulls before their eggs hatch. The chicks are mostly reared on herring, sandlance, and sauries.

4.3 Marbled Murrelet

The Marbled Murrelet forages near shore and dives for its food. The diet of nesting murrelets was studied by Carter (1984) in Barkley Sound on the west coast of Vancouver Island. He observed that adult murrelets carry chiefly Pacific sandlance and Pacific herring in their bills to their nestlings. Examination of the stomach contents of murrelets revealed that herring and sandlance were eaten by adult and juvenile Marbled Murrelets in Barkley Sound.

4.4 Cassin's Auklet

Cassin's Auklets dive for their food. During the nesting season, they apparently eat the same foods as their young (Vermeer et al. 1985). They carry zooplankton and fish in a throat pouch to their nestlings in the colony at night (Vermeer 1981a). Food samples collected from adults at Triangle Island over a five-year period showed that Cassin's Auklets fed their nestlings chiefly calanoid copepods and euphausiids (Table 1). The copepod *Neocalanus cristatus* was by far the most important item. *Neocalanus cristatus*, a high-energy food, is abundant in British Columbia waters, but not farther to the south, such as off California (Vermeer 1981a, 1984). Nestling Cassin's Auklets grow heavier in British Columbia than in California. The local abundance of *N. cristatus* may explain why northern Cassin's Auklets grow heavier and why they are the most numerous nesting marine birds in British Columbia (Vermeer et al. 1979a). Cassin's Auklets feed their nestlings three species of euphausiids: *Thysanoessa spinifera*, *T. longipes*, and *Euphausia pacifica*. Less important planktivorous foods are caridians, hyperiid amphipods, cephalopods, brachyurans, cirripeds, and medusae (Table 1). Fish retrieved from Cassin's Auklet throat pouches were often digested, but those that could be identified were Pacific sandlance, rockfish, and Irish lords (*Hemilepidotus* spp.).

4.5 Rhinoceros Auklet and Tufted Puffin

Rhinoceros Auklets and Tufted Puffins are closely related alcids that obtain their food by diving and carry fish and squid crosswise in their beaks to nestlings (Vermeer 1979). Rhinoceros Auklets carry food to their young during the night, whereas Tufted Puffins do so only during daylight. The diet of the nestlings of the two species was studied on Triangle Island: that of Rhinoceros Auklets from 1976 through 1979, and that of Tufted Puffins in 1977 and 1978 (Vermeer 1979; Vermeer and Westrheim 1984). The primary food of both species consists of Pacific sandlance and Pacific sauries. Bluethroat argentines *Nansenia candida* were important prey of Rhinoceros Auklets and Tufted Puffins in 1978. Other less important prey for both Rhinoceros Auklets and Tufted Puffins are sablefish and rockfish, whereas Pacific herring, sockeye salmon *Oncorhynchus nerka*, and kelp greenling *Hexagrammos decagrammus* are occasional foods of Rhinoceros Auklets. Both species of auklets feed on squid, including *Loligo opalescens*, *Gonatus anonychus*, and *Onychoteutis banksii*.

The diet of nestling Rhinoceros Auklets on Pine and Lucy islands, near the British Columbia mainland, showed

Table 1
Comparison of average percentage wet weight of food brought by Cassin's Auklets to their nestlings on Triangle Island during a five-year period (1978–82) (data from Vermeer 1985)

	% wet weight					
Major prey categories	1978	1979	1980	1981	1982	1978–82
Calanoid copepods (99% *Neocalanus cristatus*)	38.2	38.6	30.8	27.4	32.0	33.4
Euphausiids	24.8	15.0	25.3	39.6	58.4	32.6
Fish	3.1	17.2	4.3	30.6	7.3	12.5
Carideans	3.3	5.0	0.7	0.1	1.4	2.1
Hyperiid amphipods	4.9	0.5	0.7	0.8	0.1	1.4
Cephalopods	–	–	0.01	1.2	0.01	0.3
Brachyurans (larvae)	–	–	0.2	0.3	0.1	0.1
Cirripeds (*Polymerus pollicipes*)	–	0.4	0.01	–	0.01	0.02
Scyphozoa (medusae)	–	–	–	0.02	0.02	0.01
Digested matter	26.5	23.6	38.0	–	0.7	17.7
No. of meals collected	112	129	138	121	211	711
Total biomass of meals (g)	1975	2541	2605	2404	4466	13 931

sandlance and herring to be important foods, with sauries less important than on Triangle Island (Vermeer and Westrheim 1984).

4.6 Other species

There is little or no information on the diets of nesting Brandt's and Pelagic cormorants, Common and Thick-billed murres, and Pigeon Guillemots on the west coast of Vancouver Island, although the diets of Pigeon Guillemots and Pelagic Cormorants have been investigated on Mandarte Island in the Strait of Georgia. Drent (1965) observed that adult Pigeon Guillemots delivered 10 categories of fish to their chicks on Mandarte Island, of which benthic fish, such as blennies and sculpins, comprised at least 70%. Robertson (1974) reported that Pelagic Cormorants on Mandarte Island feed their chicks mainly crescent gunnel *Pholis laeta*, Pacific sandlance, Pacific staghorn sculpin *Leptocottus armatus*, and penpoint gunnel *Apodichthys flavidus*. Most of those fish are characteristic of the littoral benthic zone, where Pelagic Cormorants chiefly forage.

The feeding behaviour and food of Common and Thick-billed murres in the eastern North Pacific have been reviewed by Vermeer et al. (1987). During the breeding season, both species feed chiefly over the shelf, mostly in the vicinity of their colonies, but Thick-billed Murres often forage farther from land than Common Murres. The food of Common Murres consists mostly of fish, and that of Thick-billed Murres of fish and crustaceans. Swartz (1966) found that, in the Chukchi Sea in summer, both species ate chiefly arctic cod *Boreogadus saida*, whereas Thick-billed Murres ate more invertebrates, particularly polychaetes. Scott (1973) observed that the food of nesting Common Murres in Oregon varied over three summers. Fish dominated the murre diet in two summers, and euphausiids and mysids in one summer. Of the fish eaten, anchovies were an important food in three summers, and eulachons *Thaleichthys pacificus* and rockfish in one summer each.

5. Diet of birds outside the nesting season

5.1 Diet of species over offshore banks

Sixty-six birds were collected over La Pérouse and Swiftsure banks off southwestern Vancouver Island in September and October 1987 to determine prey species. Only 39 birds, comprising eight species, had identifiable food items in their esophagi and stomachs (Table 2).

Northern Fulmars *Fulmarus glacialis* fed chiefly on squid (Table 2), most of which occur along the shelf break and in waters beyond the shelf (Jefferts 1983; Kubodera and Jefferts 1984a, 1984b).

Sooty Shearwaters *Puffinus griseus* ate primarily Pacific herring, whereas euphausiids and fish were important to Short-tailed Shearwaters *P. tenuirostris* (Table 2). Sanger (1986) analyzed the food of 178 Sooty and 201 Short-tailed shearwaters from the Gulf of Alaska and also found that Sooty Shearwaters ate mostly fish, primarily capelin *Mallotus villosus*, and Short-tailed Shearwaters ate euphausiids. Chu (1984), who analyzed 173 Sooty Shearwaters collected from spring to autumn from deep and far offshore waters of the western subarctic North Pacific, found Pacific sauries to be the most important prey. Capelin is a species characteristic of more northern, colder waters, whereas the Pacific saury is a pelagic, warm-water fish (Harris and Hartt 1977; Vermeer and Westrheim 1984).

Vibilia propingua, an amphipod associated with salps, was the most frequent prey of Cassin's Auklets feeding over La Pérouse and Swiftsure banks in autumn, although it was unimportant as a summer food (Vermeer 1981a, 1984). *Neocalanus cristatus*, the most common food of nesting auklets, was not found in the diet of birds collected in autumn, when it becomes scarce in surface waters (Miller et al. 1984).

Pacific herring and sandlance occurred most frequently in the diet of Common Murres off southwest Vancouver Island in autumn. H.R. Carter and S.G. Sealy (pers. commun.) observed murres feeding mostly upon Pacific herring in neighbouring Barkley Sound during that season.

Little can be said here about the diet of the three gull species in this investigation, because of small sample sizes and the difficulty of identifying digested fishes (Table 2). Sabine's Gulls *Xema sabini* ate more marine invertebrates than California *Larus californicus* and Glaucous-winged gulls, both of which frequently feed on discarded fish offal near trawlers along the west coast of Vancouver Island (Vermeer et al. 1989).

5.2 Diet of birds in estuaries and inlets

Forty birds, representing nine species, were collected in the estuary and at the mouth of the Somass River in Alberni Inlet in April 1989. All 40 birds had identifiable food in their esophagi and stomachs (Table 3). Overall, salmon were the most important identified prey of mergansers and grebes in the Somass River estuary. Species identified from the esophagi and stomachs of Common Mergansers *Mergus merganser* were coho salmon (a total of 16 *Oncorhynchus kisutch* from five birds), chinook salmon (two *O. tshawytscha* in two birds), rainbow trout (one *Salmo gairdneri* in one bird), unidentified salmon (six salmon in two birds), threespine sticklebacks (four *Gasterosteus aculeatus* in two birds), and one prickly sculpin (one *Cottus asper* in one bird). The average fork tail length of

Table 2
Frequency of occurrence of prey organisms observed in 39 esophagi and stomachs of pelagic birds collected over La Pérouse and Swiftsure banks off southwest Vancouver Island, September and October 1987

Bird species	No. of birds with food	Prey organisms: Species	% occurrence
Northern Fulmar	7	*Gonatus pyros*	71
		Gonatus sp.	43
		Ghiroteuthis calyx	43
		Toanius pavo	30
		Loligo opalescens	14
		Digested fish	14
		Vibilia propingua	14
		Gammarid amphipod	14
Sooty Shearwater	6	Pacific herring	83
		Thysanoessa spinifera	33
Short-tailed Shearwater	4	Digested fish	100
		Gonatus sp.	25
		Euphausiids	50
		Calanus pacificus	25
		Hyperiid amphipods	25
Glaucous-winged Gull	3	Digested fish	100
Sabine's Gull	3	Digested fish	66
		Euphausiids	66
		Hyperiid amphipods	33
California Gull	2	Digested fish	100
Cassin's Auklet	9	Digested fish	11
		Thysanoessa spinifera	11
		Vibilia propingua	56
		Digested crustaceans	44
Common Murre	5	Pacific sandlance	40
		Pacific herring	40
		Digested squid	20

Table 3
Percentage wet weight of food and other items observed in esophagi and stomachs of 40 water birds collected in the Somass River estuary in April 1989

			% wet weight						
Bird species	No. of birds with food	Total wet weight (g)	Fish	Invertebrates	Plants	Unidentified digested food	Feathers	Gravel and sand	Human-made objects
Western Grebe	5	160.9	23.7	0.2	0.2	10.6	64.4	0.9	<0.1
Red-necked Grebe	2	20.6	13.2	0.7	0.2	21.2	63.7	0	0
Horned Grebe	2	22.2	4.6	22.0	<0.1	18.4	55.0	0	0
Common Merganser	14	480.0	86.4	0.8	0.2	8.9	0	3.6	0.1
Surf Scoter	8	14.0	0	16.3	16.2	15.4	0	46.6	5.5
Barrow's Goldeneye	2	10.3	0	24.3	32.9	6.8	0	36.0	0
Bufflehead	3	7.1	0	43.3	27.4	2.5	0	26.8	0
Greater Scaup	3	39.3	0	5.0	58.7	0	0	36.3	0
Mallard	1	18.2	0	51.0	12.3	15.0	0	21.7	0

12 whole fishes recovered from merganser esophagi was 8.3 ± 5.3 cm (standard deviation) (range 3.4–20.0 cm), and the average wet weight of those fishes was 14.3 ± 23.8 g (range 0.5–85.4 g). The rainbow trout was the largest fish (20 cm long), weighing 85.4 g. Three nosebar tags of unidentified salmon, raised in a fish hatchery upstream of the Somass River estuary, were recovered from two merganser stomachs. Unidentified salmon species were found in both Horned *Podiceps auritus* and Western *Aechmophorus occidentalis* grebes.

Gammarid amphipods, particularly the tube-dwelling *Corophium* species, were eaten by all collected bird species (Table 4). Blue mussels *Mytilus edulis* appeared to be an important food of Surf Scoters *Melanitta perspicillata* and Barrow's Goldeneyes *Bucephala islandica*. Insects were eaten by Red-necked Grebes *Podiceps grisegena* and Common Mergansers. Plants were not identified to species, but it was noted that those eaten by Greater Scaup *Aythya marila* were chiefly algae. Snails, commonly eaten by diving ducks elsewhere in British Columbia (Vermeer and Levings 1977; Vermeer 1981b, 1982b; Vermeer and Bourne 1984; see also Table 6), were not found in any of the collected birds. Birtwell et al. (1984), who investigated the distribution of benthic invertebrates in the Somass River estuary, found that snails were scarce, which may explain their absence from the duck diet. Gammarid amphipods, on the other hand, were abundant, so it is not surprising that amphipods were present in the diet of all birds.

Ninety birds were collected from different habitats (rocky shores, estuaries, tidal rapids) in Quatsino Sound from October 1981 through March 1982 (Table 5). All birds contained food in their esophagi and/or stomachs. Western Grebes, Glaucous-winged Gulls, and Marbled Murrelets ate mostly fish. Most fish were digested, but Pacific herring were identified in 15 of 25 Marbled Murrelets and in two of six Glaucous-winged Gulls. Pacific herring constituted 74% of the fish food of murrelets. Invertebrates were important in the diet of Marbled Murrelets, Mallards *Anas platyrhynchos*, and Bufflehead *Bucephala albeola*. All invertebrates eaten by Marbled Murrelets consisted of euphausiids, of which *Thysanoessa spinifera* and *Euphausia pacifica* were the main species. Invertebrates eaten by both Mallards and Bufflehead consisted of bivalves, snails, crabs, amphipods, and isopods

Table 4
Number of water birds containing invertebrates in esophagi and stomachs collected in the Somass River estuary, April 1989[a]

Invertebrate prey	Western Grebe	Red-necked Grebe	Horned Grebe	Common Merganser	Surf Scoter	Barrow's Goldeneye	Bufflehead	Greater Scaup	Mallard
No. of birds examined	3	2	2	8	2	2	2	3	1
Bivalves									
Mytilus edulis					2	2		1	
Unidentified bivalve shells				1	1				
Gammarid amphipods									
Corophium spinicorne	2 (2)		1 (1)	6 (29)	1 (1)	1 (3)	2 (3)	3 (104)	1 (1)
Corophium salmonis	2 (4)			1 (4)			1 (16)	1 (1)	1 (2)
Corophium brevis				1 (2)					
Corophium spp.	1 (1)			1 (14)					1 (1)
Eogammarus confervicolus	2 (250)		1 (4)					2 (84)	1 (256)
Paramoera spp.				1 (3)					
Unidentified gammarids	1 (10)	1 (5)	1 (1)	4 (35)	1 (1)		1 (22)		
Mysids									
Neomysis mercedis			1 (3)						
Isopods									
Gnorimosphaeroma insulare	1 (73)							1 (1)	
Gnorimosphaeroma oregonense						1 (10)		2 (17)	
Sphaeromatidae	1 (2)								
Caridians									
Crangon franciscorum			1 (7)						
Unidentified caridians				1 (1)					
Insects									
Diptera larvae		1 (1)							
Ephemeroptera				4 (5)					
Homoptera				4 (10)					
Trichoptera (Hydropsychidae)	1 (3)			1 (1)					
Coleoptera	1 (2)			2 (5)					
Spiders									
Araneidae				1 (1)					

[a] Numbers of individual invertebrates (except bivalve shell pieces) that were identified are indicated in parentheses.

Table 5
Percentage wet weight of food and other items observed in esophagi and stomachs of water birds collected in Quatsino Sound, October 1981 – March 1982

Bird species	No. of birds with food	Total wet weight (g)	% wet weight: Fish	Inverte-brates	Plants	Unidentified digested food	Feathers	Gravel and sand
Western Grebe	6	165.4	22.0	0	0	9.0	69.0	0
Glaucous-winged Gull	6	109.7	88.2	10.3	0	0	0	1.5
Marbled Murrelet	25	197.8	71.2	28.7	0	0	0	0
Mallard	17	138.2	0	50.8	8.5	0	0	40.7
American Wigeon	13	121.5	0	0	45.6	0	0	54.4
Bufflehead	23	116.5	0.4	55.3	0.1	0	0	44.2

(Table 6). Barnacles were eaten by Mallards, and shrimp and polychaetes by Bufflehead. American Wigeon *Anas americana* ate mostly plants, *Navicula* and *Enteromorpha* being the most common.

5.3 The importance of herring spawn

Herring spawn constitutes a major food for piscivorous as well as nonpiscivorous birds, such as diving ducks, along the coast of Vancouver Island during March. Tens of thousands of Surf Scoters, whose staple food normally consists of blue mussels and other bivalves, feed extensively on herring spawn along the west coast of Vancouver Island for about two weeks in March. Surf Scoters migrate northward along the British Columbia coast with the progress of the spawning herring. Other diving duck species, such as Greater Scaup, White-winged Scoters *Melanitta fusca*, Oldsquaws *Clangula hyemalis*, Common *Bucephala clangula* and Barrow's goldeneyes, as well as Glaucous-winged, Mew *Larus canus*, and Thayer's *L. thayeri* gulls, feed extensively upon spawn, whereas Brandt's Cormorants and Western Grebes feed mostly upon juvenile and adult herring (Vermeer 1981b). After feeding upon herring and their eggs, most birds depart from coastal feeding areas for nesting grounds in the Arctic and Canadian interior.

One of the largest herring spawn areas along the west coast of Vancouver Island is found along the north shore of Barkley Sound and ranges from Toquart River in the east to the Food Islets in the west, as well as along insular shores in adjacent waters (Fig. 1). Pacific herring have spawned in that region for at least the last 50 years (Hay et al. 1989). It was estimated that there were 23 000 Surf Scoters in the area on 22 March 1978 (Vermeer 1981b) and about 20 000 Surf Scoters and 25 000 gulls on 21 March 1979 (unpubl. data). Haegele and Schweigert (1989) conducted a survey of birds feeding upon herring spawn in Barkley Sound in 1988. Peak spawning was observed during 21–23 March, but many water birds were seen in the spawning region before and after that period. Of the birds feeding upon spawn, Glaucous-winged, Thayer's, and Mew gulls and Surf Scoters were most numerous. In addition to water

Table 6
Marine invertebrates identified in the diet of 17 Mallards and 23 Bufflehead collected in Quatsino Sound, October 1981 – March 1982

Invertebrate species	Mallard		Bufflehead	
	% occurrence	Wet weight (g)	% occurrence	Wet weight (g)
Bivalves				
Mytilus edulis	41.2	8.1	–	–
Protothaca staminea	5.9	3.4	–	–
Clinocardium nuttallii	–	–	17.4	1.6
Unidentified bivalve fragments	17.6	3.2	17.4	4.5
Snails				
Littorina sitkana	17.6	2.2	21.7	5.8
Littorina scutulata	17.6	1.9	13.0	2.9
Littorina spp.	29.4	4.9	–	–
Lammaria spp.	5.9	1.1	–	–
Margarites spp.	–	–	17.4	1.1
Nassarius spp.	–	–	4.3	0.1
Turbiniella spp.	–	–	4.3	1.5
Barnacles				
Balanus glandula	29.4	27.7	–	–
Shrimp				
Crangon spp.	–	–	4.3	0.5
Unidentified shrimp fragments	–	–	4.3	0.5
Gammarid amphipods				
Gnorimosphaeroma spp.	11.8	0.3	4.3	0.5
Isopods				
Idotea spp.	–	–	13.0	4.0
Unidentified isopod fragments	11.8	0.9	–	–
Polychaetes	–	–	21.7	14.6
Insects	17.6	0.6	–	–

birds, Bald Eagles *Haliaeetus leucocephalus* and Northwestern Crows *Corvus caurinus* were also observed feeding upon spawn.

Haegele and Schweigert (1989) collected one California, eight Glaucous-winged, four Herring *Larus argentatus*, one Mew, and three Thayer's gulls, as well as one Pelagic and five Brandt's cormorants, eight Surf Scoters, four Barrow's Goldeneyes, one Bufflehead, and three Harlequin Ducks *Histrionicus histrionicus* from the spawning area. All birds contained either adult herring or their eggs, cormorants had eaten fish, and all ducks had fed upon spawn. Only three of the collected gulls contained fish, and the remainder had eaten spawn. Haegele and Schweigert (1989) calculated that birds ate 64 000 kg of spawn, representing 271 t of Pacific herring in Barkley Sound in 1988. Birds, however, were not the only predators eating spawn. These authors calculated that 16.4 million turban snails *Astrea gibberosa* and 9.4 million leather stars *Dermasterias imbricata* consumed 1021 t, and eight gray whales *Eschrichtus robustus* consumed 235 t of herring eggs. They estimated the total herring egg loss from predation by birds, whales, turban snails, and leather stars in Barkley Sound at 1527 t, or 19.5% of the spawn in 1988.

6. Changes in prey and their effect on seabird reproduction

6.1 Seasonal changes in prey

Prey composition in the diet of marine birds changes seasonally and may affect their reproductive success. For example, the diet of nestling Rhinoceros Auklets on Triangle Island was observed to change from Pacific sandlance in July to Pacific saury in August during a five-year study (Vermeer and Westrheim 1984). In one year, however, Pacific sauries were observed to predominate in the diet of nestling Rhinoceros Auklets in both July and August, perhaps because of a scarcity of Pacific sandlance in surface waters and/or because of a rise in sea surface temperature (Vermeer et al. 1979b). In the year that sauries predominated in the auklet diet in July, many young chicks suffocated while attempting to swallow these large fishes (Vermeer 1980).

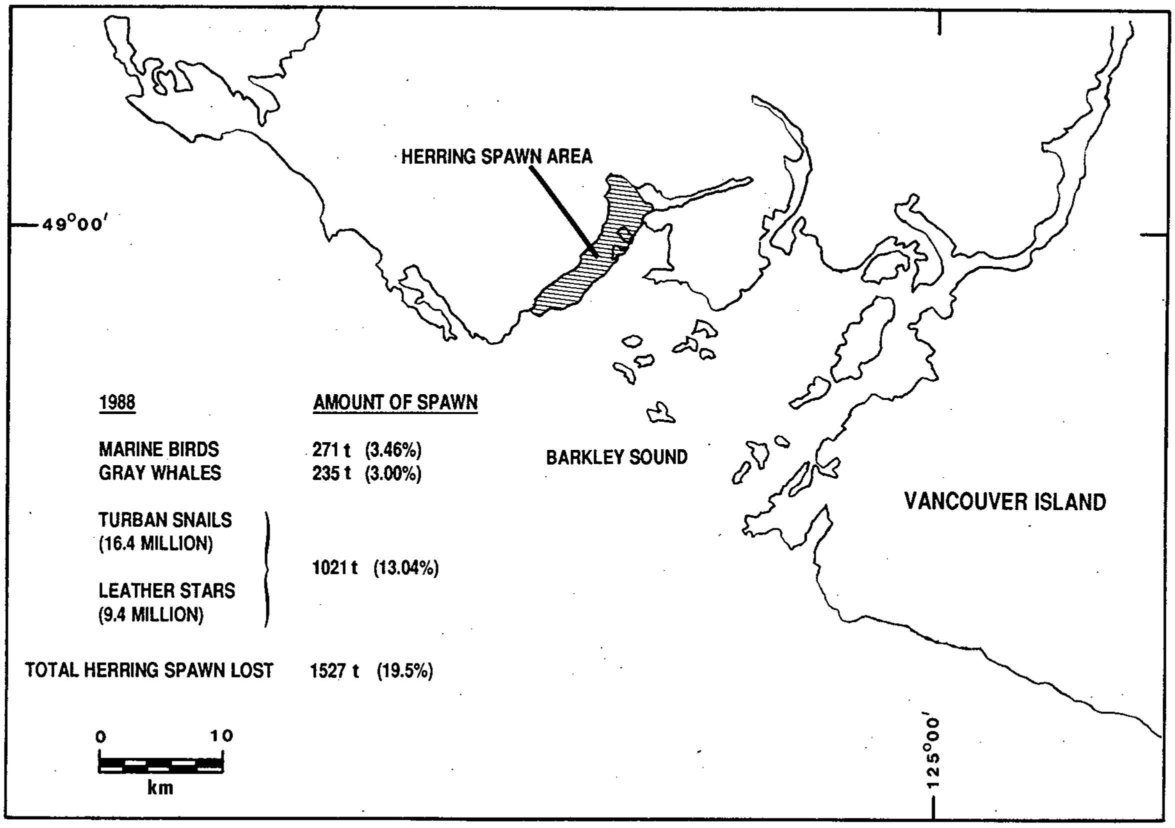
6.2 Annual changes in prey

Annual changes in the availability of prey can also affect the reproductive success of seabirds. For example, in five years of study (1975–79) on the reproductive success of Tufted Puffins on Triangle Island, the birds were observed to fail in two years, reproduce marginally in two other years, and do well in one year (Vermeer and Cullen 1979; unpubl. data). In the years of reproductive failure, puffins abandoned their nest burrows during incubation in one year and their nestlings in another year, resulting in the death of many chicks (Vermeer et al. 1979b). In the year of successful reproduction, puffins fed chiefly upon bluethroat argentines, a bathypelagic species, which became available to the birds in areas of upwelling along the west coast of Vancouver Island (Vermeer 1979). Bluethroat argentines were encountered in the diet of Tufted Puffins, as well as in that of Rhinoceros Auklets on Triangle Island, in only one of the five years of study.

Another example of how the composition of prey species in the diet of marine birds changes drastically from one year to the next is given by Vermeer and Westrheim (1984). They reported that yellowtail rockfish *Sebastes flavidus* predominated in the diet of Rhinoceros Auklets and Tufted Puffins on Triangle Island in 1977, widow rockfish *S. entomelas* in 1978, and Pacific ocean perch *S. alutus* in 1979.

Besides annual variations in prey species, year classes of fish often change from one year to the next. For example, first-year Pacific sandlance or Pacific herring appeared in the diet of Rhinoceros Auklet and Tufted Puffins in one year, but those same birds brought chiefly second-year fish to their nestlings in

Figure 1
Location of herring spawn area on the north shore of Barkley Sound and the amount of spawn estimated eaten by marine birds, gray whales, turban snails, and leather stars in 1988 (from Haegele and Schweigert 1989)



the next year (Vermeer and Westrheim 1984). In the year when adult puffins abandoned their chicks on Triangle Island, first-year sandlance predominated in the nestling diet. The combination of first-year sandlance and a seasonal decrease in the number of those fish in food loads of puffins apparently led to the starvation of puffin chicks (Vermeer et al. 1979b).

6.3 Changes during El Niños and global warming

Changes in zooplankton and fish prey reflect changes in sea surface conditions. There are generally minor fluctuations in surface salinity and surface temperature from year to year, except during El Niños. Thomson et al. (1984) observed that the surface temperature was 3°C above normal along the west coast of Vancouver Island during the 1983 El Niño.

El Niños have been linked to poor reproductive success in seabirds. For example, during the 1983 El Niño, sea surface temperatures became highly elevated off Oregon, negatively affecting the distribution and recruitment of prey fish (Bailey and Incze 1985; Pearcy et al. 1985). The altered distribution and recruitment of prey fish caused widespread nest abandonment and reproductive failure of Brandt's and Pelagic cormorants (Graybill and Hodder 1985).

Elevated sea surface temperatures during El Niños provide an indication of what sea surface temperatures may be like during future global warming trends. Relying on measurements of sea surface temperature in 18 sampling stations around the British Columbia coast over more than 50 years, Freeland (1990) concluded that these time series were sufficient in length to give clear evidence of large-scale warming. Like El Niños, global warming could affect the reproduction of seabirds by altering the availability of their prey in the future.

7. Marine birds as sampling devices and monitors

7.1 Sampling marine birds for changes in prey populations

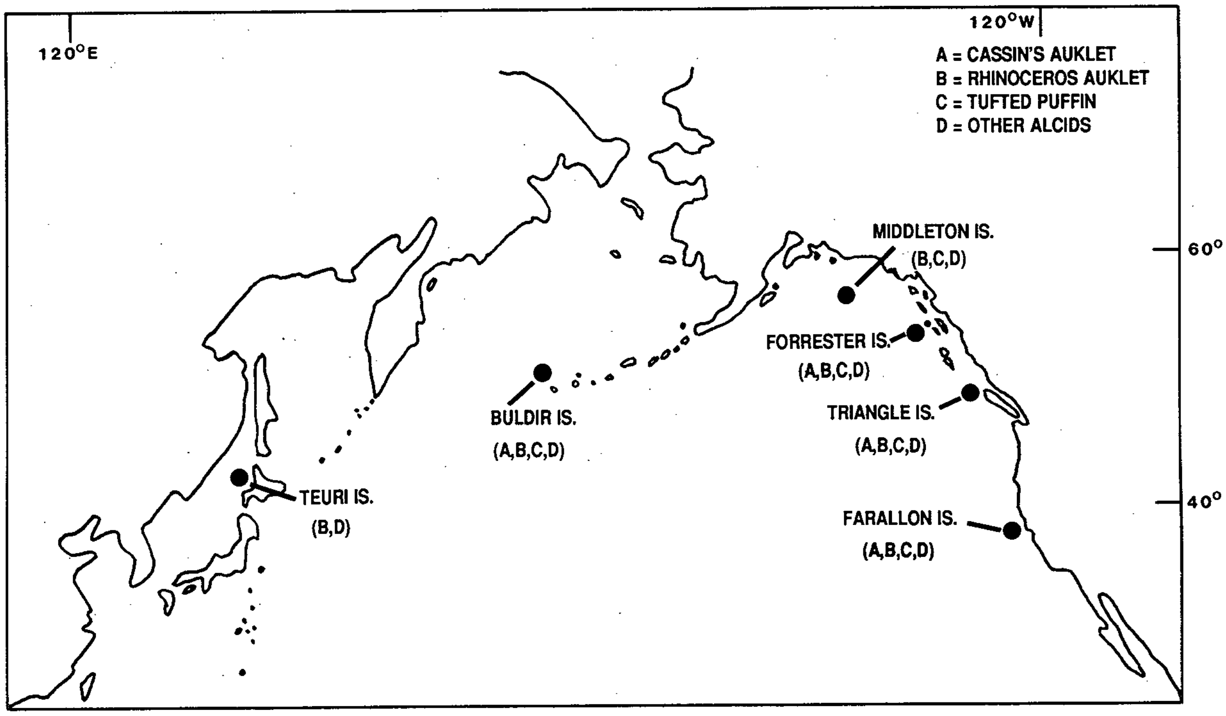
The observed changes in the diets of Rhinoceros Auklets and Tufted Puffins suggest that these species may be used as sampling devices to understand the distribution and structure of juvenile fish populations and their availability to birds. Of course, one must also conduct complementary prey sampling to establish the relationships between juvenile fish in marine surface waters and those observed in the diets of nesting seabirds. Of the two species, the Rhinoceros Auklet and the Tufted Puffin, the former can be more easily sampled by shining a flashlight at the adults when they land with fish in their bills in their colonies at night (Vermeer and Devito 1986).

Planktivorous birds could also be used as sampling devices to understand the availability and distribution of zooplankton prey in surface waters. Of the planktivorous species, the diet of the widespread Cassin's Auklet could be easily monitored at their nesting colonies at night, with little harm to the birds (Vermeer 1981a).

7.2 Monitoring marine birds for changes in oceanic conditions

Triangle Island (50°52′N, 129°05′W), on the extreme northwestern tip of Vancouver Island, has the largest breeding concentration of marine birds along the British Columbia coast. The largest nesting population of Cassin's Auklets in the world is found there, and Rhinoceros Auklets and Tufted Puffins are also numerous (Vermeer 1979; Vermeer et al. 1979a). Triangle Island is the farthest offshore island (46 km) off the west coast of Vancouver Island. The offshore location and the presence of

Figure 2
Proposed seabird monitoring stations in the North Pacific



many planktivorous and piscivorous seabirds make Triangle Island ideal for monitoring pelagic bird populations and changes in their prey.

Changes in the nesting populations, diets, and reproductive success of seabirds have been monitored on South Farallon Island off California by Ainley and Boekelheide (1990). A coordinated and integrated international program, including a number of strategically located seabird colony monitoring stations, should be established, including the Farallon Islands off California, Triangle Island off British Columbia, Forrester Island off southeastern Alaska, Middleton Island in the Gulf of Alaska, Buldir Island in the Aleutians, Teuri Island off Japan, and an as yet to be designated island off Pacific Russia (Fig. 2). This would provide marine bird biologists with a major tool to measure, as well as an early-warning system to determine, the effects of annual physical changes, El Niños, and global warming in the oceanic environment on seabird populations and their prey over a vast region of the North Pacific. The initiation and maintenance of such a monitoring program would need the full cooperation of the governments of North Pacific rim countries, such as Canada, Japan, the United States, and Russia.

7.3 Marine and estuarine birds as monitors of industrial pollution

In the marine and estuarine environment, birds occupy the highest levels of the food web, and the magnification of toxic chemical concentrations in that web makes birds vulnerable to the effects of those chemicals (Vermeer and Peakall 1977). Birds feeding on organisms in different intertidal areas show different degrees of accumulation of toxic chemical residues and constitute valuable indicators of pathways of those compounds in specific estuarine regions (Vermeer and Peakall 1979). Certain estuarine birds, such as ducks, may also acquire pollutants by ingesting nonfood items such as silt, and grebes could possibly become contaminated by ingesting feathers (Vermeer and Thompson 1992; K. Vermeer, W.J. Cretney, J.E. Elliott, R.J. Norstrom, and P.E. Whitehead, unpubl. data). Examples are given here of diet studies in Quatsino Sound and in the Somass River estuary, which were conducted in conjunction with the determination of the acquisition of contaminants by birds from mine tailings and paper mill effluents.

The Island Copper Mine discharges mine tailings into Quatsino Sound, which contain on average about 700 mg copper/kg and 5 mg arsenic/kg (Thompson and Paton 1975). Livers of American Wigeon and Mallards collected down-inlet of the mine contained 31.5 and 22.6 mg copper/kg, respectively (Vermeer and Thompson 1992). Algae, marine invertebrates, and silt ingested by those ducks showed residue levels of 0.13, 0.15, and 16 mg copper/kg, respectively, which suggests that the ducks may have obtained that metal chiefly from ingested, copper-contaminated silt. The highest arsenic residue levels (average 0.78 mg/kg) were observed in livers of Marbled Murrelets, whose diet consisted chiefly of euphausiids and herring. Arsenic residues in those organisms (retrieved from murrelet stomachs) averaged 0.10 and 0.06 mg/kg, respectively. Murrelets may have derived arsenic from those two food sources.

The Port Alberni Paper Mill at the mouth of the Somass River contaminates the nearby estuary with effluents (Waldichuk 1956; Parker and Siebert 1972). Because chlorophenol treatment of wood chips and bleached pulp mill effluent are sources of dioxins, which are highly toxic to birds (Bellward et al. 1989), the presence of dibenzodioxins in tissues of estuarine birds in the Somass River estuary was examined (K. Vermeer, W.J. Cretney, J.E. Elliott, R.J. Norstrom, and P.E. Whitehead, unpubl. data). Of nine bird species examined, Red-necked (hexachlorodibenzodioxin: 910 ng/kg H6CDD) and Western (pentachlorodibenzodioxin: 380 ng/kg P5CDD) grebe livers had the highest dioxin residues, which were also the highest for any estuarine bird examined for dioxin in British Columbia. High dioxin concentrations observed in those grebes as well as in other estuarine birds closely followed concentrations observed in beach deposits from the same area. Also, an increasing gradient of higher dioxins observed in surficial sediments in sampling stations closer to the mill suggested the latter as a dioxin source. All nine species of birds had fed upon tube-dwelling *Corophium*, which contained high dioxin levels. The grebes may have acquired the dioxins from eating contaminated *Corophium* and from the preening and ingestion of contamin-ated breast feathers. The grebes frequently swam through the effluent discharge, and their stomach contents were made up mostly of feathers (see Table 3).

8. Recommendations

This brief review shows that, except for the major nesting species, such as Glaucous-winged Gulls, Cassin's Auklets, Rhinoceros Auklets, Tufted Puffins, and perhaps Marbled Murrelets, there is little information on the feeding ecology of most marine and estuarine birds on the west coast of Vancouver Island. This information needs to be obtained before we can understand the overall interaction of seabirds and their prey. Information gaps could be addressed by the following investigations:

(1) The winter diets of all marine and estuarine bird species and the summer diets of nesting Pelagic Cormorants, Common Murres, and Pigeon Guillemots should be investigated.
(2) The type and size of prey occurring in the diet of birds should be correlated with the distribution and abundance of prey found in surface waters to determine prey availability and selection.
(3) The feeding ecology of whole marine and estuarine bird communities and their interactions in specific feeding habitats should be determined.
(4) A monitoring station should be established on Triangle Island at the northwestern tip of Vancouver Island to determine long-term changes in bird populations, their diets, and reproductive success.
(5) Birds and their prey should be monitored for pollutants derived from mines and pulp and paper mills.

9. Acknowledgements

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Part II

Population and breeding ecology of marine and shoreline birds

Seabird breeding populations in the Scott Islands on the west coast of Vancouver Island, 1982–89

Michael S. Rodway, Moira J.F. Lemon, and Ken R. Summers

1. Abstract

Seabird population studies were conducted on the Scott Islands between 1982 and 1989. Surveys conducted in 1989 to assess the impact of the *Nestucca* oil spill focused on Common Murres *Uria aalge* and Cassin's Auklets *Ptychoramphus aleuticus*. Results from 1989 were compared with those from previous years.

In 1989, all species except Common Murres were nesting in larger numbers than previously recorded. Occupancy rates of Cassin's Auklets, Rhinoceros Auklets *Cerorhinca monocerata*, and Tufted Puffins *Fratercula cirrhata* were higher and numbers of nests of Pelagic Cormorants *Phalacrocorax pelagicus* and Glaucous-winged Gulls *Larus glaucescens* were greater than those recorded on past surveys. The mortality of Cassin's Auklets during the oil spill had no detectable impact on breeding populations in the Scott Islands.

More Common Murres were counted in 1989 than in previous years, but increases were thought to be largely due to more complete coverage of colony areas. There was no apparent decline in numbers of murres as a result of the oil spill. Common Murres were not as successful as other species in 1989. Almost all sites on the east side of Triangle Island were abandoned.

In 1984, Pelagic Cormorants, Common Murres, Thick-billed Murres *Uria lomvia*, and Glaucous-winged Gulls suffered almost total reproductive failure, and breeding efforts of Tufted Puffins and growth rates of Rhinoceros Auklets were low. Increases in population estimates for Cassin's Auklets between 1977 and 1989 and for Tufted Puffins between 1982 and 1989 were largely due to higher burrow occupancy rates in 1989. Increases in population estimates for Rhinoceros Auklets between 1984 and 1989 appear to indicate actual population change, although they were partially due to more intensive survey methodology.

2. Résumé

Des études sur les populations d'oiseaux marins des îles Scott ont été réalisées entre 1982 et 1989. Les inventaires effectués en 1989 afin de déterminer l'impact du déversement d'hydrocarbures du *Nestucca* sur les populations d'oiseaux nicheurs furent centrés sur la Marmette de Troïl *Uria aalge* et l'Alque de Cassin *Ptychoramphus aleuticus*. Les résultats des inventaires de 1989 sont comparés à ceux des années précédentes.

En 1989, toutes les espèces, sauf les Marmettes de Troïl, nichaient en plus grand nombre qu'auparavant. Comparativement aux études antérieures, le taux d'occupation des terriers de l'Alque de Cassin, du Macareux rhinocéros *Cerorhinca monocerata* et du Macareux huppé *Fratercula cirrhata* fut plus élevé, et un plus grand nombre de nids de Cormorans pélagiques *Phalacrocorax pelagicus* et de Goélands à ailes grises *Larus glaucescens* ont été dénombrés. La mortalité des Alques de Cassin constatée à la suite du déversement d'hydrocarbures n'a manifestement pas eu d'effet sur les populations d'oiseaux nicheurs des îles Scott.

On a noté un plus grand nombre de Marmettes de Troïl en 1989 qu'au cours des années précédentes, mais cette croissance est probablement reliée pour une grande part à un examen plus complet des colonies. Il n'y a pas eu de baisse apparente du nombre de marmettes à la suite du déversement d'hydrocarbures. Les Marmettes de Troïl n'affichaient toutefois pas un taux de reproduction aussi élevé que celui des autres espèces en 1989. Presque tous les lieux de nidification de la côte est de l'île Triangle ont été abandonnés.

En 1984, le taux de reproduction des Cormorans pélagiques, des Marmettes de Troïl, des Marmettes de Brünnich *Uria lomvia* et des Goélands à ailes grises a été presque nul, et les tentatives de reproduction chez les Macareux huppés ainsi que les taux de croissance de Macareux rhinocéros ont été minimes. La hausse notée dans les estimations de population d'Alques de Cassin entre 1977 et 1989 et de Macareux huppés entre 1982 et 1989 était principalement due à des taux d'occupation de terriers plus élevés en 1989. Dans le cas des Macareux rhinocéros, la hausse notée dans les estimations de population entre 1984 et 1989 semble indiquer un changement réel de la situation démographique de la population, bien qu'elle puisse également être le résultat d'une méthode de dénombrement plus systématique.

3. Introduction

The Scott Islands (Fig. 1) support the densest concentration of breeding seabirds in the eastern North Pacific, south of Alaska, and are the most important breeding grounds for seabirds in British Columbia. The outer three islands in the group support more than 2 million breeding birds, 38% of the total seabird breeding population in the province (Table 1). The outer three Scott Islands are the most important breeding areas for Cassin's Auklets *Ptychoramphus aleuticus* in the world, supporting approximately 58% of the estimated world population of that species. Triangle Island supports the majority of Common Murres *Uria aalge* and Tufted Puffins *Fratercula cirrhata* breeding in British Columbia and is the only known breeding site for Thick-billed Murres *Uria lomvia* in the province (Rodway 1991).

Figure 1
Location of the Scott Islands

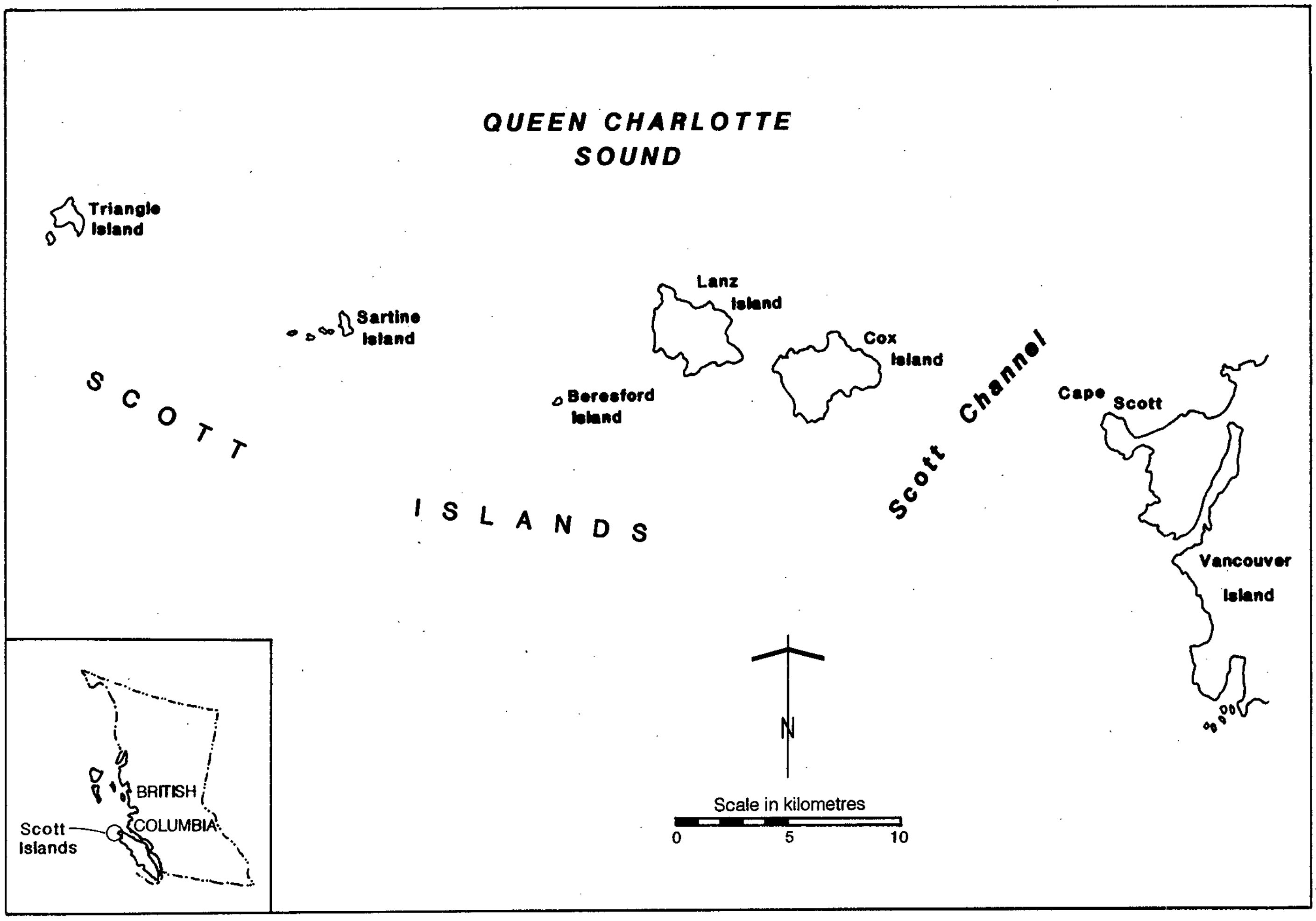


Table 1
Summary of most recent estimates of seabird breeding populations in the Scott Islands

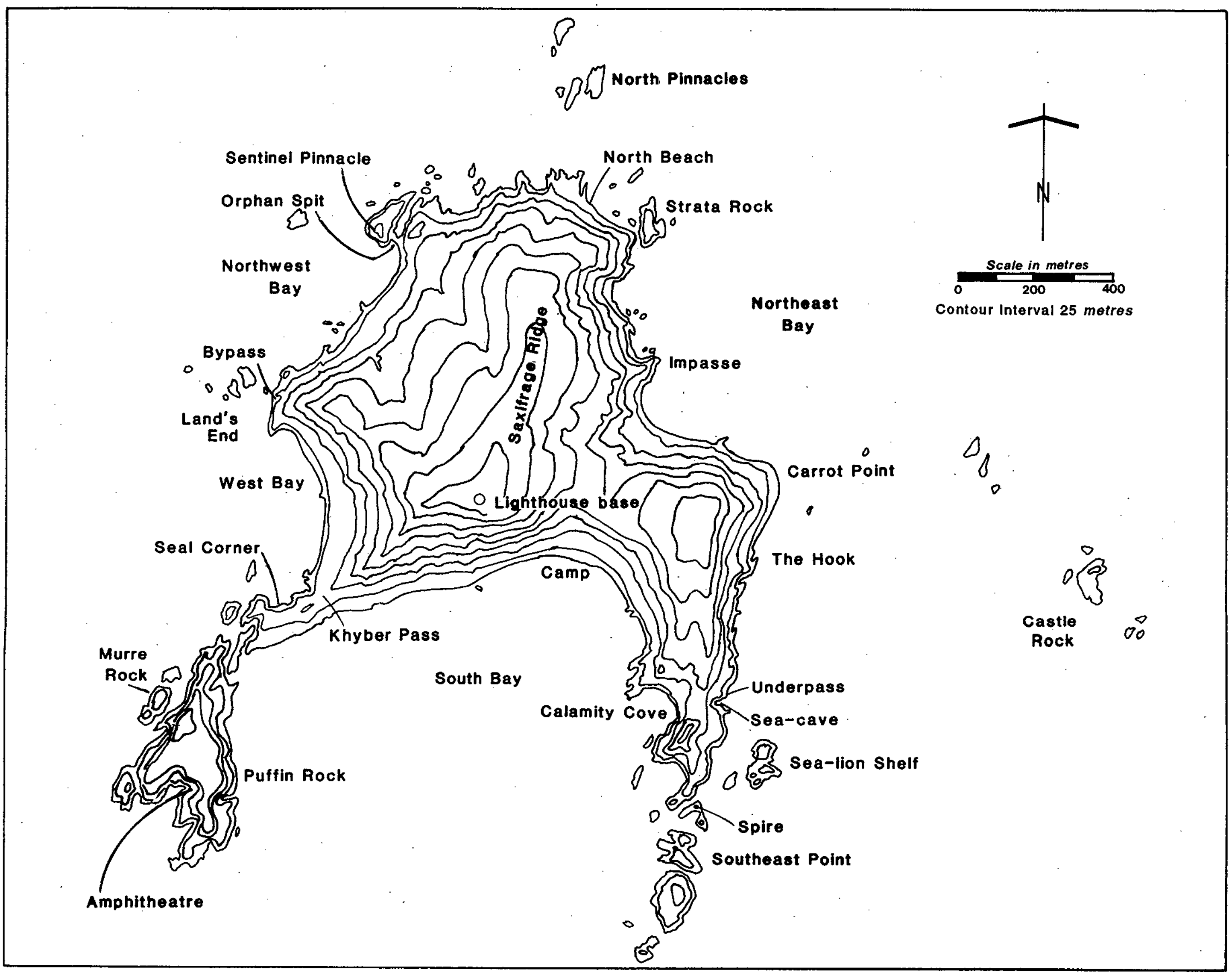
Site code	Site name	No. of nesting pairs[a,b]													Total
		FTSP	LSPE	BRCO	PECO	BLOY	GWGU	COMU	TBMU	PIGU	CAAU	RHAU	TUPU	HOPU	no. of birds
SC-010	Triangle Island	100e	200e		433	25	577e	4 100	7e(41)	x(331)	548 000t	41 700t	26 400t	S(4)	1 243 419
SC-020	Sartine Island			39	168	S(1)	390e	0(113)		x(116)	376 000t		6 400t	S(6)	766 118
SC-030	Beresford Island	2 900t	12 500t		6	S(3)	110e	0		x(146)	66 000t		2 100t	S(1)	167 385
SC-040	Lanz Island				56(0)					S(26)	0	0			138
SC-050	Cox Island				78(0)										156
Total no. of nesting pairs		3 000	12 700	39	741	29	1 077	4 100	7		990 000	41 700	34 900		
Total no. of breeding birds		6 000	25 400	78	1 482	58	2 154	8 200	14	619	1 980 000	83 400	69 800	11	2 177 216

[a] Numbers in parentheses refer to total number of birds in breeding plumage sighted around the colony.

[b] Acronyms for species names follow Campbell and Harcombe (1985):
FTSP = Fork-tailed Storm-Petrel
LSPE = Leach's Storm-Petrel
BRCO = Brandt's Cormorant
PECO = Pelagic Cormorant
BLOY = American Black Oystercatcher
GWGU = Glaucous-winged Gull
COMU = Common Murre
TBMU = Thick-billed Murre
PIGU = Pigeon Guillemot
CAAU = Cassin's Auklet
RHAU = Rhinoceros Auklet
TUPU = Tufted Puffin
HOPU = Horned Puffin

Abbreviations are as follows:
e = population estimated from numbers of breeding birds seen
x = breeding confirmed, but population not estimated
t = population estimate derived from systematic sampling along transects
S = suspected breeding

Figure 2
Triangle Island showing place names used in the text (given to island locations by the authors)



Observations on the status and distribution of seabirds on the Scott Islands made by Carl et al. (1951) are primarily anecdotal. Extensive studies on Triangle Island by K. Vermeer in the 1970s provided population estimates for most species. Surveys were conducted to determine the nesting populations of Tufted Puffins in 1975, Rhinoceros Auklets *Cerorhinca monocerata* in 1976, and Cassin's Auklets in 1977 on Triangle Island (Vermeer et al. 1979; Vermeer 1979). Common Murres were counted on Triangle and Sartine islands in 1975 (Vermeer et al. 1976a, 1976b). In 1975, the determination of the puffin population was not a main objective; consequently, only the population on Puffin Rock (Fig. 2) was determined from actual field measurements. Sampling of Rhinoceros and Cassin's auklet colony areas was more systematic, and results are more comparable with those obtained on subsequent surveys.

Oil from the barge *Nestucca*, which was damaged off the Washington coast in late December 1988, spread along the length of the west coast of Vancouver Island in January and February 1989. The condition of the Scott Islands was a major concern, and the islands were monitored for the presence of oil at that time. Small quantities of oil came ashore on Triangle, Lanz, and Cox islands, but cleanup was not required (Rodway et al. 1989). Approximately 13 000 seabirds, mostly Common Murres and Cassin's Auklets, in Washington and British Columbia were known to have died as a result of this spill (Rodway et al. 1989); Burger (this volume) estimated the total mortality to be 45 000 birds.

In order to assess the impact of such mortality on local breeding populations, we conducted studies on the Scott Islands during the summer of 1989. Results from 1989 studies were compared with those from studies conducted in 1982, 1984, 1985, and 1987 to determine whether breeding populations had declined following the *Nestucca* oil spill.

4. Study area and methods

4.1 Study area

The Scott Islands are a group of five islands extending in a line west from Cape Scott at the northwest tip of Vancouver Island (Fig. 1). The inner two islands, Cox and Lanz, are large forested islands, whereas the outer two, Triangle and Sartine, are completely treeless. Beresford, the smallest island, lies in the middle of the chain and exhibits transitional features. Detailed descriptions of these islands are in Carl et al. (1951) and Rodway et al. (1990).

4.2 Methods

Surveys of the breeding seabirds on the five islands in the Scott Islands group were carried out in different years from 1982 to 1989. On Triangle Island, an intensive survey of Tufted Puffins was conducted between 8 and 31 July 1982. Counts of murres (*U. aalge* and *U. lomvia*) and observations of other species were also made during that period. In 1984, we surveyed the part of the Rhinoceros Auklet colony on Triangle Island in the south bay and on the southeast ridge, but no other parts of the island. Burrow occupancy rates for Tufted Puffins and Rhinoceros Auklets were determined in 1984 and 1985. Observations on surface-nesting species were made during both years. A complete survey of all nesting species of seabirds on Triangle Island was carried out in 1989. Sartine, Beresford, Lanz, and Cox islands were explored and their breeding seabirds censused in 1987.

Census methods were selected according to the area, habitat, and species of birds nesting on an island (Nettleship 1976). All accessible areas on Triangle, Sartine, and Beresford islands were explored to determine distribution of nesting species. On Cox and Lanz islands, we explored within 50 m of shore, and occasionally up to 200 m from shore.

4.2.1 Total count

All nests of Brandt's Cormorants *Phalacrocorax penicillatus*, Pelagic Cormorants *P. pelagicus*, American Black Oystercatchers *Haematopus bachmani*, and Glaucous-winged Gulls *Larus glaucescens* were counted unless nests were inaccessible. Population estimates equal the number of nests counted. In inaccessible areas, numbers of gull nests were estimated to be half the number of adults present. Total numbers of Pigeon Guillemots *Cepphus columba* seen around colonies were counted, but no standardized observation techniques were employed (see Nettleship 1976), and no attempt was made to estimate actual nesting populations. A complete census of American Black Oystercatchers during their incubation period was conducted in 1989 on Triangle Island.

4.2.2 Strip transects

We used 3-m-wide strip transects to sample Tufted Puffin colony areas on Triangle Island in 1982. Transects were spaced 20–30 m apart on Puffin Rock and, where topography permitted, in other areas. All burrow entrances were counted along the transects. Mean burrow density was calculated using each strip transect as one sample. On the inaccessible parts of the east and north slopes of Triangle Island, burrowing areas were identified from observations of puffins sitting on or flying to or from the slopes.

4.2.3 Line transects with quadrats

Line transects with quadrats were used to estimate breeding populations of burrowing species on Triangle, Sartine, and Beresford islands. Quadrats were set at predetermined intervals along transect lines. Detailed descriptions of plot sizes and spacing are in Rodway et al. (1990). In general, the size was selected so that an average of at least one burrow occurred in each quadrat. The density of burrowing encountered in most areas was best sampled with smaller, more frequent plots (Savard and Smith 1985). Counts from all plots within colony areas were used to calculate means and standard errors of burrow densities.

4.2.4 Colony area

Distance, elevation, and slope measurements were used to draw colony areas on topographic maps or air photos. Normally, horizontal surface areas of the colonies were measured from these figures with a compensating polar planimeter. However, for Tufted Puffins on Puffin Rock, Triangle Island, we mapped and measured colony area in planar view based on extensive field measurements of nesting habitat.

4.2.5 Burrow occupancy

The percentage of burrows that contained nesting birds was determined by excavating a sample of burrows in selected plots. The recorded occupancy rates are means plus or minus one standard error.

4.2.6 Photographic counts

In 1989, murres on Triangle Island were censused using the method described by Birkhead and Nettleship (1980). In brief, this method involved counting birds in photographs taken from the water, adjusted by a ratio of direct telescope counts to counts from photographs determined at a study plot. Counts by telescope of areas not visible from the water were added to yield a total population estimate. An estimate of the breeding population was determined from the proportion (K) of breeding sites to total birds present on a study plot. A full description of these methods is in Rodway (1990).

5. Results

A total of 12 species of seabirds, as well as an additional suspected breeder (Horned Puffin *Fratercula corniculata*), nest in the Scott Islands. The total breeding population on the islands was estimated to be approximately 2.2 million birds (Table 1), with virtually all of the nesting occurring on Triangle, Sartine, and Beresford islands.

5.1 Storm-petrels

Although storm-petrels nested sparsely on Triangle Island, most of the population was found on Beresford Island (Tables 1 and 2). They nested in the centre of Beresford Island, primarily under the sparse forest. Burrows occurred in grass, in forbs, around tree roots and fallen logs, and under dense salmonberry *Rubus spectabilis*. They were also numerous in large, mossy logs, forming apartment-like complexes above the ground. Fork-tailed *Oceanodroma furcata* and Leach's *O. leucorhoa* storm-petrels nested in the same areas; Leach's Storm-Petrels outnumbered Fork-tailed Storm-Petrels four to one.

5.2 Brandt's Cormorant

The only observations of nesting Brandt's Cormorants were on Sartine Island in 1989, when 39 nests containing large young were found at two sites on 29 July.

5.3 Pelagic Cormorant

Pelagic Cormorants nested on all the Scott Islands (Table 1), but the number and location of nests varied between years and within single seasons. Fifteen nesting sites were used on Triangle Island between 1982 and 1989, but only some of them were used in any one season. Minimum numbers were recorded in 1984, when there were only 33 nests at three sites; maximum numbers occurred in 1989, with 433 occupied nests at 13 sites (Table 3). An additional 45 nests that were subsequently abandoned were found in 1989.

Table 2
Current estimates of breeding populations of storm-petrels in the Scott Islands[a]

Site code	Site name	Colony area (ha)	Density (burrows/ha ± SE)	No. of sample plots	Area sampled (%)	Burrow occupancy (% ± SE)	Sampling effort (%)	Total storm-petrels (pairs ± SE)	Fork-tailed Storm-Petrel (pairs ± SE)	Leach's Storm-Petrel (pairs ± SE)
SC-010	Triangle Island							300e	100e	200e
SC-030	Beresford Island	1.7	11 000 ± 1 857	50	0.3	81 ± 7	0.11	15 478 ± 2 950	2 941 ± 560	12 537 ± 2 390

[a] e = population estimated from numbers of breeding birds seen

Table 3
Number of pairs of nesting Pelagic Cormorants in the Scott Islands, 1982–89[a]

	No. of nesting pairs				
Location	1982	1984	1985	1987	1989
Triangle Island	69+	33	144	–	433
Sartine Island	–	–	–	137	168
Beresford Island	–	–	–	161	6
Lanz Island	–	–	–	56	–
Cox Island	–	–	–	78	–

[a] + = incomplete count
– = no survey conducted

Table 4
Calculation of Common Murre breeding population on Triangle Island in 1989

	Mean	SE	Minimum	Maximum
Total counts from photographs of murres at breeding sites around Triangle Island	5 839	87	3 335	6 144
Total counts adjusted by ratio of telescope to photograph counts on study plot	8 408	171	4 802	8 847
Total adjusted counts plus birds counted from land that were not visible from the water	9 943	202	5 679	10 462
Ratio of breeding sites to total birds counted on study sites (k)	0.41	–	0.53	0.39
1989 breeding population estimate (k x total birds at breeding sites) (in pairs)	4 077	83	3 010	4 080

On Sartine Island, there were 137 attended nests at the north end of the island in 1987; in 1989, there were 168 nests at the southwest corner of the island in June and 164 nests at four different sites in July. All nests were occupied in June 1989, but only 49 had attending adults in July 1989. Numbers on Beresford Island were highest in 1987, when 161 nests were counted at three sites. In 1989, there were only six occupied nests on Beresford Island, none at sites used in 1987 (Table 3).

Lanz and Cox islands were surveyed only in 1987. On Lanz Island, we found 56 abandoned nests on the south side of the island. All nests had been built that season; eggs or eggshells were visible in two nests, and one depredated egg was found on the adjacent point. On Cox Island, we found two sites with 78 nests and three attending adults (Table 3). However, these nests were abandoned by the third week in July.

5.4 American Black Oystercatcher

A perimeter survey of Triangle Island in 1989 revealed 24 oystercatcher nests, plus one additional territory. Nests were located along upper edges of beaches. Although no nests were found on the other Scott Islands, we suspected from their defensive behaviour that one pair nested on Sartine Island and three pairs on Beresford Island.

5.5 Glaucous-winged Gull

Nesting Glaucous-winged Gulls were present at the same locations on the outer three Scott Islands each year we visited the colonies. Complete censuses were made on Triangle Island in 1984 and 1989. Gulls experienced a major nesting failure in 1984: an estimated 337 pairs were present on territories, but few were attending nests. Of 81 nests inspected, only three contained eggs, and none had full clutches. Although we found many broken or depredated eggshells, we saw no young, hatched eggshells, trampled nests, or uneaten fish. In 1989, we estimated 577 pairs nesting on Triangle Island. Most nests contained eggs or chicks.

We estimated a nesting population of 240 pairs of Glaucous-winged Gulls on Sartine Island in 1987 and 390 pairs in 1989; estimates for Beresford Island are 145 pairs in 1987 and 110 pairs in 1989. Most recent counts from all islands gave a total estimate of about 1100 pairs nesting in the Scott Islands (Table 1).

5.6 Common Murre

Throughout our surveys of the Scott Islands, murres nested only on Triangle Island. A census of one portion of the colony revealed 3631 murres in 1982, 0 in 1984, 1680 in 1985, and 2779 in 1989 (Rodway 1990). In 1984, breeding failure was complete: broken or depredated eggshells were found on Puffin Rock, and, although an estimated total of 12 000 murres clustered in tight rafts on the water around nesting sites, no birds were observed incubating eggs.

We identified and photographed 37 sites frequented by murres on Triangle Island in 1989. The mean ratio of counts by telescope to counts from photographs made on the study plot was 1.44 (SE = 0.02; N = 33). We used that ratio, and counts from land of areas that could not be photographed, to compute a total population estimate of 9943 (SE = 202) birds and a breeding population of 4077 pairs (SE = 83) (Table 4). Because murres were unsuccessful at almost all sites on the east side of the island, we estimated that 3372 pairs (SE = 49) hatched young in 1989.

We counted no more than 440 murres in 1987 and 113 in 1989 around Sartine Island, where birds were not observed on or near the cliffs.

5.7 Thick-billed Murre

Thick-billed Murres were seen only on Triangle Island, where they nested alongside Common Murres. In 1982, we counted 70 Thick-billed Murres, some incubating eggs. In 1984, at least 50 Thick-billed Murres landed with Common Murres on the west side of Puffin Rock, but none nested. We counted 34 and 41 Thick-billed Murres in July 1985 and 1989, respectively. In 1989, only seven birds were sitting as if incubating; the rest were standing, and there was no sign of chicks.

5.8 Pigeon Guillemot

Pigeon Guillemots were present around the outer four of the five Scott Islands. Twenty-six birds probably nested at two sites on Lanz Island in 1987, but breeding was not confirmed.

Table 5
Current estimates of breeding populations of Cassin's Auklets, Rhinoceros Auklets, and Tufted Puffins in the Scott Islands

Site code	Site name	Colony area (ha)	Density (burrows/ha ± SE)	No. of sample plots	Area sampled (%)	Burrow occupancy (% ± SE)	Sampling effort (%)	Population estimate (pairs ± SE)	Survey year
Cassin's Auklets									
SC-010	Triangle Island								
	– Side slope and top ridges	65.3	10 518 ± 224	1 870	1.1				1989
	– Level interior	28.0	1 561 ± 198	248	0.4				1989
	– Total	93.3		2 118	0.9	75 ± 3	0.03	547 637 ± 25 748	1989
SC-020	Sartine Island	14.9	27 816 ± 1 503	174	0.1	91 ± 4	0.01	375 902 ± 26 597	1987
SC-030	Beresford Island	5.5	13 400 ± 1 616	100	0.2	90 ± 10	0.01	66 067 ± 10 697	1987
SC-040	Lanz Island							0	1987
Rhinoceros Auklets									
SC-010	Triangle Island	11.2	5 494 ± 245	379	1.4	68 ± 6	0.08	41 682 ± 4 216	1989
SC-040	Lanz Island							0	1987
Tufted Puffins									
SC-010	Triangle Island								
	– Puffin Rock	2.3	6 092 ± 551	34	10.3	84 ± 4	0.49	11 982 ± 1 217	1982, 1989
	– Main island	4.8	3 646 ± 446	12	2.9	82 ± 6	0.19	14 466 ± 2 056	1982, 1989
	– Total	7.1		46	5.3	84 ± 4	0.33	26 448 ± 2 389	1982, 1989
SC-020	Sartine Island	1.7	5 550 ± 1 230	27	0.2			6 359 ± 1 410	1987
SC-030	Beresford Island	0.2	13 750 ± 3 750	8	0.3			2 122 ± 579	1987

Maximum totals counted around the other islands where breeding was confirmed were: 331 at nine locations around Triangle Island in 1989; 176 around Sartine Island in 1987; and 267 around Beresford Island in 1987. The most recent counts around all islands totalled 619 birds (Table 1).

5.9 Cassin's Auklet

The breeding population of Cassin's Auklets in the Scott Islands was estimated at almost 1 million pairs (Tables 1 and 5). They nested on Triangle, Sartine, and Beresford islands, with some nesting attempts on the west tip of Lanz Island. Nesting occurred in almost all vegetated habitat on the outer three islands, including beneath the densest thickets of salmonberry, crabapple *Pyrus fusca*, and salal *Gaultheria shallon* on Triangle Island. The preferred habitat for burrows was in all open areas of herbaceous vegetation, except where Rhinoceros Auklets or Tufted Puffins predominated. On Triangle Island, burrow density was greatest under tufted hairgrass *Deschampsia caespitosa* in the west bay, under tall salmonberry on Puffin Rock, beneath saxifrage *Saxifraga ferruginea* and wood fern *Dryopteris austriaca* along the top ridge of the island, and in mixed tufted hairgrass, short salmonberry, and lady fern *Athyrium felix-femina* at Northwest Bay (Fig. 2). Low-density burrowing occurred under dense shrubbery across most interior slopes and under tall lady fern at Northeast Bay. On Sartine and Beresford islands, burrows were also abundant in most grassy areas. They were sparse in the middle of the southeast grassy slope, in some pockets of *Elymus*, and under dense salmonberry on Sartine Island and in high, dense salmonberry on Beresford Island.

Several Cassin's Auklets that had attempted to nest on the southwest point of Lanz Island had been killed by mink *Mustela vison*. There were large piles of mink scats, some of which were composed entirely of feathers, and numerous mink trails in the area.

5.10 Rhinoceros Auklet

Rhinoceros Auklets nested only on Triangle Island. In 1984, Rhinoceros Auklets nested on all slopes in the eastern half of South Bay but were absent from most dense salmonberry habitat on the west side of the bay. Burrows were densest on steep tufted hairgrass slopes and also beneath short salmonberry. Average burrow density in 1984 was 4477 ± 693 burrows/ha (N = 26) over 8.7 ha of colony. Burrow occupancy was 64.6 ± 2.9% (N = 14), and breeding population at South Bay was estimated at 25 125 ± 4045 pairs.

The Rhinoceros Auklet population is apparently expanding on Triangle Island. The colony area at South Bay in 1989 was 9.8 ha compared with 8.7 ha in 1984, extending farther up the ridge and farther above Calamity Cove and along the east side of the island than mapped in 1984. As in 1984, most burrows occurred in grass, but they were also found up to 50 m into tall, dense salmonberry habitat along steep, south slopes. Including a nesting area at Northeast Bay that we had not discovered on previous surveys, the breeding population in 1989 was estimated to be 41 700 ± 4200 pairs (Table 5).

5.11 Tufted Puffin

In total, 34 900 pairs of Tufted Puffins were estimated to have bred on Triangle, Sartine, and Beresford islands (Table 1). We detected no change in distribution of nesting puffins on Triangle Island between 1982 and 1989, and data from both years were used to map colony areas. Because the 1982 survey was concerned only with puffins, the sampling intensity was much higher than in 1989. Therefore, burrow density estimates in 1982 were considered more accurate than in 1989 and were used for calculations of breeding populations in both years (Table 5). Occupancy rates of Tufted Puffin burrows on Triangle Island differed in the four survey years from a low of 25% in 1984 to a high of 90% in 1985 on Puffin Rock (Rodway et al. 1990). In 1982, occupancy rates were 74.7 ± 5.5% (N = 9) on Puffin Rock and 61.3 ± 5.2% (N = 14) on the main island. In 1989, the burrow occupancy rates were similar— 84.3 ± 3.9% (N = 32) on Puffin Rock and 82.4 ± 6.0% (N = 22) on the main island. Only rates on the main island (Triangle Island) differed significantly between the two years (Puffin Rock: $z = 1.424$, $P = 0.078$; Triangle Island: $z = 2.657$, $P < 0.005$). Higher occupancy rates in 1989 accounted for the 24% increase in estimated population from 21 400 ± 2000 pairs in 1982 to 26 400 ± 2400 pairs in 1989.

The main colony areas on Triangle Island were in tufted hairgrass slopes on Puffin Rock and on the east side of the main island. Sporadic nesting also occurred over large portions of Triangle Island, including on steep rocky ribs high on inaccessible slopes, in tall salmonberry habitat, and across upper grassy slopes. On Sartine and Beresford islands, puffins were nesting in perimeter areas above cliffs or rock outcroppings in primarily tufted hairgrass habitat.

5.12 Horned Puffin

Small numbers of Horned Puffins (1–7 birds) were regularly seen and suspected of nesting around Triangle, Sartine, and Beresford islands. Birds sat outside crevices and flew to and from steep slopes in inaccessible areas, but breeding was not confirmed.

6. Discussion

6.1 Population trends

Numbers of nesting cormorants have fluctuated between years on the Scott Islands. Carl et al. (1951) estimated that more than 1200 pairs of Pelagic Cormorants nested on Triangle Island in 1949. In our study, Pelagic Cormorant numbers peaked in 1989, when 433 pairs nested on Triangle Island. Brandt's Cormorants nested on Sartine Island in 1975 (Vermeer et al. 1976a) and were observed there in 1989 but not 1987.

More Common Murres were counted in 1989 than in previous seasons, but increases were largely due to more complete coverage of colony areas. Comparable counts at specific nesting sites in 1982, 1985, and 1989 were highest in 1982 and lowest in 1985. In 1989, almost all birds on the east side of Triangle Island, representing about 15% of the total population, bred unsuccessfully, and the ratio of breeding birds to total birds present on the study site on Puffin Rock was lower than all other values reported in the literature (Rodway 1990). Lack of comparative data from previous seasons precluded evaluation of those events.

Thick-billed Murres were first documented nesting on Triangle Island in 1981 (Vallée and Cannings 1983), and small numbers have been present on subsequent visits.

The breeding population of Cassin's Auklets on Triangle Island in 1977 was estimated to be 359 000 pairs (Vermeer et al. 1979). The estimate for 1989 indicated an increase of 53% from the 1977 breeding population. We recalculated burrow density and occupancy from original data collected in 1976 and 1977 to allow statistical comparisons between years. Only data for the main side slopes that were sampled systematically in both years were used in density comparisons. Densities were similar, ranging from 0 to 4.72 in 1977 and from 0 to 5.25 in 1989, with means of 1.26 ± 0.10 ($N = 113$) and 1.36 ± 0.05 ($N = 587$) burrows/m^2, respectively (Kruskall-Wallis test: $P = 0.84$, $df = 1$).

Occupancy rates in 1977 ($62.0 \pm 1.7\%$) and 1989 ($75.0 \pm 3.1\%$) were significantly different (z test: $P << 0.001$). Differences in occupancy rates accounted for 21% of the increase in the population estimates. Estimates of colony area in the two years were similar (97.6 ha in 1977 and 93.3 ha in 1989) and did not contribute to the apparent increase. The remainder of the difference between the two estimates is attributable to the extrapolation of different density classes to various areas of the colony. More intensive sampling in 1989, especially across the top and on the north and east sides of the main island and across Puffin Rock, provided a finer resolution of colony boundaries and burrow densities. Unexplored areas assigned to lower density classes in 1977 were found to have higher densities when surveyed in 1989.

We also compared Cassin's Auklet burrow densities in the Rhinoceros Auklet colony at South Bay in 1984 and 1989. Mean densities there were 0.26 ± 0.05 burrows/m^2 ($N = 26$) in 1984 and 0.32 ± 0.02 burrows/m^2 ($N = 283$) in 1989. Differences were not significant (Kruskall-Wallis test: $P = 0.87$).

Rhinoceros Auklets appear to have expanded on Triangle Island in the last 40 years. They were not found nesting in 1949, although large numbers of birds in breeding plumage were observed at South Bay, and nesting was suspected in inaccessible areas (Carl et al. 1951). An extensive colony was present at South Bay in 1966 (Hancock 1970) and, from descriptions, was similar in extent to that reported in 1976 (Vermeer 1979). Vermeer (1979) estimated that 15 000 pairs of Rhinoceros Auklets nested on Triangle Island in 1976. Colony area was estimated to be 7.4 ha in 1976 (K. Vermeer and K.R. Summers, unpubl. data) and 8.7 ha in 1984. Although burrow density (average 4166 burrows/ha) in 1976 was similar to that determined in 1984, the occupancy rate of 43% in 1976 was considerably lower than the rates calculated in 1984 and 1989. Reproductive success was also low in 1976 (Vermeer 1978) and may have accounted for the low occupancy rate.

The 1989 population estimate exceeded that from 1984 by 16 600 pairs (66% of the 1984 estimate). Some of that increase may be due to more intensive exploration and survey methodology in 1989, but a portion may represent actual population change. The extent of Rhinoceros Auklet colony area at South Bay was greater by 1.1 ha (13%) in 1989 than that mapped from explorations in 1984. Changes at Northeast Bay are more difficult to interpret, but historical records suggest that the colony has probably expanded.

Rhinoceros Auklet occupancy rates were $64.6 \pm 2.9\%$ ($N = 14$) in 1984 and $68.0 \pm 6.2\%$ ($N = 15$) in 1989 and were not significantly different ($z = 0.497$; $P = 0.31$). Burrow density in 1989 in the area surveyed in 1984 was 6531 ± 330 burrows/ha ($N = 240$) and was not significantly different from that determined in 1984 (Kruskall-Wallis test: $P = 0.17$). Although not significantly different, higher burrow density and occupancy rate in 1989 accounted for 29% and 8%, respectively, of the 66% increase in population estimates from 1984. Added colony area at South and Northeast bays accounted for the remaining 29%.

Nesting populations of Tufted Puffins in 1975 were estimated to be 25 000 pairs (Vermeer 1979). Original survey data were not available for statistical comparison with 1982 or 1989 results, but colony area (2.6 ha) and average burrow density (6667 burrows/ha) on Puffin Rock, where plots were surveyed in 1975 (K. Vermeer, unpubl. data), were similar to those determined in 1982. Estimated colony area on the east side of the island in 1975 (0.9 ha) was less than that mapped in 1982 and 1989, but exploration of that area in 1975 was limited. The method used in 1975 to determine occupancy rate was considered unreliable at a later date (K. Vermeer, pers. commun.). Consequently, the high 1975 occupancy rate (95%), which resulted in a population level on Puffin Rock greater than that observed in 1982, makes comparisons with later surveys difficult.

Most of the changes in numbers of breeding birds between 1982 and 1989 appear to be seasonal fluctuations in response to environmental conditions. In 1984, surface-nesting species suffered almost total reproductive failure, and breeding efforts of Tufted Puffins and growth rates of Rhinoceros Auklets were low (Bertram and Kaiser 1988). Those failures were attributed to a week of severe storms at the end of June combined with a shortage of sandlance, the primary prey for fish-eating species (Rodway et al. 1990).

Breeding populations of burrow-nesting seabirds in the Scott Islands may have been larger in the past prior to the introduction of mink and raccoon *Procyon lotor* to Cox and Lanz islands in the 1930s. Carl et al. (1951) reported abandoned Cassin's Auklet burrows on all grassy headlands of Lanz Island in 1950, and we found small numbers of prospecting Cassin's Auklets killed by mink on the west end of that island in 1987.

6.2 Impact of the *Nestucca* oil spill on breeding populations in 1989

In 1989, all species except Common Murres were nesting in higher numbers than previously recorded. Occupancy rates of burrow-nesting species were higher and numbers of nests of surface-nesting species were greater than those recorded on past surveys. The reproductive success of Common Murres could not be evaluated owing to lack of baseline data. We found no live or dead birds that had been oiled, and the mortality of Common Murres and Cassin's Auklets during the oil spill had no detectable impact on breeding populations in the Scott Islands in 1989.

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Population trends of Pelagic Cormorants and Glaucous-winged Gulls nesting on the west coast of Vancouver Island

Kees Vermeer, Ken H. Morgan, and Peter J. Ewins

1. Abstract

In 1989, the numbers of nesting Pelagic Cormorants *Phalacrocorax pelagicus* and Glaucous-winged Gulls *Larus glaucescens* on the west coast of Vancouver Island were censused, and the reproductive success of 16 gull colonies was investigated. The numbers of Pelagic Cormorants had declined by 70% and that of Glaucous-winged Gulls by 13% since a census in 1974–75. Comparison with a partial census of these two species in 1988 showed that both populations on the northern section of the west coast declined between the summer of 1988 and that of 1989. The implications of these declines are discussed in relation to an oil spill from the barge *Nestucca* in December 1988 as well as to other factors that could have contributed to them.

The reproductive success of Glaucous-winged Gulls varied between nesting localities. The average fledging rate was higher in large colonies than in smaller ones.

2. Résumé

En 1989, les populations de Cormorans pélagiques *Phalacrocorax pelagicus* et de Goélands à ailes grises *Larus glaucescens* nicheurs de la côte ouest de l'île de Vancouver ont été dénombrées, et le succès de reproduction dans 16 colonies de goélands a fait l'objet d'investigations. Depuis le dénombrement effectué en 1974–1975, la population de Cormorans pélagiques a diminué de 70 %, et celle de Goélands à ailes grises, de 13 %. La comparaison de ces chiffres avec ceux d'un dénombrement partiel des deux espèces en 1988 a révélé que, au cours de la période s'étendant de l'été 1988 à l'été 1989, les deux populations dans la partie nord de la côte ouest avaient diminué. Les conséquences de ces diminutions de population sont discutées en tenant compte du déversement d'hydrocarbures du *Nestucca* en décembre 1988 ainsi que d'autres facteurs qui auraient pu y contribuer.

Le succès de reproduction des Goélands à ailes grises variait selon l'aire de nidification, et le taux moyen d'envol était plus élevé dans les grandes colonies que dans les petites.

3. Introduction

In December 1988, 875 000 L of bunker oil were spilled from the barge *Nestucca* off Gray's Harbor, Washington. The oil drifted northward to the west coast of Vancouver Island. A total of 3568 marine birds that had died as a result of the spill were found along Vancouver Island beaches; Common Murres *Uria aalge* (42%) and Cassin's Auklets *Ptychoramphus aleuticus* (32%) were most affected (Rodway et al. 1989). Overall, it was estimated that a total of 56 000 seabirds died as a result of the *Nestucca* spill; most of the birds were not found (Ford et al. 1991).

A survey of nesting colonies of Pelagic Cormorants *Phalacrocorax pelagicus* and Glaucous-winged Gulls *Larus glaucescens* along the west coast of Vancouver Island was conducted in the summer of 1989. The primary objective was to determine whether breeding populations of these two species had been affected by the *Nestucca* oil spill. Other objectives were to measure the reproductive success of large and small nesting colonies of Glaucous-winged Gulls on the west coast of Vancouver Island and to compare their success with that observed by Vermeer and Devito (1989) in the Strait of Georgia, British Columbia, in 1987.

4. Methods

The surveys were conducted from 20 June to 14 July 1989 using an inflatable boat. Very small Pelagic Cormorant and Glaucous-winged Gull colonies were censused, when possible, from the water. A few large colonies were also censused from the boat when sea conditions prevented safe landing. We counted the number of birds on occupied territories and assumed that each territorial pair had a nest. For most large colonies, two observers walked systematically throughout the colony counting nests. All nests were counted, whether empty or containing eggs. The surveys were conducted in areas indicated by shading in Figure 1. Gaps between shaded areas were not surveyed because of time constraints, limited fuel capacity, or inclement weather. However, no colonies of Pelagic Cormorants and Glaucous-winged Gulls had previously been reported in these nonsurveyed areas, except for a small colony of Pelagic Cormorants observed by Campbell (1976) at Providence Cove (Fig. 1). Nesting colonies were also checked for signs of predators or predation.

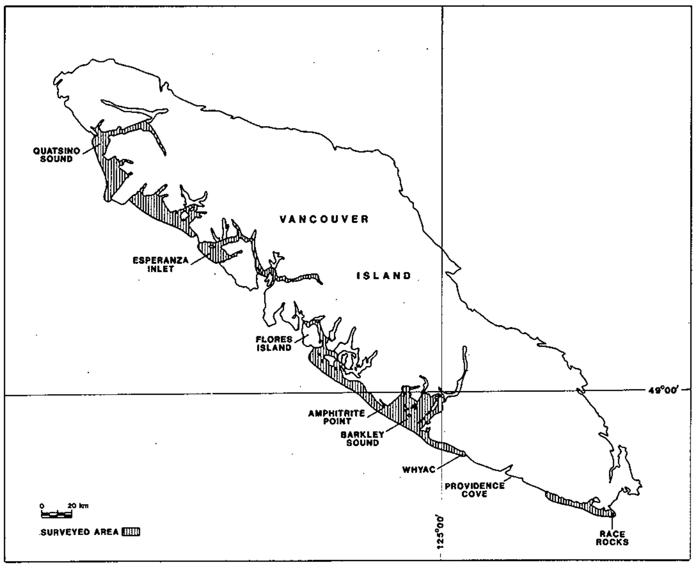
Breeding productivity of Glaucous-winged Gulls was investigated at 16 colonies. Nests were counted in these colonies between 14 and 29 June, and fledglings, or chicks near fledging age (which were assumed to have fledged later), were counted at the same sites from 8 to 12 August.

5. Results

5.1 Pelagic Cormorant population

We counted a total of 382 nests of Pelagic Cormorants on the west coast of Vancouver Island in 1989 (Table 1, Fig. 2), compared with 1260 nesting pairs in the same area in 1974–75 (Campbell 1976); this suggests a decline of 70% in the total number of nesting cormorants between the two surveys. Most

Figure 1
The area censused for nesting Pelagic Cormorants and Glaucous-winged Gulls on the west coast of Vancouver Island in 1989



(89%) of this decline occurred in the Barkley Sound and Flores Island – Amphitrite Point region; 252 pairs nested there in 1974–75, but only 27 nests were found in 1989 (Table 1). The number of nesting cormorants in the Quatsino Sound – Esperanza Inlet region declined only slightly from 771 pairs in 1974–75 to 731 nests observed there by M. Lemon (pers. commun.; Table 1) in 1988. However, in 1989, only 188 nests were found in that region, indicating a 74% decline from the preceding year. On 4 July, all 72 nests on Volcanic Islets were empty, most having unhatched or broken eggs and few adults on territories. The southernmost colony, at Race Rocks, has remained about the same size since 1974–75 (Table 1).

5.2 Glaucous-winged Gull population

We counted a total of 5972 nests of Glaucous-winged Gulls on the west coast of Vancouver Island in 1989 (Table 2, Fig. 2), compared with 6835 nesting pairs reported there in 1974–75 (Campbell 1976). The total number of nesting Glaucous-winged Gulls appears to have declined by 12% between these two surveys. However, in the Quatsino Sound – Esperanza Inlet region, the number of nesting gulls changed little from 1974–75 to 1988 (Table 2); it then dropped by 29% to 2372 pairs at the time of the 1989 survey. By 1989, the 1974–75 nesting population had declined by 20% in Barkley Sound and by 6% in the Flores Island – Amphitrite Point region. On the other hand, the colony at Race Rocks increased from 141 pairs in 1974–75 to 424 nests in 1989.

5.3 Reproductive success of Glaucous-winged Gulls

The reproductive success varied greatly from island to island in 16 colonies (Table 3). The average fledging rate was significantly higher in the larger colonies than in the smaller ones ($t = 4.32$, $P = 0.03$). However, two small colonies, Monks Islet and Pinder Rock, had the highest fledging rates. The lowest rates were found at four sites with solitary pairs and at one site with three pairs. Baeria Rocks, a colony with 130 nests, produced few fledglings, perhaps because of predation by Bald Eagles *Haliaeetus leucocephalus* and a Peregrine Falcon *Falco peregrinus*; both were observed there.

Table 1
Comparison of the nesting distribution of Pelagic Cormorants on the west coast of Vancouver Island in 1974–75 (Campbell 1976) with that in 1989 (this study), as well as with that in the Quatsino Sound – Esperanza Inlet region in 1988 (M. Lemon, pers. commun.)

No.[a]	Name of nesting locality	No. of pairs, 1974–75	No. of nests, 1988	No. of nests, 1989
1	Gillam Island	6	8	0
2	Rowley Reefs	1	1	0
6	Solander Island	416	464	67
8	O'Leary Islets	83	41	10
13	Moos Islets	1	0	0
14	White Cliff Head	30	1	0
15	Thornton Islands	62	125	39
16	Munsie Rocks	118	0	0
17	Nipple Rocks	50	0	0
18	Volcanic Islets	4	89	72
20	McQuarrie Islets	0	2	0
28	White Islet	19		0
29	Sea-Lion Rocks	10		4
30	Cormorant Rock	25		0
31	Florencia Island	79		0
32	Fletcher's Beach	12		6
33	Rutley Islands[b]	0		0
35	Baeria Rocks	32		0
36	Weld Island[b]	0		0
38	Swiss Boy Island	0		5
39	Gibralter Island	1		0
40	Dempster Island	19		0
42	Alley Rock	1		0
45	Great Bear Rock	2		0
46	Fleming Island[b]	0		0
49	Effingham Island	27		0
50	Austin Island	3		0
52	Folger Island	2		0
53	Edward King Island[b]	0		0
54	Bordelais Islets[b]	0		0
55	Execution Rock[b]	0		0
56	Lawton Point[b]	0		0
57	Cape Beale	20		0
58	Seabird Rocks	0		12
59	Cliff, Vancouver Island	0		8
60	Cliff, Vancouver Island	0		4
61	Whyac	50		3
62	Providence Cove	15		?
63	San Simon Point	12		0
67	Race Rocks	160		152
Total no. of nests or pairs		1260		382

[a] Numbers correspond to locations in Figure 2.
[b] Small numbers of cormorants (1–18 pairs) nested on those islands in 1977–82 (Carter et al. 1984).
? = not surveyed in 1989.

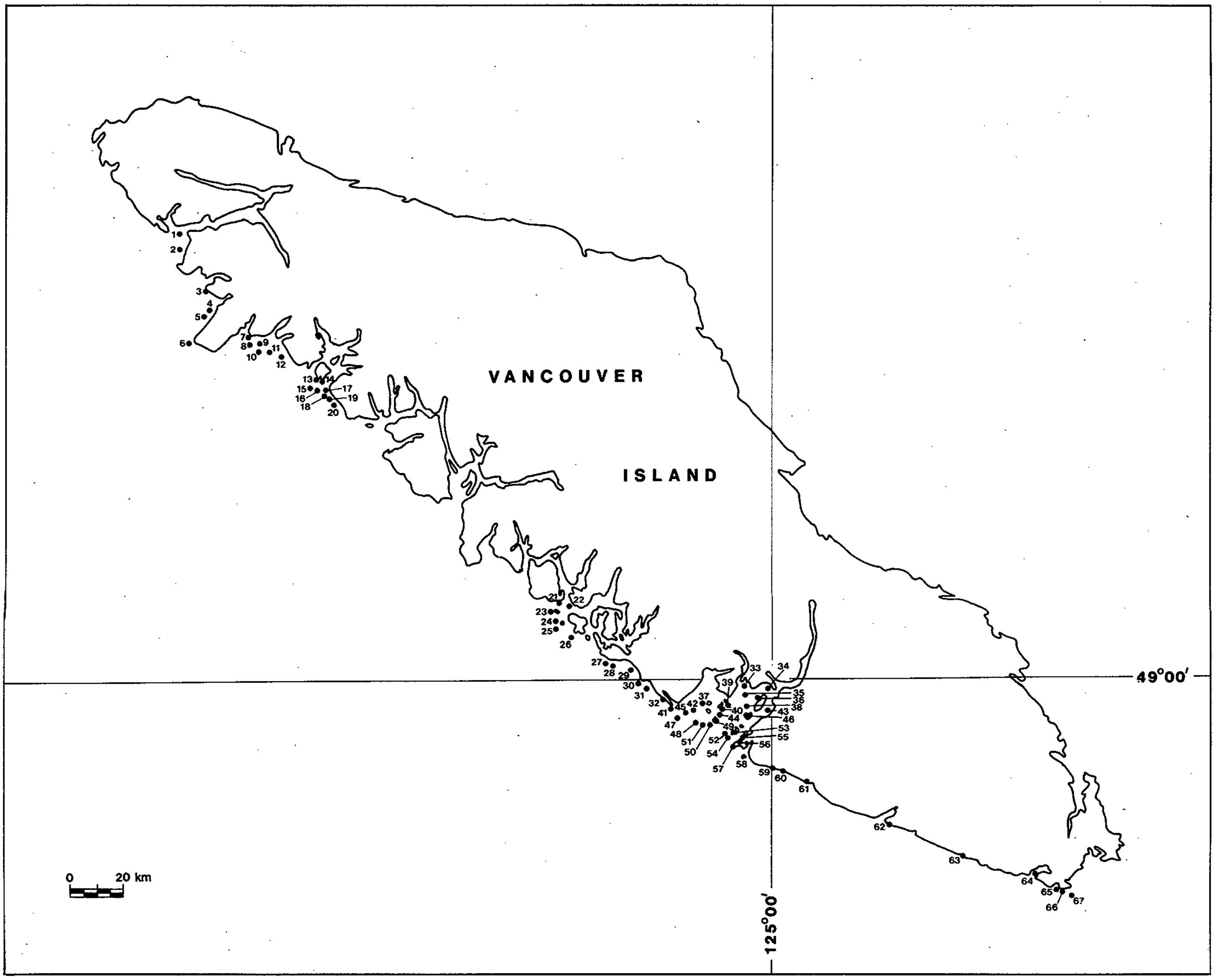
6. Discussion

6.1 Pelagic Cormorant population

The reasons for the substantial decrease of Pelagic Cormorants along the west coast of Vancouver Island between 1974–75 and 1989 are unknown. The declines could be related to the *Nestucca* oil spill, as the cormorant population in the Quatsino Sound – Esperanza Inlet region, for which there is prespill information, decreased markedly between 1988 and 1989—and this decline was much larger between 1988 and 1989 (74%) than between 1974–75 and 1988 (5%). On the other hand, the number of live or dead oiled cormorants found along the west coast of Vancouver Island was very small (Rodway et al. 1989), suggesting that the spill was not responsible for the large decline of cormorants. Further, much of the coastline in the Quatsino Sound – Esperanza Inlet region is remote and relatively inaccessible and was not checked as completely for corpses as those areas to the south.

Another possible reason for the low number of nesting cormorants observed in 1989 is a shortage of food. At the time

Figure 2
Distribution of nesting sites of Pelagic Cormorants and Glaucous-winged Gulls on the west coast of Vancouver Island in 1989. Numbered colonies are identified in Tables 1 and 2.



of the census in July, we observed that many cormorants in breeding plumage in the vicinity of known nesting colonies had not built nests or laid eggs. It may be noted that, in the Strait of Georgia on the east coast of Vancouver Island, the vast majority of Pelagic Cormorants usually start laying between the end of May and the middle of June (Drent et al. 1964). Brandt's Cormorants *Phalacrocorax penicillatus* at southeast Farallon Island in California are known to skip breeding in "poor" food years (Boekelheide and Ainley 1989). On the west coast of Vancouver Island, Tufted Puffins *Fratercula cirrhata* have been observed either to lay late or to not produce young in years of apparent scarcity of prey fish (Vermeer 1979). Pelagic Cormorants could have been similarly affected in 1989. We collected 20 food pellets from Pelagic Cormorants on Volcanic Islets, and these contained mostly remains of invertebrates, which are an uncommon food for cormorants (Robertson 1974).

We do not think that human disturbance caused the cormorant decline on the west coast of Vancouver Island. These colonies are much less accessible to boaters than those in the Strait of Georgia. Also, cormorant predators such as Bald Eagles are less abundant on the west coast than in the Strait of Georgia (Vermeer et al. 1989; Vermeer and Morgan 1989; pers. obs.), suggesting that predation was not a significant factor in the cormorant decline on the west coast.

It is noteworthy that the cormorant population at Race Rocks did not diminish between 1974–75 and 1989. Because of its position away from the path of the *Nestucca* spill, Race Rocks was not affected by the oil pollution. Also, Race Rocks is located at the inner end of Juan de Fuca Strait, where surface water temperatures vary less and are on average 2°C colder in summer than those near islands on the west coast of Vancouver Island (Thomson et al. 1984). During El Niño years, surface water temperatures near Race Rocks are also colder and more stable than those on the west coast. For example, satellite thermal images of the British Columbia coast during the 1983 El Niño showed surface water temperatures to be much higher in spring and early summer along the west coast of Vancouver Island than in the sheltered inner waters of Juan de Fuca Strait and the Strait of Georgia. These elevated surface water temperatures affected the distribution and recruitment of fish (on some of which the cormorants feed) on the North American west coast (Bailey and Incze 1985; Pearcy et al. 1985). This in

Table 2
Comparison of the nesting distribution of Glaucous-winged Gulls on the west coast of Vancouver Island in 1974–75 (Campbell 1976) with that in 1989 (this study), as well as with that in the Quatsino Sound – Esperanza Inlet region in 1988 (M. Lemon, pers. commun.)

No.[a]	Name of nesting locality	No. of pairs, 1974–75	No. of nests, 1988	No. of nests, 1989
1	Gillam Island	482	646	477
3	Gould Rock	5		0
4	Clerke Islet	20	29	12
5	Hackett Island	1		0
6	Solander Island	318	347	530
7	Yule Rock	1	0	0
8	O'Leary Islets	115	117	92
9	Cuttle Islets	2	0	0
10	Clara Islets	40	93	53
11	Bunsby Islands	190	124	105
12	Unnamed islet	24		0
12	Thomas Island	7	7	1
13	Moos Islets	552	148	79
15	Thornton Islands	688	1053	523
16	Munsie Rocks	72	28	119
17	Nipple Rocks	122	149	72
18	Volcanic Islets	134	153	155
19	Diver Islet	27	33	11
19	Grassy Island	141	188	73
19	Clark Island	13	16	7
19	Unnamed islet	4	5	1
20	McQuarrie Islets	256	203	62
20	Unnamed islets	1		0
21	Kutcous Islets	1		0
22	Monks Islet	42		35
23	Tibbs Islet	0		10
24	Plover Reefs	10		0
25	Murre Reef	0		154
25	Cleland Island	1500		1694
26	La Croix Group	1		1
27	Gowland Rocks	2		0
28	White Islet	61		77
29	Sea-Lion Rocks	167		120
31	Florencia Island	479		186
33	Rutley Islands	0		1
34	Boyson Island	0		1
35	Baeria Rocks	210		130
37	Pinder Rock	0		9
41	George Fraser Islands	10		0
41	Janson Islet	0		1
41	Humphries Reef	0		1
42	Alley Rock	3		5
43	San Jose Islets	2		3
44	Faber Islets	2		0
45	Great Bear Rock	274		175
47	Starlight Reef	306		320
48	Sail Rock	1		0
51	Wouwer Island	1		0
58	Seabird Rocks	400		225
64	Sooke Bay	2		0
65	South Bedford Island	2		28
66	Church Island	3		0
67	Race Rocks	141		424
Total no. of nests/pair		6835		5972

[a] Numbers correspond to locations in Figure 2.

turn resulted in widespread nest abandonment and reproductive failure of Brandt's and Pelagic cormorants off the Oregon coast (Graybill and Hodder 1985). However, nesting Pelagic Cormorants in the Strait of Georgia and at Race Rocks thrived in 1983, and their overall population had increased since their last census in 1974–75 (Vermeer and Rankin 1984).

Because of the relatively stable surface water temperatures, the food regime of cormorants at Race Rocks and in the Strait of Georgia may be less variable than on the open west coast. Such a regime may in turn result in less annual variability of nesting cormorant numbers.

Table 3
Comparison of fledging rates of large and small colonies of Glaucous-winged Gulls on the west coast of Vancouver Island, 1989

Nesting locality	No. of nests checked for fledging success (colony size)	No. of fledglings	Fledging rate (no. of fledglings/ nest
Nest localities with more than 100 nests			
Cleland Island	398 (1694)	321	0.81
Murre Reef (associated with Cleland Island)	154 (154)	142	0.92
Great Bear Rock	97 (175)	103	1.06
Seabird Rocks	110 (225)	68	0.62
Starlight Reef	320 (320)	237	0.74
Baeria Rocks	130 (130)	7	0.05
Nest localities with less than 100 nests			
Alley Rock	5 (5)	2	0.40
Boyson Island	1 (1)	0	0
Humphries Reef	1 (1)	0	0
Janson Islet	1 (1)	0	0
La Croix Group	1 (1)	0	0
Monks Islet	35 (35)	52	1.49
Rutley Island	1 (1)	0	0
Pinder Rock	9 (9)	11	1.22
San Jose Islets	3 (3)	0	0
Tibbs Islet	10 (10)	8	0.80

6.2 Glaucous-winged Gull population

Glaucous-winged Gull numbers also declined considerably in the Quatsino Sound – Esperanza Inlet region between 1988 and 1989. However, relatively few Glaucous-winged Gulls were found to be oiled following the *Nestucca* oil spill (Rodway et al. 1989). Unlike cormorants, gulls are not diving birds and generally escape a spill by taking flight (Vermeer and Vermeer 1975). Hence, it is unlikely that this 1988–89 decline of the gull population in the Quatsino Sound – Esperanza Inlet region is related to the *Nestucca* spill.

The overall decline of the nesting population of Glaucous-winged Gulls on the west coast between 1974–75 and 1989 is in sharp contrast to the observed increase of the gull population in the Strait of Georgia between 1974–75 and 1987. The difference may be food related. The main hypothesis for the increase of Glaucous-winged Gulls in the Strait of Georgia is that gulls benefit from the increasing supply of human garbage available near large urban centres (Vermeer and Devito 1989).

There are no large urban centres on the west coast of Vancouver Island, and, consequently, the supply of garbage to gulls is limited. Before and during egg laying, food pellets of Glaucous-winged Gulls in Strait of Georgia colonies were observed to contain much refuse, whereas pellets in west coast colonies contained mostly gooseneck barnacles *Pollicipes polymerus*. Gulls were also seen feeding extensively on schooling fish near the water surface at that time. Later in the nesting season, when gulls are raising their young, regurgitations from adult gulls on both the east and west coasts contained mostly fish (Vermeer 1982). Perhaps the large decline of gull numbers in the Quatsino Sound – Esperanza Inlet region in 1989 was related to a shortage of prey fish, mainly Pacific sandlance *Ammodytes hexapterus* and Pacific herring *Clupea harengus pallasi* in June and July (Ward 1973; Vermeer 1982), as the availability of prey fish to marine birds on the west coast varies markedly from year to year (Vermeer and Westrheim 1984). However, we have no information as to which prey were available or what the diet of gulls was in 1989.

6.3 Reproductive success of Glaucous-winged Gulls

The average fledging rate of Glaucous-winged Gulls on the west coast in 1989 was about 0.6 fledglings/nest. The average fledging rate of small and large colonies of Glaucous-winged Gulls in the Strait of Georgia was about 0.85 fledglings/nest in 1986 (Vermeer and Devito 1989). At the latter rate, the gull population in the Strait of Georgia was calculated to increase by 2.7% per year. If survival probabilities of postfledged and older age classes are similar in the Strait of Georgia and on the west coast, then, with an average fledging rate of 0.6 fledglings/nest, the gull population on the west coast will gradually decrease. There is some evidence that a decrease occurred between 1974–75 and 1989 (Table 2).

The reasons for the lower reproductive rate and the currently decreasing Glaucous-winged Gull population on the west coast are not understood. Predation is a contributing factor to the low reproductive rate, as we commonly observed signs of predation on eggs, chicks, and adults. However, it is not thought to be the main factor causing the decline. Predation by eagles and river otters *Lutra canadensis* was observed to be much more severe on nesting gulls in the Strait of Georgia, and yet the number of gulls still increased (Vermeer and Devito 1989). As previously suggested, both the more stable regime of natural food and the greater availability of human refuse in the Strait of Georgia area could account for opposite population trends of gulls in these two ecosystems.

7. Recommendations

Much of the difficulty in determining the reasons for the observed population declines of Pelagic Cormorants and Glaucous-winged Gulls on the west coast of Vancouver Island results from the meagre information available on the basic nesting biology, diet, and population status of these species. We recommend that the nesting biology and diet of these species be examined over several years and that their populations be more frequently censused than previously.

These two species are reasonably numerous, accessible, and well suited to serve as indicators of changes or perturbations on the British Columbia coast and marine environment. With better information on their populations and biology, we will be able to predict the effects of future oil spills or environmental changes on the populations of Pelagic Cormorants and Glaucous-winged Gulls on the west coast.

8. Acknowledgements

Pacific Rim National Park of the Canadian Parks Service and the Environmental Protection Directorate of Environment Canada provided financial assistance for conducting the census of Pelagic Cormorants and Glaucous-winged Gulls in 1989. The Institute of Ocean Sciences provided a coxswain and a boat for the census. Moira Lemon kindly provided unpublished 1988 census results for the two species. H. Boyd, L.F. Giovando, and N.A.M. Verbeek reviewed the manuscript and made pertinent comments. S. Garnham typed the manuscript.

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Population, nesting habitat, and reproductive success of American Black Oystercatchers on the west coast of Vancouver Island

Kees Vermeer, Peter J. Ewins, Ken H. Morgan, and G.E. John Smith

1. Abstract

The nesting population of American Black Oystercatchers *Haematopus bachmani* was censused and their island and nest site habitat were investigated in Barkley Sound and in the Flores Island – Cape Beale region on the west coast of Vancouver Island in 1989. Of 628 islands surveyed in Barkley Sound, 13 had nesting oystercatchers; of 429 islands surveyed in the Flores Island – Cape Beale region, 25 had oystercatchers. There were significant regional differences in the proportion of islands occupied by oystercatchers. Cleland Island, in the Flores Island – Cape Beale region, supported about 30% of the breeding population investigated on the west coast of Vancouver Island.

There were significant regional differences in the distance oystercatchers nested from the high-tide line and from one another. In all regions, oystercatchers preferred to nest on less forested islands, as well as on those with breeding gulls. In the Flores Island – Cape Beale region, oystercatchers nested at significantly higher density on islands with nesting gulls.

On Cleland Island, the average clutch size was 2.24 and hatching success 39%. Egg losses resulted from predation and washout by waves. Hatching success of nests at a short vertical distance above high tide was significantly lower than that of nests at greater distance above high tide.

2. Résumé

La population d'Huîtriers de Bachman nicheurs *Haematopus bachmani* a été dénombrée, et les îles qui leur servent d'habitat ainsi que leurs lieux de nidification ont été étudiés dans la baie Barclay de même que dans la zone de l'île Flores et du cap Beale sur la côte ouest de l'île de Vancouver, en 1989. Des huîtriers nicheurs habitaient 13 des 628 îles étudiées dans la baie Barclay et 25 des 429 îles examinées dans la zone de l'île Flores et du cap Beale. La proportion des îles habitées par les huîtriers présentait d'importantes différences zonales. Environ 30 % de la population d'oiseaux nicheurs étudiée sur la côte ouest de l'île de Vancouver fréquentait l'île Cleland, dans la zone de l'île Flores et du cap Beale.

La distance entre le nid des huîtriers et la laisse de haute mer de même que celle d'un nid à l'autre variaient considérablement selon les zones. Dans toutes les zones, les huîtriers préféraient nicher dans des îles moins boisées et dans celles fréquentées par les goélands nicheurs. Dans la zone de l'île Flores et du cap Beale, les huîtriers nichaient en nombre beaucoup plus grand dans les îles où se trouvaient des goélands nicheurs.

Dans l'île Cleland, la quantité moyenne d'oeufs pondus était de 2,24, et le succès d'éclosion, de 39 %. Les pertes d'oeufs étaient dues à la prédation ou à l'action des vagues. Le succès d'éclosion dans les nids situés à une faible distance verticale de la laisse de haute mer était beaucoup moins grand que dans le cas des nids plus élevés.

3. Introduction

American Black Oystercatchers *Haematopus bachmani* nest predominantly on barren rocky shores of islands, just above the high-tide line, and feed in the adjacent rocky intertidal zone. The nesting biology and foraging ecology of American Black Oystercatchers have been studied on Cleland Island on the west coast of Vancouver Island (Hartwick 1974, 1976; Groves 1982, 1984; L'Hyver 1985). The status of the population and selection of nesting habitat have not been investigated there but were examined by Vermeer et al. (1989) in the Gulf Islands in the Strait of Georgia on the east coast of Vancouver Island.

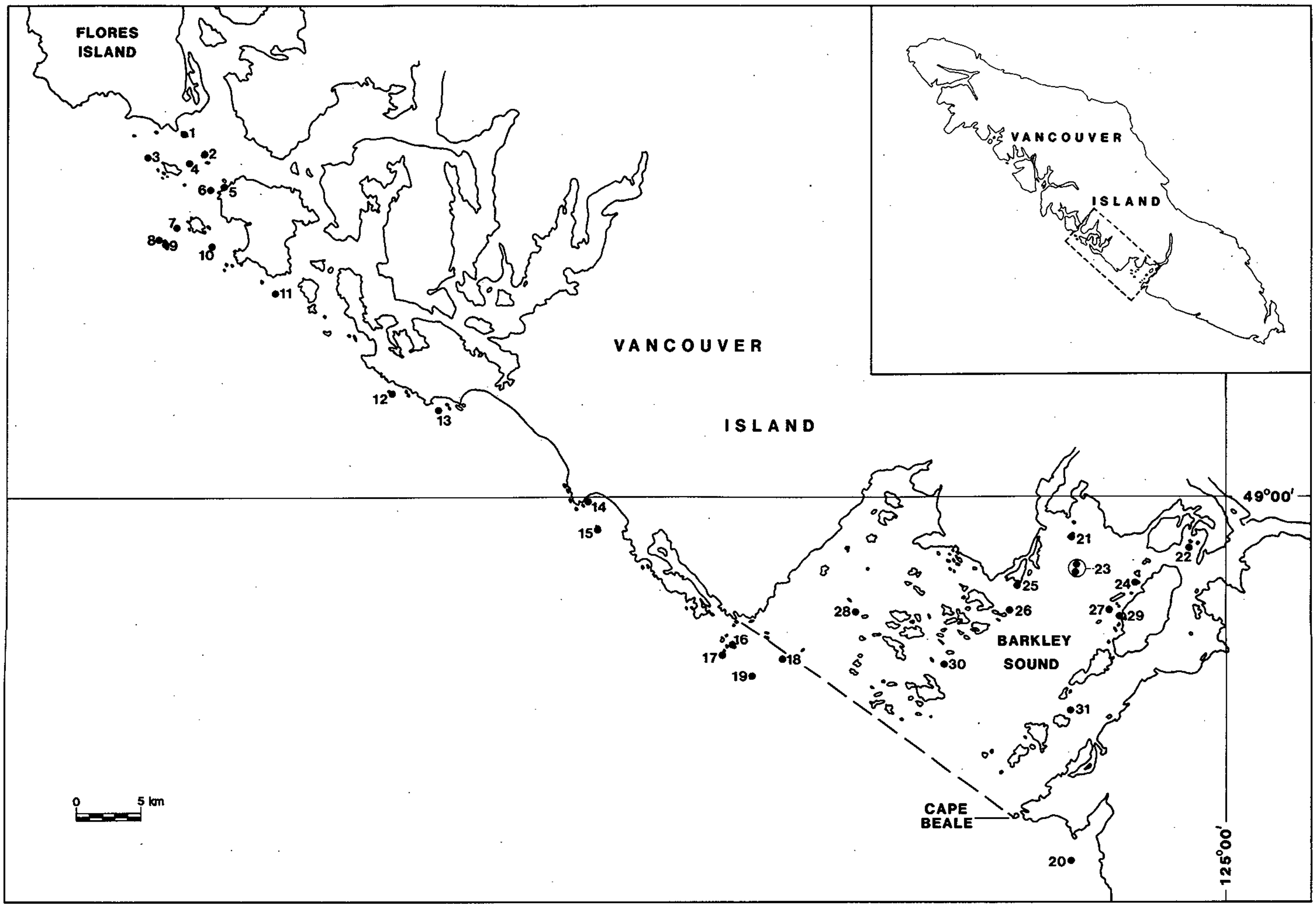
The first objective of this paper was to examine the status and nesting habitat of American Black Oystercatchers on the west coast of Vancouver Island, to determine whether the proportion of islands occupied by the species, its breeding density, and its nesting habitat were similar to those on the east coast. A second objective was to examine the nesting status and reproductive success of American Black Oystercatchers on Cleland Island. A third was to investigate the effects of an oil spill from the barge *Nestucca* off Gray's Harbor, Washington, which drifted northward along the west coast of Vancouver Island early in 1989 and resulted in contamination along the intertidal zone of Cleland Island as well as the finding of 3326 oiled marine birds along the west coast of Vancouver Island (Rodway et al. 1989).

4. Methods

4.1 Survey methods

Islands in Barkley Sound (inner coast) and in the Flores Island – Cape Beale region (outer coast) (Fig. 1) were surveyed for nesting oystercatchers from 19 to 30 June 1989. We circled all islands (N = 1057) by motorboat and landed on any island on which oystercatchers were observed. The islands were searched on foot to obtain evidence of nesting attempts, such as presence of chicks, nests, or nest remains or adult behaviour indicative of successful nesting. We also recorded the nesting status of Glaucous-winged Gulls. The perimeter of each island was measured from charts with a planimeter. For each oystercatcher nest, we measured the distances to and above the high-tide line

Figure 1
Distribution of nesting sites of American Black Oystercatchers in Barkley Sound and in the Flores Island – Cape Beale region on the west coast of Vancouver Island. Numbered nesting sites are identified in Table 1.



(taken as the upper limit of the barnacle zone), to the nearest land vegetation, to the nearest gull nest, and to the nearest oystercatcher nest. The same method was used for 284 islands in the Gulf Islands survey in 1987 (Vermeer et al. 1989).

Breeding timing and success of 35 nests studied on Cleland Island between 18 May and 26 July 1989 were investigated. All clutches were checked weekly, and clutch commencement was either observed from the appearance of eggs or calculated by subtracting the incubation period (26 days; Hartwick 1974) and egg laying interval (mean 2.4 days; L'Hyver 1985) from observed hatching times. The hatching success of oystercatchers could be determined for 33 clutches. Only completed clutches have been used in the analysis.

4.2 Statistical analysis

Data collected from islands in Barkley Sound, the Flores Island – Cape Beale region, and the Gulf Islands were analyzed. Two questions were discussed. The first was island specific: that is, what characteristics make islands attractive for nesting? These include geographic area and the presence or absence of gulls. The second was nest specific: that is, what characteristics make a nest site attractive for nesting? We considered how the nest's location on an island was related to horizontal distance to and vertical distance above the barnacle zone, the distance to land vegetation, and the distance to the nearest conspecific nest. We also considered how the distance from an oystercatcher nest to the nearest gull nest varied by geographic area.

The measurements of the islands' characteristics and nest locations on the islands were not normally distributed. Most physical parameters of islands and nests had highly skewed frequency distributions. Therefore, we used the Kruskall-Wallis nonparametric analysis of variance (Zar 1984). For presentation purposes, however, most of the data summaries are given as means. When the Kruskall-Wallis test found differences, a nonparametric analogue of Tukey's multiple comparison test (Zar 1984, section 12.6) was used to determine which ones were significant.

5. Results

5.1 Populations

In the Flores Island – Cape Beale region, 25 of the 429 islands surveyed (5.8%) held nesting oystercatchers, compared with only 13 of the 628 islands surveyed (2.1%) in Barkley Sound (Table 1). In the Gulf Islands, 36 of 284 islands surveyed (12.7%) held nesting oystercatchers (Vermeer et al. 1989).

Although a significantly higher proportion of the Gulf Islands were occupied in 1987 by nesting oystercatchers than islands in Barkley Sound in 1989 (Table 2), the overall nesting densities in the two regions were nearly identical, whereas that

Table 1
Islands with nesting American Black Oystercatchers in Barkley Sound and in the Flores Island – Cape Beale region on the west coast of Vancouver Island, 1989

Location[a]	No. of nesting islands	No. of nesting pairs (no. of nests found)
Flores Island – Cape Beale region		
1. Kutcous Islets	2	2
2. Shot Islets	2	2
3. Tibbs Islet	1	1
4. Whaler Islets	1	1
5. Burgess Islet	1	1
6. Hobbs Islet	1	1
7. Plover Reefs	1	2
8. Murre Reef	1	9 (9)
9. Cleland Island	1	35 (35)
10. Foam Reefs	1	1
11. Wilf Rock	1	1
12. Gowland Rocks	1	1
13. White Islet	1	2
14. Unnamed islet	1	1 (1)
15. Florencia Island	1	9 (4)
16. Janson Islet	1	2 (1)
17. Humphries Reef	1	1 (1)
18. Great Bear Rocks	2	4 (2)
19. Starlight Reef	2	4 (2)
20. Seabird Rocks	2	12 (10)
Barkley Sound		
21. Rutley Islands	1	1
22. Boyson Islands	1	1
23. Baeria Rocks	3	11 (10)
24. Stud Islets	1	1 (1)
25. Mahk Rock	1	1 (1)
26. Swale Rock	1	1 (1)
27. Meade Islets	1	2 (1)
28. Pinder Rock	1	4 (3)
29. Tzartus Island	1	1 (1)
30. Village Reef	1	2 (2)
31. Wizard Islet	1	5 (4)
Total	38	122 (89)

[a] Numbered colonies are indicated in Figure 1.

in the Flores Island – Cape Beale region was an order of magnitude higher than in the other two geographic regions (Table 3). Much of the relative high density in the Flores Island – Cape Beale region resulted from the nesting concentration on Cleland Island and adjacent Murre Reef. Omitting this nesting population, the average density in the Flores Island – Cape Beale region was 0.40 pairs per kilometre of shoreline. Cleland Island and Murre Reef between them held 44 pairs of nesting oystercatchers, the largest number on any island in the three geographic regions. Overall, there were significantly more oystercatchers nesting on islands with than without gulls ($K = 15.35$, $P = 0.009$).

5.2 Island habitat and nest sites

Islands used by oystercatchers in both surveyed areas on the west coast of Vancouver Island as well as in the Gulf Islands were significantly less forested and more used by nesting Glaucous-winged Gulls than were nonnesting islands (Table 4). Islands used by oystercatchers in Barkley Sound and the Gulf Islands were significantly smaller (i.e., less shoreline) than nonnesting islands, but nesting islands in the Flores Island – Cape Beale region were significantly larger (Table 4). There were significant overall differences in the distance oystercatchers nested from the high-tide line, from terrestrial vegetation, and from one another in the three geographic regions (Table 5). Oystercatchers in the Flores Island – Cape Beale region nested significantly farther from the high-tide line and from land vegetation than in either Barkley Sound or the Gulf Islands

Table 2
Proportions of islands with nesting American Black Oystercatchers in Barkley Sound, the Flores Island – Cape Beale area, and the Gulf Islands

Results of surveys in three geographic regions	No. of islands surveyed	No. of islands with oystercatchers	% of islands with oystercatchers
Barkley Sound	628	13	2.1
Flores Island – Cape Beale	429	25	5.8
Gulf Islands	284	36	12.7
Results of chi-square tests	χ^2	df	P
All three regions	19.74	3	<0.001
Barkley Sound vs. Flores Island – Cape Beale	10.38	2	<0.005
Barkley Sound vs. Gulf Islands	43.27	2	<0.005
Flores Island – Cape Beale vs. Gulf Islands	10.24	2	<0.005

Note: P must be less than 0.051/3, or 0.017, for the pairwise comparisons to be significantly different at P = 0.05.

Table 3
Comparison of nesting densities of American Black Oystercatchers for all islands surveyed in Barkley Sound, the Flores Island – Cape Beale region, and the Gulf Islands

Geographic region	Total no. of islands surveyed	Total perimeter of shoreline (km)	Total no. of pairs	Average no. of pairs/km
Barkley Sound	628	427	30	0.07
Flores Island – Cape Beale	429	123	92	0.75
Gulf Islands	284	848	54	0.06

Table 4
Comparison of variables of islands with and without American Black Oystercatchers in Barkley Sound, the Flores Island – Cape Beale region, and the Gulf Islands (Vermeer et al. 1989)

Variables	Nesting islands	Non-nesting islands	Significance χ^2	df	P
Barkley Sound	N = 13	N = 615			
Forested islands (%)	7.7	68.1	21.0	1	0.001
Nesting gulls present (%)	46.2	0.3	187.9	1	0.001
Median island perimeter (m)	160	180	9.5	2	0.009
Flores Island – Cape Beale region	N = 25	N = 404			
Forested islands (%)	8.0	34.2	7.3	1	0.001
Nesting gulls present (%)	52.0	1.0	161.0	1	0.001
Median island perimeter (m)	360	120	14.0	2	0.001
Gulf Islands	N = 36	N = 248			
Forested islands (%)	11.1	44.0	14.1	1	0.001
Nesting gulls present (%)	55.6	17.3	28.1	1	0.001
Median island perimeter (m)	245	320	12.8	2	0.002

($P < 0.05$). Oystercatchers in both Barkley Sound and the Flores Island – Cape Beale region nested significantly closer to conspecifics than those in the Gulf Islands ($P < 0.01$).

Because Cleland Island and adjacent Murre Reef (Cleland group) had a large concentration of nesting oystercatchers, a comparison was made of nesting variables between that group and those of 11 other islands with nesting gulls in the Flores Island – Cape Beale region. Oystercatchers in the Cleland group nested significantly closer to nesting gulls and significantly farther from the nearest land vegetation (Table 6).

Predominant nest materials of oystercatchers in both Barkley Sound and the Flores Island – Cape Beale region consisted of white shells, but grey rock chips were also common (Table 7). In the Gulf Islands, the opposite was true: grey rock chips predominated in nests, with white shells also common. The nesting substrate of American Black Oystercatchers on

Table 5
Comparison of nesting variables for American Black Oystercatchers in Barkley Sound, the Flores Island – Cape Beale region, and the Gulf Islands (Vermeer et al. 1989)

	Mean ± SD (no. of measurements)						Overall significance with Kruskall-Wallis	
Nesting variables (m)	Barkley Sound		Flores Island – Cape Beale region		Gulf Islands		K	P
Distance to barnacle zone	10.46 ± 5.49	(26)	16.57 ± 9.87	(60)	7.08 ± 4.38	(32)	29.88	<0.0001
Height above barnacle zone	3.43 ± 2.69	(26)	2.79 ± 2.13	(60)	2.31 ± 1.63	(32)	4.61	0.098
Distance to nearest land vegetation[a]	4.98 ± 8.31	(14)	24.41 ± 40.99	(50)	1.13 ± 1.39	(32)	33.70	<0.0001
Distance to nearest oystercatcher nest[b]	20.85 ± 31.1	(19)	26.37 ± 35.44	(58)	116.31 ± 132.7	(12)	13.76	0.001
Distance to nearest gull nest	4.87 ± 1.85	(15)	13.35 ± 38.91	(60)	3.55 ± 1.75	(13)	3.48	0.17

[a] Islands on which there was no vegetation were omitted.
[b] Islands on which there was only one oystercatcher nest were omitted.

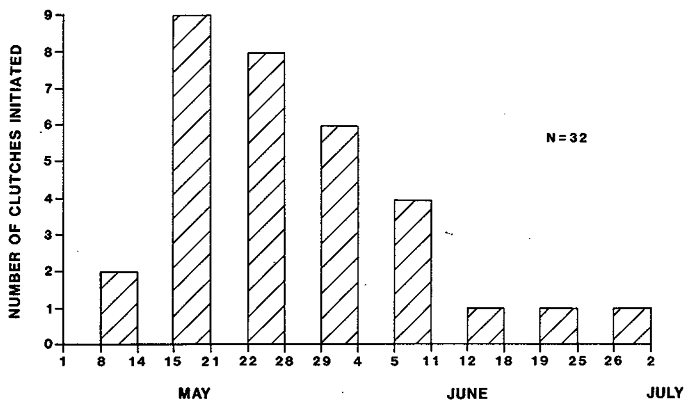
Table 6
Comparison of island and nesting variables for American Black Oystercatchers on Cleland Island and Murre Reef with those of other islands with nesting gulls in the Flores Island – Cape Beale region, 1989

	Mean ± SD (N)				Significance with Kruskall-Wallis	
Nesting variables	Cleland Island and Murre Reef		Other islands with nesting gulls		K	P
No. of nesting pairs	44		35			
No. of pairs/km shoreline	17.60		7.09			
Distance to barnacle zone (m)	17.55 ± 9.80	(44)	14.00 ± 10.21	(16)	1.24	0.54
Height above barnacle zone (m)	2.19 ± 1.21	(44)	4.24 ± 3.16	(16)	4.42	0.11
Distance to nearest land vegetation (m)	31.97 ± 46.38	(35)	4.07 ± 6.72	(14)	9.24	0.001
Distance to nearest oystercatcher nest (m)	20.54 ± 15.36	(44)	44.71 ± 65.12	(14)	0.10	0.95
Distance to nearest gull nest (m)	3.69 ± 1.77	(44)	39.92 ± 70.13	(16)	12.62	0.002

Table 7
Predominant nest material, colour, and nest substrate of 90 nests of American Black Oystercatchers on the west coast of Vancouver Island in 1989, with comparative data for 32 nests in the Gulf Islands in 1987 from Vermeer et al. (1989)

	% of nests	
Variables	West coast of Vancouver Island	Gulf Islands
Nest material		
Rock (chips, gravel)	36	66
Shells (entire or fragments)	63	31
Plant material	1	3
Nest colour		
White	51	31
Grey	25	56
Brown	10	13
Blue	13	0
Yellow	1	0
Nest substrate		
Solid rock	59	66
Shells (some gravel)	20	0
Gravel (some shells)	14	9
Sod (soil and roots)	4	9
Live vegetation	3	13
Driftwood	0	3

Figure 2
Frequency distribution of clutch initiations of American Black Oystercatchers on Cleland Island on the west coast of Vancouver Island, 1989



both the east and west coasts of Vancouver Island consisted mostly of solid rock. Shells were a common nesting substrate for oystercatchers on the west but not on the east coast of Vancouver Island.

5.3 Egg laying and hatching success

On Cleland Island, most pairs commenced laying in the second half of May (Fig. 2), with the mean and median laying dates falling on 27 May ± 11.3 days and 26 May, respectively.

For 33 nests on Cleland Island, the average clutch size was 2.24 and average hatching success was 39% (Table 8).

Eggs that vanished between nest visits accounted for the bulk (71%) of hatching failure. Eggs in three nests were washed out by waves, and eggshells in another had peck holes, signs characteristic of bird predation.

The 15 nests in which chicks hatched averaged 3.76 ± 1.89 m from the nearest gull nest and 19.2 ± 8.9 m from and 2.29 ± 1.16 m above the high-tide level. The 18 nests in which chicks did not hatch averaged 3.70 ± 1.96 m from the nearest gull nest and 18.8 ± 11.5 m from and 1.48 ± 0.64 m above the high-tide line. Only the distance above the high-tide line differed significantly between the groups of nests (K = 3.932, P < 0.05).

Table 8
Clutch size, egg loss, and hatching success of American Black Oystercatcher nests on Cleland Island, 1989

Variable	Value
No. of clutches	33
No. of eggs	74
Average clutch size	2.24
No. of chicks hatched (15 nests)	29
Hatching success of eggs (%)	39
Hatching success of clutches (hatched at least 1 egg) (%)	45
No. of eggs missing	32
No. of eggs washed out by waves (3 nests)	5
No. of eggs lost to predation (2 nests)	4
No. of eggs found outside nest	2
No. of chicks died in hatching	1
No. of nests taken over by gulls	1

6. Discussion

6.1 Populations

The reason that Cleland Island supported a large oystercatcher population likely relates to the presence of an unusually extensive intertidal zone, where the birds feed mostly on mussels and limpets, but also on annelids, barnacles, chitons, crabs, isopods, sea cucumbers, and snails (Hartwick 1976; Groves 1982).

We observed 35 breeding pairs of American Black Oystercatchers on Cleland Island in 1989. Hartwick (1974) observed 56, 57, and 42 breeding pairs in 1970, 1971, and 1972, respectively, an average of 52 pairs per year. Groves (1982) reported the presence of 54 clutches of oystercatchers on Cleland Island in 1976 and 60 clutches in 1978. Although Groves did not indicate the number of breeding pairs in those two years, the number of clutches she observed suggests similar-sized oystercatcher populations on Cleland Island in 1976 and 1978 and in 1970–72. L'Hyver (1985) observed 39 and 35 breeding pairs there in 1982 and 1983, respectively, an average of 37 pairs per year. The nesting population of oystercatchers on Cleland Island seemed to have declined by 29% between 1970–72 and 1989.

6.2 Island habitat and nest sites

The reason that American Black Oystercatchers nested on mostly nonforested islands in Barkley Sound and in the Flores Island – Cape Beale region may relate to forested islands harbouring more predators, such as river otters *Lutra canadensis* and Bald Eagles *Haliaeetus leucocephalus* (see Vermeer and Morgan 1990). Vermeer et al. (1989) ascribed the significant avoidance of large forested islands by nesting American Black Oystercatchers in the Gulf Islands to the presence of predators such as river otters and domestic cats and dogs.

The preference of oystercatchers in Barkley Sound and on the Gulf Islands to nest on smaller islands likely relates to the fact that larger islands tend to have more forest cover and so generally to have more predators than smaller islands. In the Flores Island – Cape Beale region, the opposite trend (i.e., of oystercatchers to nest on larger islands) may relate to the islands being more exposed there to extensive wave action than in the sheltered regions of Barkley Sound and the Gulf Islands. Small islands on the outer west coast are more frequently washed over during storms (pers. obs.) than larger islands, which results in washout of nests.

The preference of American Black Oystercatchers to nest predominantly on islands with nesting Glaucous-winged Gulls appears to be a common phenomenon on the west coast as well as on the east coast of Vancouver Island. The presence of gulls may indicate to oystercatchers a site relatively safe from mammalian predators. Alarm calls of gulls can also serve as a warning of approaching predators. Both Hartwick (1974) and Nysewander (1977) suggested that the nesting of American Black Oystercatchers near gull nests reduced crow predation on the oystercatchers.

Islands on the west coast of Vancouver Island had a broader periphery of bare rock (particularly in the exposed Flores Island – Cape Beale region) than those in the Gulf Islands. This extensive periphery, on which oystercatchers nested, is likely the result of intensive wave action. Perhaps because of potential washout of nests by waves, oystercatchers nested on average farther from the high-tide line on the west coast than in the more sheltered Gulf Islands.

What materials oystercatchers used to construct their nests depended upon availability. White shell beaches were generally larger and more numerous on the west coast of Vancouver Island than in the Gulf Islands. Oystercatchers used white shells both as nesting material and as nesting substrate on the west coast. Solid grey rock, however, was the predominant nesting substrate there. White shell nest material on a grey rock substrate made oystercatcher nests very conspicuous to us and relatively easy to locate. Oystercatchers therefore did not seem to make adjustments in camouflaging nests in that regard. Fragments of California mussels *Mytilus californianus* were also commonly used as a nest material on the west coast, resulting in a light blue nest colour. California mussels were uncommon in the Gulf Islands, whereas another smaller species, the blue mussel *M. edulis*, predominated there. Oystercatchers in the Gulf Islands used blue mussels only sparingly as a nest material.

6.3 Egg laying and reproductive success

Hartwick (1974) collected information on egg laying of American Black Oystercatchers on Cleland Island during 1970–72. We calculated from Hartwick's data that the mean and median laying dates, respectively, fell on 7 June ± 11.3 days and 7 June in 1970, on 5 June ± 11.5 days and 4 June in 1971, and on 31 May ± 17.5 days and 27 May in 1972. L'Hyver (1985) reported mean and median dates, respectively, falling on 2 June ± 11 days and 29 May in 1982 and on 30 May ± 12.8 days and 1 June in 1983. Oystercatchers therefore started laying earlier in 1989 than in 1970–72 and in 1982–83.

The average clutch size on Cleland Island from 1970 to 1978 was consistently lower than that found in 1989 (Table 9). Hatching success of oystercatchers on Cleland Island ranged from 25% in 1971 to 46% in 1972 (Hartwick 1974) and from 37% in 1982 to 29% in 1983 (L'Hyver 1985), so that the observed hatching success of 39% in 1989 was well within that range. From the above comparisons, it appears that neither the timing of breeding nor hatching success of oystercatchers on Cleland Island in 1989 was adversely affected by the *Nestucca* oil spill.

The reproductive output of American Black Oystercatchers on Cleland Island was low in all years studied compared with that observed by Drent et al. (1964) on Halibut, Imrie, and Mandarte islands in the Gulf Islands and on Race Rocks in Juan de Fuca Strait (Table 9). The two main factors responsible for the low reproductive success on Cleland Island appear to be predation and washouts of nests by waves (Hartwick 1974; Groves 1982; this study). Predation was almost certainly the most important mortality factor in this study, but predators were not identified. Hartwick (1974) and Groves (1982) identified Northwestern Crows *Corvus caurinus* and Glaucous-winged Gulls as predators of eggs and chicks of oystercatchers on Cleland Island, but these authors did not quantify predation. Crows were rarely seen on Cleland Island in 1989, hence we

Table 9
Comparison of reproductive success of American Black Oystercatchers in British Columbia

Location	Year	No. of breeding pairs	No. of clutches	No. of eggs	Mean clutch size	% of eggs hatched	Chicks fledged/ pair	Reference
Cleland Island	1970	56	60	117	1.95	34	0.27	Hartwick 1974
	1971	57	59	120	2.03	25	0.19	Hartwick 1974
	1972	42	48	102	2.13	46	0.31	Hartwick 1974
	1976	–	54	115	2.13	–	0.15[a]	Groves 1982
	1978	–	60	118	1.97	–	0.15[a]	Groves 1982
	1982	39	52	107	2.06 [b]	37	–	L'Hyver 1985
	1983	35	44	94	2.14 [b]	29	–	L'Hyver 1985
	1989	35	33	74	2.24	39	–	This study
Race Rocks	1956–60	–	16	38	2.38 [c]	71	–	Drent et al. 1964
Halibut, Imrie, Mandarte islands	1957–61	10	–	–	–	–	0.70	Drent et al. 1964

[a] 0.15 chicks fledged/clutch.
[b] L'Hyver (1985) gave a mean clutch size of 2.24 eggs (N = 37) in 1982 and 2.08 eggs (N = 38) in 1983.
[c] Drent et al. (1964) gave a mean clutch size of 2.6 eggs for 28 first clutches from Halibut, Imrie, and Mandarte islands and Race Rocks.

believe they were not significant predators that year. We found no evidence of mammalian predation either. That leaves the Glaucous-winged Gull as a possible major predator.

The nesting population of Glaucous-winged Gulls on Cleland Island increased from about 500 pairs in 1967 (Campbell and Stirling 1967) to about 1500 pairs in 1974–75 (Campbell 1976) and to 1694 pairs in 1989 (Vermeer, Morgan, and Ewins, this volume). At present, the nests of oystercatchers on Cleland Island are surrounded by those of gulls (indeed, we found oystercatcher nests in much closer proximity to gull nests than on any other island in the study region). Conflicts between gulls and oystercatchers, which were commonplace on Cleland Island in the 1970s (Hartwick 1974), have likely increased as a result of higher nesting densities of gulls. Gull predation on oystercatchers may also have increased. Because space is at a premium on Cleland Island, American Black Oystercatchers may face a trade-off there between nest protection from gull attacks on wandering predators and egg and chick losses due to territorial activities of gulls (or a small number of specialist egg predators). Some oystercatchers may be forced, by the increasing numbers of gulls, to nest closer to the high-tide line, where they become subject to washouts by wave action during storms.

7. Acknowledgements

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Marbled Murrelet activity patterns in the Carmanah Valley on the southwest coast of Vancouver Island

Irene Manley, Robyn Shortt, and Alan E. Burger

1. Abstract

Inland observations of Marbled Murrelets *Brachyramphus marmoratus* were made in the Carmanah Valley on the southwest coast of Vancouver Island during the summer of 1990. Murrelets were detected at all sites along Carmanah Creek, but activity declined with increasing distance from the ocean. Murrelets were detected more frequently in the morning than in the evening and were most active in the 40 minutes before sunrise. Cloud cover was associated with a delay in the start and length of activity. Auditory detections made up 25% of all detections and were most frequent before dawn. Murrelet activity reached its peak in late June and ceased by August. Murrelets were most frequently detected as single birds or in pairs, but the frequency of larger groups increased near the end of the season. A brief description of the first two Marbled Murrelet nests found in British Columbia (both in the Walbran Valley) is given.

2. Résumé

Au cours de l'été 1990, des observations de l'Alque marbrée *Brachyramphus marmoratus* à l'intérieur des terres ont été effectuées dans la vallée Carmanah, sur la côte sud-ouest de l'île de Vancouver. La présence d'alques a été constatée partout le long du ruisseau Carmanah, mais leur activité était inversement proportionnelle à leur distance de l'océan. Les alques se manifestaient plus souvent le matin que le soir, et elles étaient le plus actives dans les 40 minutes précédant le lever du soleil. Par temps couvert, leur période d'activité était moins longue et débutait plus tard. Dans 25 % des cas, les alques se manifestaient par leurs cris, le plus fréquemment avant l'aube. Leur activité a atteint son maximum vers la fin de juin et cessé en août. Les alques ont été le plus souvent aperçues seules ou en couples, mais leur présence en groupes plus importants s'est intensifiée vers la fin de la saison. Une brève description des deux premiers nids d'Alques marbrées découverts en Colombie-Britannique (dans la vallée Walbran) est présentée.

3. Introduction

Marbled Murrelets *Brachyramphus marmoratus* are found along the west coast of North America from the Aleutian Islands to central California. Although they are frequently encountered far from marine areas during the breeding season (Rodway 1990), their activity and behaviour inland have not been well described. Of the 23 Marbled Murrelet nests found in North America, all 20 south of Alaska have been in trees in old-growth, temperate rain forests (Marshall 1988; Rodway 1990; Singer et al. 1991).

This paper describes research undertaken to determine the extent and character of Marbled Murrelet use of the Carmanah Valley, British Columbia. The Carmanah Valley is a 6700-ha watershed drained by Carmanah Creek (23 km long) and situated on the west coast of southern Vancouver Island (Fig. 1). The lower portion of the watershed is contained within the Carmanah Pacific Provincial Park reserve, and the creek mouth falls within Pacific Rim National Park. The watershed is 40 km south of Barkley Sound, an important foraging area for murrelets during their breeding season (Carter 1984).

This valley contains extensive groves of mature Sitka spruce *Picea sitchensis*, western hemlock *Tsuga heterophylla*, and western red cedar *Thuja plicata*, which are thought to be suitable nesting habitat for Marbled Murrelets. Preliminary surveys in 1989 by Canadian Wildlife Service personnel documented a high number of murrelet detections in the lower Carmanah Valley (Rodway 1990). The apparent high density of murrelets and concern over potential loss of murrelet habitat through logging prompted the present study.

4. Methods

Murrelet activity (or detections) at dawn and/or dusk was monitored as the birds flew over the forest. Detections were defined as "the sighting and/or hearing of a single bird or a flock of birds acting in a similar manner" (Paton et al. 1990). Morning observations started 45 minutes before sunrise and continued after sunrise for 30 minutes after activity had ceased. Evening surveys began approximately 30 minutes before sunset and averaged one hour. From 28 May until 27 August 1990, 83 surveys were conducted at 17 different sites.

Survey sites are shown in Figure 1. Most effort focused on the upper valley (sites b–e). The majority of sites were in or near the creek bed, which afforded better visibility of the sky. In addition, observations were made in the forest, where murrelets were observed entering trees. Observations were also made in a 167-ha clear-cut (site a), near the Carmanah headwaters.

The data recorded included time of detection, number of calls, number of birds seen, the type of flight path, and the height and direction of the birds' flight. Although most of the surveys were conducted by solitary researchers, observations on two mornings (7 and 8 July 1990) were made simultaneously at six sites spread along the valley (Fig. 1).

5. Results

5.1 Daily activity

Murrelets were detected more frequently in the morning (203 times) than in the evening (28 times). On the nine

Figure 1
Survey locations in the Carmanah Valley

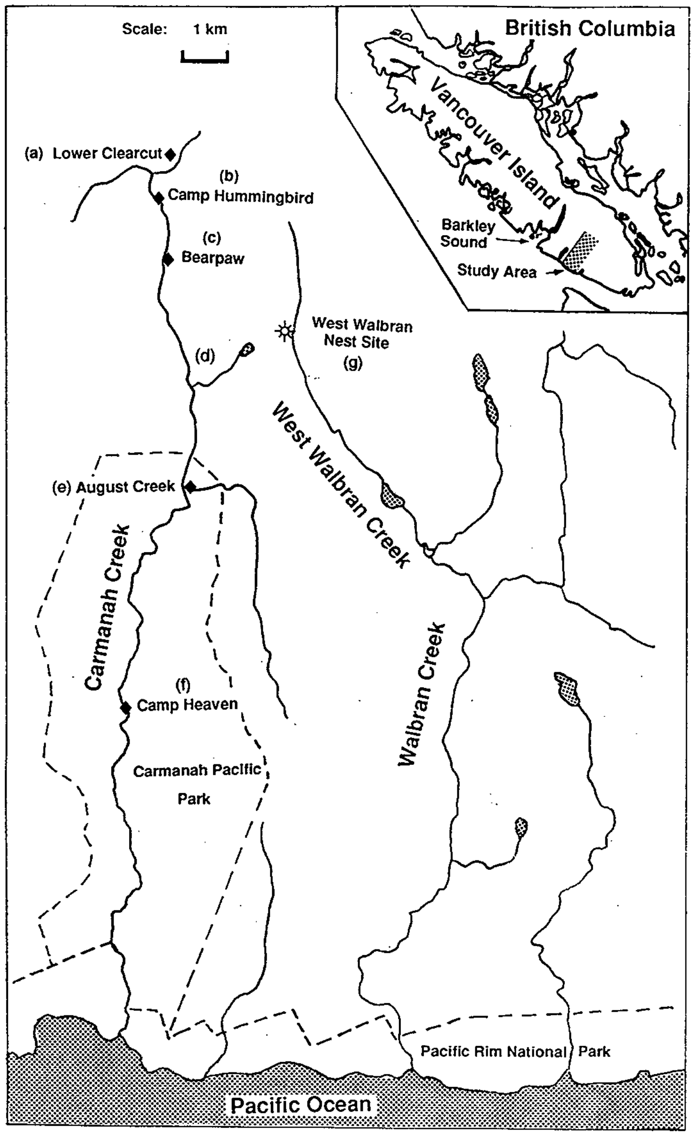


Figure 2
Frequency of detections before and after sunrise on clear (<80% cloud cover) and cloudy (>80% cloud cover) days at all sites along Carmanah Creek, 28 May – 27 August 1990

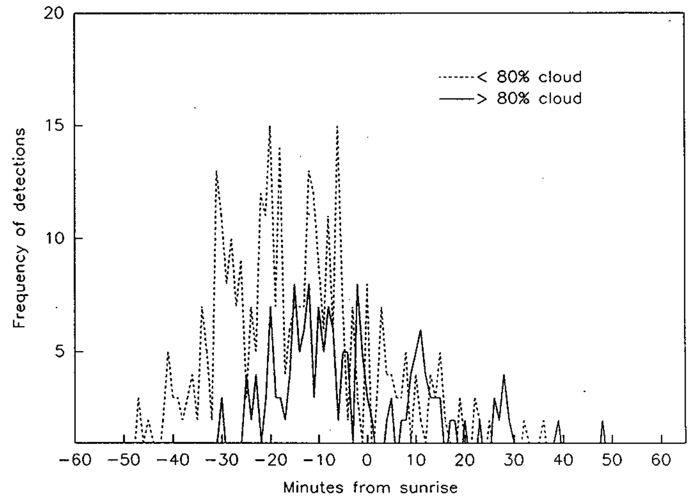
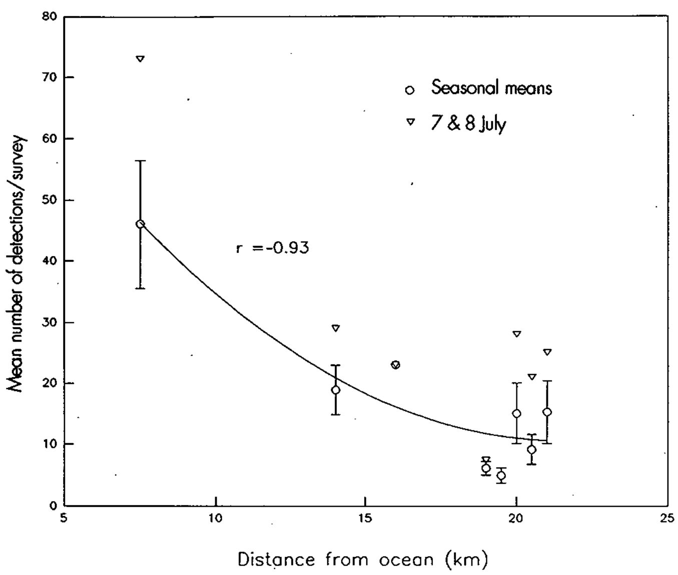


Figure 3
Mean number of detections per survey at sites along the Carmanah Valley from the clear-cut at 21 km from the ocean to Camp Heaven at 7 km from the ocean, 28 May – 30 July 1990. Bars show standard error, numerals indicate the number of surveys, and the line was produced by a second-order regression of the means. Distances were measured along the creek bed.



occasions when both dawn and dusk surveys were conducted within a 24-hour period, the number of dusk detections averaged 16% of the total activity. Based on the low frequency of evening detections, we used only data from morning surveys in the analyses.

Detections along Carmanah Creek were observed to occur mainly between 50 minutes before and 50 minutes after sunrise (Fig. 2). Murrelet activity along Carmanah Creek occurred significantly earlier on clear days (<80% cloud cover) than on cloudy days (>80% cloud cover) ($\chi^2 = 90.25$, $P < 0.01$). On clear days, the majority of detections (80%) occurred between 40 minutes before and five minutes after sunrise (mode at six minutes before sunrise). On cloudy days, 80% of activity occurred between 23 minutes before and 21 minutes after sunrise (mode at two minutes after sunrise) (Fig. 2).

5.2 Spatial variation

There was a strong negative correlation ($r = -0.93$) between activity levels and distance from the ocean (Fig. 3). The mean number of detections per survey for site f (7.5 km inland) was more than twice as high as the mean for site b (20 km inland) (one-way ANOVA, $P < 0.001$). Data collected from these sites over a single 24-hour period (7 and 8 July 1990) were not significantly different from the seasonal means (Student's t-test $t = 1.39$, $P > 0.05$). Further analyses in this paper will consider only the upper Carmanah Valley, sites a–e.

5.3 Seasonal activity

Activity over the entire season was highly variable, with a mean coefficient of variation of 0.67. The peak in activity (25 June – 1 July) was approximately three times greater than activity recorded in any other period (Fig. 4). After 29 July, murrelets were seldom seen in the study area.

Figure 4
Mean number of detections per survey per week along upper Carmanah Creek, 28 May – 27 August 1990. The standard error and number of surveys per week are also shown.

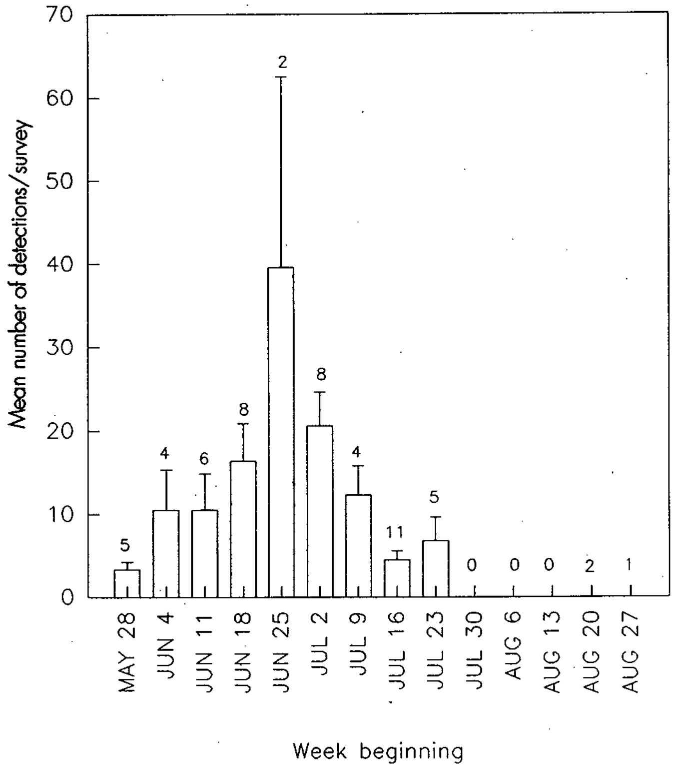
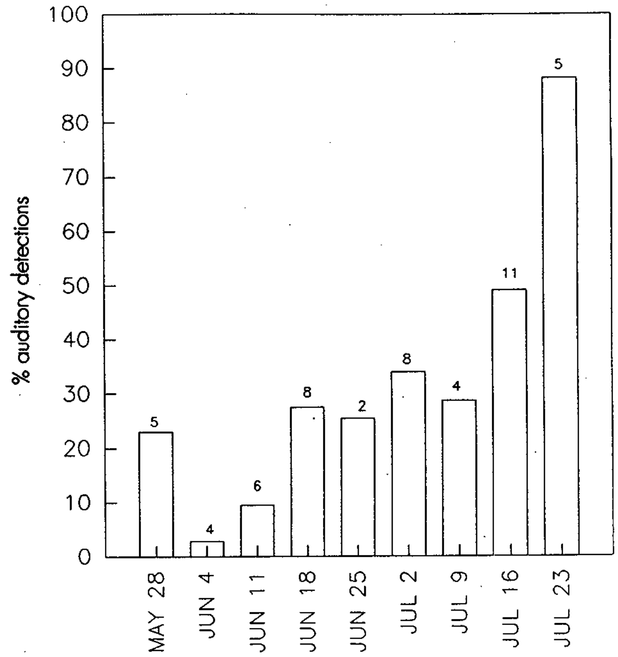


Figure 5
The percentage of auditory detections of Marbled Murrelets along upper Carmanah Creek, 28 May to 23 July 1990. The numeral above the bars indicates the number of surveys in that week.



5.4 Behaviour

5.4.1 Variation in detection type

In 1990, 68% of all detections made along Carmanah Creek were visual, 25% were auditory, and 7% were both. The frequencies of detections grouped in 20-minute intervals from 60 minutes before sunrise to 60 minutes after sunrise showed significant temporal variation ($\chi^2 = 63.62$, $P < 0.001$). Detections made earlier than 40 minutes before sunrise were predominantly auditory, whereas those made later in the morning were mostly visual.

The proportions of auditory and visual detections along Carmanah Creek showed seasonal variation (Fig. 5), with a significantly greater proportion of auditory detections later in the season ($\chi^2 = 205.58$, $P < 0.001$).

5.4.2 Variation in Marbled Murrelet flocks

Most detections were of single birds (39%) or pairs (44%), but groups of up to six birds were observed. Group size varied with time of day (Fig. 6): detections earlier than 20 minutes before dawn were largely single birds, whereas later observations included larger groups of murrelets ($\chi^2 = 35.25$, $P < 0.001$).

Group size also varied through the season ($\chi^2 = 21.6$, $P < 0.001$). Detections of single birds, although remaining the predominant type of detection, decreased proportionately as the season progressed, whereas the proportion of pairs increased (Fig. 7). Groups of four or more murrelets appeared after 17 June.

5.4.3 Observations made in the clear-cut

Eight morning surveys were conducted in the clear-cut at the headwaters of Carmanah Creek. The clear-cut area provided a wider view over the forest than the creek bed sites, and we analyzed these data separately. Generally, activity began later (34 minutes before sunrise) and continued longer (121 minutes after sunrise) in the clear-cut than along the creeks, both on cloudy and on clear days. Ninety percent of the detections made in the clear-cut were between 30 minutes before and 20 minutes after sunrise on clear days and between 10 minutes before and two hours after sunrise on cloudy days.

The highest number of detections recorded in the clear-cut occurred on 30 June, in the same week as the peak in activity observed along the creek. Twenty-three percent of all detections made in the clear-cut were auditory, 51% were visual, and 26% were both. Only 9% of all murrelets seen from the clear-cut were flying singly, 41% were flying in pairs, and 36% were observed in groups of four or more. From 28 May to 30 July, there was a significant decline in the proportion of detections of pairs and an increase in the proportion of single birds and birds in groups of three ($\chi^2 = 173.7$, $P < 0.001$).

5.5 Other indications of breeding activity

On five occasions, Marbled Murrelets were observed to land briefly in trees. Typically, these landings were characterized by a silent, straight, low approach and a similar exit after less than one minute. Two landings were in Sitka spruce trees, two in western red cedar, and one in a western hemlock. All of these trees were climbed, but no evidence of nesting could be found.

On 3 August 1990, an empty Marbled Murrelet nest was found in a 300-year-old Sitka spruce in the Walbran Valley, adjacent to and south of the Carmanah Valley (Fig. 1, site g). The nest was at 44 m on an 18-cm-diameter mossy branch, 3.4 m from the trunk. The depression was 12 cm across, surrounded by a ring of white droppings with a fishy odour, and contained shell fragments and down. In 1991, murrelet activity

Figure 6
Variations in group size with time of day along upper Carmanah Creek, 28 May – 30 July 1990. The numeral above the bars indicates the total number of detections (a) or birds (b) in that time period.

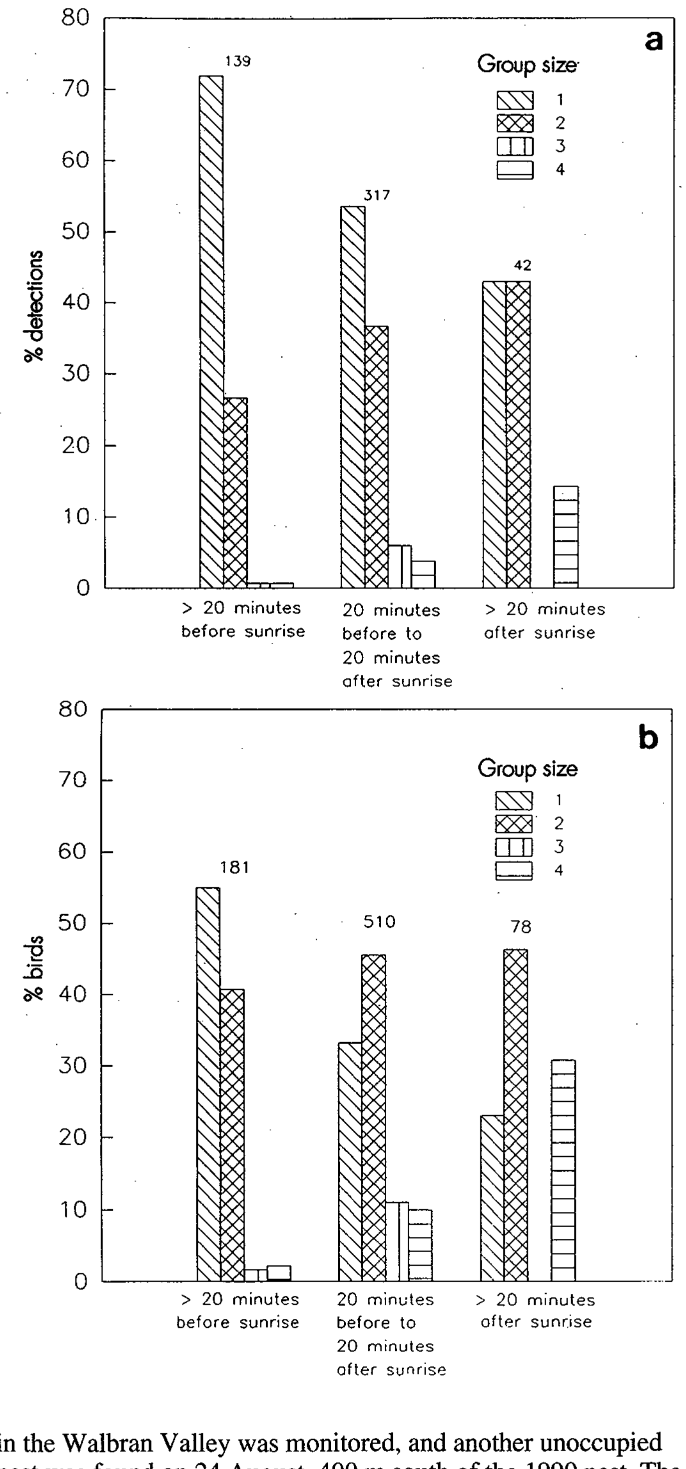
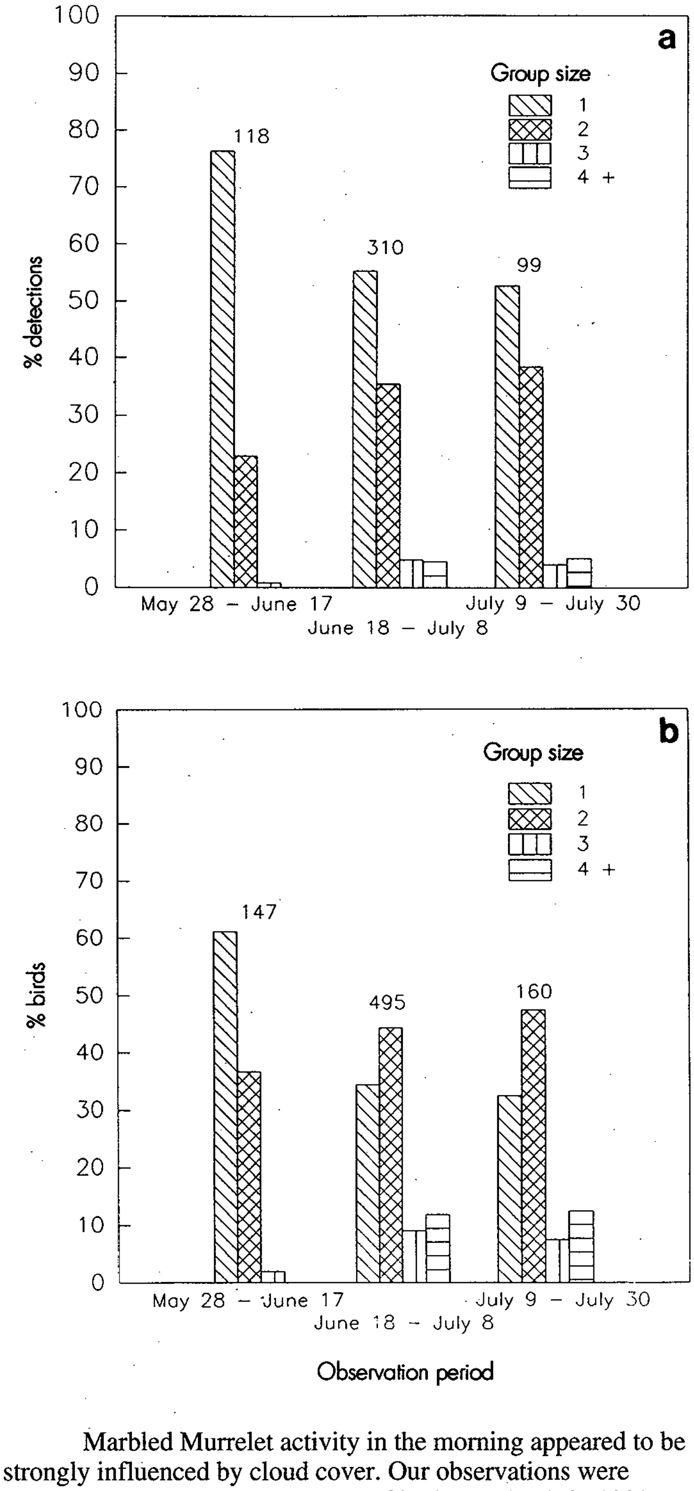


Figure 7
Group size among Marbled Murrelets observed from creek bed sites in upper Carmanah Creek, 28 May – 30 July 1990. The numeral above the bars indicates the total number of detections (a) or birds (b) in that time period.



in the Walbran Valley was monitored, and another unoccupied nest was found on 24 August, 400 m south of the 1990 nest. The 1991 nest was also in a large spruce tree and contained eggshells but no down.

6. Discussion

We observed little murrelet activity in the evenings. Studies elsewhere have also noted that morning activity tends to be greater than evening activity (Paton and Ralph 1988; Nelson 1989; Rodway et al. 1991). Auditory detections were scarce in the evening surveys, and the possibility remains that silent birds may be flying inland during darkness.

Marbled Murrelet activity in the morning appeared to be strongly influenced by cloud cover. Our observations were similar to those made in the Queen Charlotte Islands in 1990 (Rodway et al. 1991), with detections declining sharply five minutes after sunrise on clear days but continuing for approximately 30 minutes after sunrise on overcast days. The type of detection and the group size of murrelets also appeared to be influenced by the time of day. The high proportion of auditory detections earlier than 40 minutes before sunrise was likely due to the poor visibility at that time.

We observed a higher proportion of visual detections than has been noted elsewhere (Nelson 1989; Rodway et al. 1991), which may have been due to differences in the amount of visible sky or canopy opening. Detections of single birds were highest before dawn, but detections of groups of two or more continued well after dawn. Murrelets actively brooding or incubating chicks have been observed arriving and leaving singly before dawn (Singer et al. 1991). The larger groups of birds we observed after dawn may have represented prospecting or courting birds.

Our data showed a pronounced seasonal peak of detections (Fig. 4). Rodway et al. (1991) noted a similar peak in activity in the last week of June in the Queen Charlotte Islands. In contrast, Paton and Ralph (1988) and Nelson (1989) noted maximum activity in California and Oregon in mid-July. This suggests that geographic location influences the pattern of seasonal behaviour. The high day-to-day variation in detection frequency that we observed has also been noted in other studies (Paton and Ralph 1988; Nelson 1989).

The cause of the seasonal peak of detections is not clear, and we suggest two possible explanations. First, peak detections may correspond with the time of fledging and an increase in activity levels in the resident breeding adults. Once their chicks fledge, the adults may become less secretive and more vocal and gregarious.

A second alternative is that an influx of Marbled Murrelets occurs in this area in late June. Systematic marine surveys conducted in nearby Barkley Sound in 1979 by Carter (1984) showed that Marbled Murrelet density on the water underwent a fivefold increase during the last week of June and the first week of July. Carter (1984) attributed this increase to an influx of nonbreeding birds, because it was larger than the two- to threefold increase that would be expected from the arrival of successful breeders and newly fledged chicks. There may thus have been an influx of nonbreeders and prospecting young adults to the forest and the coast. These birds might have been more vocal and gregarious than the established breeders, and this could account for the seasonal increase in group size and auditory detections over the Carmanah Valley.

It is important to understand the behaviour and breeding status of murrelets detected in morning surveys. The frequency of detections is commonly used as a measure of breeding activity in the forest (Rodway 1990). If a large proportion of detections at the seasonal peak is due to prospecting adults, failed breeders, or immature birds, then the true density and seasonality of active breeders would be much more difficult to estimate. Clearly, the behaviour of the birds flying over the forests needs to be investigated in detail.

Marbled Murrelets used the entire length of the Carmanah Valley as a flight corridor. The frequencies of detections tended to decline with increasing distance from the ocean. A simple linear pattern would be expected if nest sites were evenly distributed and the birds followed similar flight paths; detections in the lower valley would include those in transit to or from the upper valley. However, the observed pattern was not the simple linear one that might be expected for evenly distributed nests (Fig. 3). Some areas had higher levels of flight activity, which might correspond with higher nest densities. High numbers of detections, observations of tree landings, and other breeding activities all indicated that the upper Carmanah Valley contained a high density of murrelet nests.

The Walbran Valley nests were the first documented nests of Marbled Murrelets in British Columbia. Previous records of nesting activity in British Columbia have been nestlings recovered from fallen trees during logging and fledglings found on the forest floor in or near old-growth forests (Rodway 1990). The documentation of these nests provides further support for the use of large, old-growth trees as nesting sites in British Columbia.

7. Acknowledgements

We thank the many volunteers who helped with this study, particularly those associated with the University of Victoria, the Western Canada Wilderness Committee, and the Victoria Natural History Society. We also thank John Kelson for finding the two nests in the Walbran Valley and climbing many other trees in the process. Funding and logistical support were provided by the Wildlife Branch of the B.C. Ministry of Environment, Friends of Ecological Reserves, the Western Canada Wilderness Committee, and the University of Victoria.

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Part III

Distribution of marine and shoreline birds

Habitat analysis and co-occurrence of seabirds on the west coast of Vancouver Island

Kees Vermeer, Ken H. Morgan, and G.E. John Smith

1. Abstract

The distribution of pelagic birds on the west coast of Vancouver Island was related to physical and biological parameters and co-occurrence of bird species during spring, summer, and fall. Twenty-six significant correlations of pelagic birds with water depth, 31 with distance from land, 18 with surface salinity, and 20 with surface temperature were observed. Glaucous-winged *Larus glaucescens* and California *L. californicus* gulls were associated with fish boats and Fork-tailed Storm-Petrels *Oceanodroma furcata* with cetaceans. Common Murres *Uria aalge* correlated inversely with cetaceans. Many bird species co-occurred. The implications of those correlations and co-occurrences are discussed.

2. Résumé

La répartition des oiseaux pélagiques sur la côte ouest de l'île de Vancouver a été reliée à des paramètres physiques et biologiques ainsi qu'à la cooccurrence de différentes espèces d'oiseaux au printemps, à l'été et à l'automne. Les observations effectuées ont permis d'établir d'importantes corrélations entre les oiseaux pélagiques et la profondeur de l'eau (26), la distance à la terre (31), la salinité de la surface de l'eau (18) et la température de la surface de l'eau (20). Le Goéland à ailes grises *Larus glaucescens* et le Goéland de Californie *L. californicus* ont été associés aux bateaux de pêche, et le Pétrel à queue fourchue *Oceanodroma furcata* a été corrélé aux cétacés. Une corrélation inverse a été établie entre la Marmette de Troïl *Uria aalge* et les cétacés. De nombreuses espèces d'oiseaux étaient simultanément présentes. Les conséquences de ces corrélations et cooccurrences sont discutées.

3. Introduction

Before the mid-1970s, seabird biologists related the distribution of pelagic birds to sea surface water temperature alone (e.g., Ashmole 1971; Shuntov 1972); even in the 1980s, sea surface water temperature was considered one of the more important physical variables affecting the distribution of birds at sea (Briggs et al. 1987). Brown et al. (1975), Pocklington (1979), and Dunlop et al. (1988) related seabird assemblages to water types defined by sea surface water temperature and salinity. Several authors (e.g., Kinder et al. 1983; Vermeer and Rankin 1984; Briggs et al. 1987; Hayes and Baker 1989) statistically correlated seabird occurrence with sea surface water temperature, but we do not know of any study in which the occurrence of seabirds has been quantitatively related to sea surface water salinity. Other authors correlated the presence of pelagic bird species with water depth, distance from land (e.g., Kinder et al. 1983; Vermeer and Rankin 1984; Vermeer et al. 1989), and the presence of fish boats (e.g., Wahl and Heinemann 1979). Briggs et al. (1987) reported on the association between seabird species. Many authors reported on the association between seabirds and cetaceans (e.g., Bailey 1966; Jehl 1974; Gould 1974; Barton 1979; Harrison 1979; Jackson 1988), but there does not appear to be a statistical analysis of this association.

In this paper, we determine the relationships between the distribution of pelagic birds off the west coast of Vancouver Island and sea surface water temperature and salinity, distance from land, water depth, and presence of fishing boats, whales, and other bird species during three sequential seasons. The study was facilitated by six oceanographic cruises, which generally followed the same route off the west coast of Vancouver Island, in the Alaska Current and Upwelling Domains (see Favorite et al. 1976).

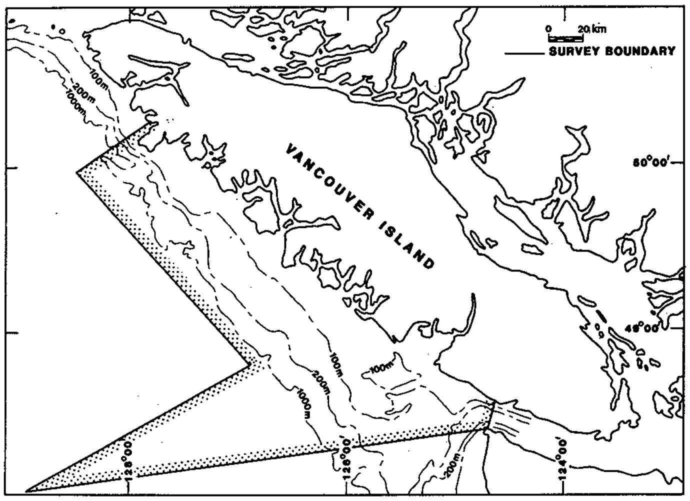
4. Methods

4.1 Bird surveys

Six pelagic bird surveys were conducted from a research vessel of the Institute of Ocean Sciences (Sidney) over the shelf, shelf break, and deep waters immediately beyond the shelf break (five cruises went to about 120 km from land, and one went to 281 km) off western Vancouver Island (Fig. 1) in spring (23–28 May, 14–23 June), summer (8–18 August, 23 August – 1 September), and fall (28 September – 4 October and 25 October – 2 November) of 1988. Observations were made during daylight hours when the ship was in motion and were not carried out in heavy fog, rain, or rough seas or when the vessel was within 5 km of Vancouver Island. The sea was scanned with 10 × 50 binoculars in a 180-degree field forward. Each transect lasted for a 10-minute period. In total, 1081 transects were made over a length of 3338 km. The research vessel travelled at 8–10 knots (15–19 km/h).

Because the research vessel followed approximately the same route during each of the six cruises, bird observations were frequently made on the same transects during spring, summer, and fall. Birds were mostly identified to species, but unidentified birds were counted as well. The sizes of large flocks were estimated because of the difficulty in counting individuals in a flock. Birds that approached and followed the ships, such as large gulls and albatrosses, were counted only once in a transect, and only once per three transects if they continued to follow the ship.

Figure 1
Area surveyed for pelagic birds off the west coast of Vancouver Island in the spring, summer, and fall of 1988



4.2 Measurements of physical parameters

Engine intake sea surface temperature (SST) and sea surface salinity (SSS), Loran-C coordinates of latitude and longitude, and time were continuously monitored on a SAIL (Sequential ASCII Interface Loop) system. The positions of all transects were plotted on 1:150 000 Canadian hydrographic charts. Mean SST and SSS values were calculated for each transect. Distances from land and water depth were calculated for each transect by using transect midpoints.

4.3 Analysis of bird distribution

The occurrence of the most numerous pelagic species—such as California *Larus californicus*, Glaucous-winged *L. glaucescens*, and Sabine's *Xema sabini* gulls, Sooty *Puffinus griseus*, Pink-footed *P. creatopus*, and Buller's *P. bulleri* shearwaters, Black-footed Albatrosses *Diomedea nigripes*, Northern Fulmars *Fulmarus glacialis*, Fork-tailed *Oceanodroma furcata* and Leach's *O. leucorhoa* storm-petrels, Common Murres *Uria aalge*, Cassin's Auklets *Ptychoramphus aleuticus*, Tufted Puffins *Fratercula cirrhata*, and Rhinoceros Auklets *Cerorhinca monocerata*—was analyzed with respect to the occurrence of other seabirds, distance from shore, water depth, SST, SSS, and the presence of fish boats and cetaceans. Transects on which fish boats (35) occurred were eliminated from the statistical analysis between bird occurrence and physical variables and from the analysis of bird species associations, as the presence of fish boats might introduce a bias in these relationships. Cetacean species encountered during the surveys were killer whales *Orcinus orca*, sperm whales *Physeter macrocephalus*, humpback whales *Megaptera novaeangliae*, short-finned pilot whales *Globicephala macrorhynchus*, Pacific white-sided dolphins *Lagenorhynchus obliquidens*, Risso's dolphins *Grampus griseus*, northern right whale dolphins *Lissodelphis borealis*, and Dall's porpoises *Phocoenoides dalli*.

For each transect, we also calculated the abundance (no. of birds/km) of each species. This measure was used rather than number of birds per unit area because it was difficult to tell how far away individual birds were or to establish a reliable measure of distance. We grouped the data from the transects according to three seasons: 384 transects (total length: 1155 km) were conducted in the spring (May–June), 375 transects (1189 km) in the summer (August–September), and 322 transects (994 km) in the fall (October–November).

4.4 Statistical analysis

The numbers of birds for each species were recorded by transect along with the habitat factors SSS, SST, mean ocean depth, and distance from shore. Initially, a chi-square test was conducted to determine if the presence of boats or cetaceans affected the bird counts. Three bird species were significantly correlated with boats and two species with cetaceans. No effect was discernible on the others. These two phenomena tended to make their own microenvironments, masking the influences of natural physical factors such as temperature, salinity, depth, and distance from shore. In the analysis of the data, these transects were omitted.

In the analysis, the frequency of occurrence of a species was defined by its presence (1) or absence (0) on all transects, regardless of the numbers of birds present. This was done because the numbers were extremely skewed—a few transects had very large numbers and the majority had none, making the data nonnormal and invalidating significance tests on the correlation coefficients. The transformation to zeros and ones gives the counts a binomial distribution that, for large sample sizes, makes the classical significance test for the correlation valid. For similar reasons, depths and distances were transformed using log transformations.

As large numbers of tests were made, we adjusted the significance level so that the overall type I error level was 0.05. For the results in Table 3, 14 species (including adults and immatures of two species) were each correlated with four habitat variables for each of three seasons for a total of 192 tests. Thus, we adjusted the significance level for individual correlations from 0.05 to 0.05/192, or 0.00026, so that the overall significance level would be 0.05. This resulted in a correlation coefficient of about 0.18 being significant. Similarly, in Table 4, 120 interspecific correlations were tested for each of three seasons, and we adjusted the individual significance level to 0.05/360, or 0.00014.

To obtain a pictorial representation of the tendency of various species to share the same habitats, dendrograms were produced for each season. To generate dendrograms, we used a similarity index based on the Pearson correlation between bird species. The index ([1 + correlation]/2) values were entered into a hierarchical average linkage cluster analysis. The average linkage distance between all species pair combinations was calculated to identify species groups; species with linkages less than the average were considered to be part of a group.

5. Results

5.1 Physical parameters

The relationship of SSS and SST with distance from land over the spring, summer, and fall is shown in Figure 2. SSS and SST are generally lower over the shelf and near land, and they increase in a curvilinear fashion away from land. A similar relationship was observed for SSS and SST with increasing water depth, which is not surprising, as depth generally increases with greater distance from land and as water depth and distance from land are highly correlated with one another (Table 1). Besides the curvilinear relationship of SSS and SST with distance from land, SSS was correlated with water depth in spring and with distance from land in summer and fall, whereas SST was correlated with water depth during summer and fall and with distance from land during all three seasons (Table 1).

Figure 2
Sea surface temperature (SST) and salinity (SSS) as related to distance off the west coast of Vancouver Island in the spring, summer, and fall of 1988

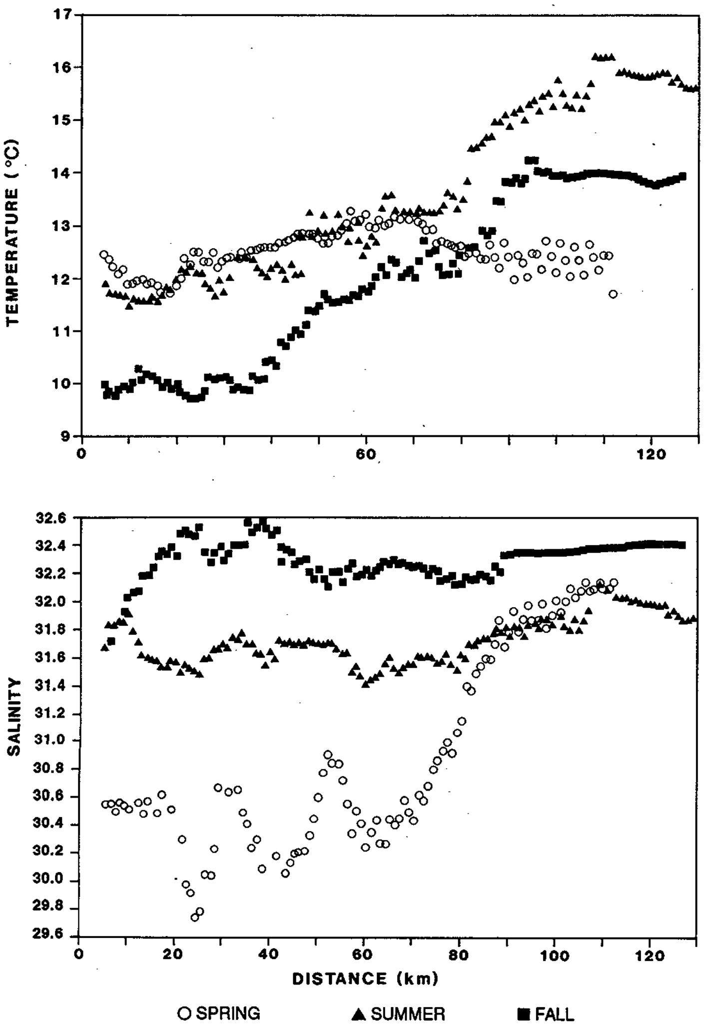


Table 1
Significant Pearson correlation coefficients between water depth, distance from land, SSS, and SST during spring (May–June), summer (August–September), and fall (October–November), 1988

	Log depth			Log distance		
	Spring	Summer	Fall	Spring	Summer	Fall
Log distance	0.70	0.77	0.73			
SSS	0.50	–	–	–	0.21	0.23
SST	–	0.71	0.80	0.30	0.80	0.74

5.2 Species abundance

The species that were most numerous in spring were Glaucous-winged Gulls, Sabine's Gulls, Sooty Shearwaters, Fork-tailed Storm-Petrels, and Cassin's Auklets. In summer, the most numerous species were California Gulls, Sooty Shearwaters, Leach's Storm-Petrels, Common Murres, and Cassin's Auklets. In fall, California Gulls, Northern Fulmars, Cassin's Auklets, and Common Murres were most numerous (Table 2).

5.3 Bird occurrence related to physical parameters

We observed 26 significant correlations of pelagic birds with water depth, 31 with distance from land, 18 with SSS, and 20 with SST (Table 3). Species that were observed to correlate positively with at least three of the four variables were Buller's Shearwaters, Black-footed Albatrosses, and Leach's Storm-Petrels; those correlating only inversely with those variables were Glaucous-winged and California gulls (both adults and immatures), Sooty Shearwaters, and Common Murres. Some species, such as Sabine's Gulls and Pink-footed Shearwaters, correlated positively with distance from land but negatively with water depth. Northern Fulmars, Fork-tailed Storm-Petrels, Cassin's Auklets, and Tufted Puffins correlated positively with one variable in one season but inversely with the same variable in the next season. The Rhinoceros Auklet was the only species that correlated positively with SSS and negatively with SST in the same season (Table 3).

5.4 Co-occurrence of bird species

Table 4 shows the results of the correlation analyses between species. Positive correlations occurred among the three gull species and between gulls and shearwaters. The three alcid species, Cassin's Auklet, Tufted Puffin, and Rhinoceros Auklet, correlated significantly with one another, but not with the fourth alcid, the Common Murre. Common Murres, however, were significantly associated with Glaucous-winged and California gulls and Sooty Shearwaters. Of the storm-petrels, Fork-tailed Storm-Petrels co-occurred with California and Sabine's gulls, Sooty and Pink-footed shearwaters, Black-footed Albatrosses, and Northern Fulmars, but only Leach's Storm-Petrels were significantly correlated with Fork-tailed Storm-Petrels and Buller's Shearwaters. Black-footed Albatrosses and Northern Fulmars were both significantly associated with one another and with Sabine's Gull, at least two of the three shearwater species, Fork-tailed Storm-Petrels, and Tufted Puffins.

Overall correlations of co-occurrence between species are depicted in Figure 3. Based on the significant correlations listed in Table 4 and the depicted linkages in Figure 3, four distinct species groups were discernible in spring, three in summer, and four in fall. The groups in spring were:

(1) Black-footed Albatross, Fork-tailed and Leach's storm-petrels, Cassin's and Rhinoceros auklets, and Tufted Puffin;
(2) adult and immature Glaucous-winged Gulls and Sooty Shearwater;
(3) Sabine's Gull and Buller's Shearwater; and
(4) adult and immature California Gulls.

The groups in summer consisted of:

(1) adult and immature California and Glaucous-winged gulls, Sabine's Gull, and Common Murre;
(2) Fork-tailed and Leach's storm-petrels, Buller's Shearwater, and Northern Fulmar; and
(3) Cassin's and Rhinoceros auklets, Tufted Puffin, Black-footed Albatross, and Pink-footed Shearwater.

The groups in fall were:

(1) adult and immature California Gulls, Sabine's Gull, Fork-tailed Storm-Petrel, and Pink-footed Shearwater;
(2) Rhinoceros Auklet and Tufted Puffin;
(3) Black-footed Albatross, Northern Fulmar, and Buller's Shearwater; and
(4) adult and immature Glaucous-winged Gulls and Common Murre.

Species co-occurrence (represented by significant correlations) changed considerably over the seasons, but similarities could be discerned. For example, the two age-groups of Glaucous-winged Gulls on the one hand, and those of California Gulls on the other, always occurred together in the three seasons. Other species that co-occurred in all seasons were Rhinoceros Auklets and Tufted Puffins. Besides the above species, ones co-occurring in spring and summer were:

Table 2
Numbers of pelagic birds observed and their abundance off the west coast of Vancouver Island on 384 transects (total length: 1155 km), 375 transects (1189 km), and 322 transects (994 km) during May–June, August–September, and October–November, 1988, respectively

	May–June		August–September		October–November	
Species	No. of birds	No. of birds/km	No. of birds	No. of birds/km	No. of birds	No. of birds/km
Adult Glaucous-winged Gull	935	0.81	321	0.27	374	0.38
Immature Glaucous-winged Gull	302	0.26	108	0.09	244	0.25
Adult California Gull	22	0.02	2 746	2.31	5 268	5.30
Immature California Gull	30	0.03	1 191	1.00	926	0.93
Sabine's Gull	504	0.44	428	0.36	194	0.20
Sooty Shearwater	8 939	7.74	4 878	4.10	582	0.59
Pink-footed Shearwater	122	0.11	389	0.33	17	0.02
Buller's Shearwater	4	0.00	113	0.10	114	0.12
Black-footed Albatross	290	0.25	162	0.14	143	0.14
Northern Fulmar	25	0.02	298	0.25	1 499	1.51
Fork-tailed Storm-Petrel	1 380	1.20	553	0.47	405	0.41
Leach's Storm-Petrel	150	0.13	963	0.81	7	0.01
Common Murre	357	0.31	1 265	1.06	1 599	1.61
Cassin's Auklet	830	0.72	1 451	1.22	1 392	1.40
Tufted Puffin	185	0.16	300	0.25	3	0.00
Rhinoceros Auklet	94	0.08	336	0.28	27	0.03
All birds[a]	14 898	12.90	21 371	17.98	17 432	17.54

[a] Includes all birds seen.

Table 3
Significant Pearson correlation coefficients between pelagic birds and water depth, distance from shore, SSS, and SST during spring (A), summer (B), and fall (C), 1988

Species	Season	Log depth	Log distance	SSS	SST
Adult Glaucous-winged Gull	A	–0.28	–0.26	–0.20	NS
	B	–0.45	–0.39	NS	–0.29
	C	–0.38	–0.48	NS	–0.40
Immature Glaucous-winged Gull	A	–0.19	–0.17	NS	NS
	B	–0.30	–0.24	NS	NS
	C	–0.24	–0.29	NS	–0.29
Adult California Gull	A	NS	NS	NS	NS
	B	–0.50	–0.30	–0.22	–0.21
	C	NS	–0.20	NS	NS
Immature California Gull	A	NS	NS	NS	NS
	B	–0.40	–0.22	–0.27	NS
	C	NS	NS	NS	NS
Sabine's Gull	A	NS	0.19	NS	NS
	B	–0.24	NS	NS	NS
	C	NS	0.18	NS	NS
Sooty Shearwater	A	NS	NS	NS	NS
	B	–0.50	–0.51	–0.29	–0.53
	C	–0.27	–0.18	NS	–0.24
Pink-footed Shearwater	A	NS	0.24	0.32	NS
	B	–0.20	NS	–0.21	–0.23
	C	NS	NS	NS	NS
Buller's Shearwater	A	NS	NS	NS	NS
	B	0.24	0.28	NS	0.26
	C	NS	0.18	NS	NS
Black-footed Albatross	A	0.27	0.35	0.17	NS
	B	NS	NS	NS	NS
	C	0.20	0.33	NS	0.31
Northern Fulmar	A	NS	NS	NS	NS
	B	–0.19	NS	–0.18	–0.24
	C	0.18	0.41	0.20	0.19
Fork-tailed Storm-Petrel	A	0.51	0.59	0.22	0.21
	B	NS	NS	–0.21	–0.19
	C	NS	0.25	NS	NS
Leach's Storm-Petrel	A	0.65	0.39	0.38	NS
	B	0.70	0.61	NS	0.57
	C	NS	NS	NS	NS
Common Murre	A	–0.19	–0.40	NS	NS
	B	–0.50	–0.57	NS	–0.37
	C	–0.56	–0.51	NS	–0.53
Cassin's Auklet	A	0.41	0.24	0.32	NS
	B	NS	–0.24	–0.29	–0.22
	C	NS	NS	NS	NS
Tufted Puffin	A	0.44	0.31	0.37	NS
	B	NS	–0.18	–0.25	–0.20
	C	NS	NS	NS	NS
Rhinoceros Auklet	A	0.22	NS	0.27	–0.19
	B	NS	NS	–0.32	NS
	C	NS	NS	NS	0.20

NS = not significant

(1) Cassin's Auklet, Rhinoceros Auklet, Tufted Puffin, and Black-footed Albatross;
(2) California Gull and Common Murre; and
(3) Fork-tailed and Leach's storm-petrels.

Species co-occurring in both summer and fall were:
(1) Sabine's and California gulls;
(2) Glaucous-winged Gull and Common Murre; and
(3) Buller's Shearwater and Northern Fulmar.

5.5 Relationships of birds with fish boats and cetaceans

The occurrence of immature Glaucous-winged Gulls as well as that of both adult and immature California Gulls were significantly correlated with the presence of fish boats (Table 5). Fork-tailed Storm-Petrels were positively, and Common Murres negatively, correlated with cetaceans.

6. Discussion

6.1 Species abundance

Sooty Shearwaters were the most numerous birds on the west coast of Vancouver Island in spring. Sooty Shearwaters generally arrive there in May, and Buller's and Pink-footed shearwaters arrive there in June (Vermeer et al. 1987a). Sooty and Buller's shearwaters are visitors from nesting colonies in New Zealand (the Sooty Shearwater perhaps also from colonies at Cape Horn), and Pink-footed Shearwaters from central Chile.

Table 4
Significant Pearson correlation coefficients between pelagic bird species off the west coast of Vancouver Island during spring (A), summer (B), and fall (C), 1988

Species	Season	GWGU Adult	GWGU Imm.	CAGU Adult	CAGU Imm.	SAGU	SOSH	PFSH	BUSH	BFAL	NOFU	FTSP	LESP	COMU	CAAU	TUPU
Immature Glaucous-winged Gull (GWGU Imm.)	A	0.38														
	B	0.54														
	C	0.29														
Adult California Gull (CAGU Adult)	A	NS	NS													
	B	0.59	0.55													
	C	NS	0.21													
Immature California Gull (CAGU Imm.)	A	NS	NS	0.23												
	B	0.49	0.49	0.74												
	C	NS	0.21	0.69												
Sabine's Gull (SAGU)	A	NS	0.22	NS	NS											
	B	0.26	0.20	0.36	0.34											
	C	NS	NS	0.38	0.36											
Sooty Shearwater (SOSH)	A	NS	NS	NS	NS	NS										
	B	0.25	0.19	0.28	0.33	0.20										
	C	0.23	NS	NS	NS	NS										
Pink-footed Shearwater (PFSH)	A	NS	NS	NS	NS	NS	NS									
	B	NS	NS	NS	NS	NS	0.30									
	C	NS	NS	0.21	0.26	NS	NS									
Buller's Shearwater (BUSH)	A	NS	NS	NS	NS	0.26	NS	NS								
	B	NS	NS	NS	NS	NS	NS	NS								
	C	NS	NS	0.21	0.27	0.18	NS	NS								
Black-footed Albatross (BFAL)	A	NS	NS	NS	NS	0.19	NS	NS	NS							
	B	-0.17	NS	-0.21	NS	NS	NS	0.28	NS							
	C	-0.23	NS	NS	NS	0.19	NS	NS	0.20							
Northern Fulmar (NOFU)	A	NS	NS	NS	NS	NS	NS	NS	NS	NS						
	B	NS	NS	NS	NS	NS	0.22	0.32	NS	0.27						
	C	-0.17	NS	NS	NS	0.17	NS	NS	0.21	0.33						
Fork-tailed Storm-Petrel (FTSP)	A	-0.21	NS	NS	NS	NS	NS	0.29	NS	0.45	NS					
	B	NS	NS	NS	NS	NS	0.18	0.18	NS	NS	0.42					
	C	NS	NS	0.28	0.34	0.49	NS	0.25	0.19	0.30	0.24					
Leach's Storm-Petrel (LESP)	A	-0.26	NS	NS	NS	NS	-0.26	NS	NS	NS	NS	0.28				
	B	-0.28	-0.18	-0.28	-0.32	-0.18	-0.42	-0.21	0.29	NS	-0.29	NS				
	C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS				
Common Murre (COMU)	A	NS	NS	NS	NS	NS	NS	NS	NS	-0.17	NS	-0.22	NS			
	B	0.44	0.30	0.34	0.26	NS	0.21	-0.19	NS	-0.18	-0.25	-0.18	-0.27			
	C	0.28	NS	NS	NS	NS	0.18	NS	NS	-0.26	-0.25	-0.20	NS			
Cassin's Auklet (CAAU)	A	NS	NS	NS	NS	NS	NS	NS	NS	0.24	NS	0.33	0.23	NS		
	B	NS	NS	NS	NS	NS	0.20	NS	NS	NS	NS	0.20	NS	NS		
	C	NS	NS	NS	0.18	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Tufted Puffin (TUPU)	A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.32	0.29	NS	0.21	
	B	NS	NS	NS	NS	NS	0.30	0.27	NS	0.31	0.26	NS	NS	NS	0.20	
	C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Rhinoceros Auklet (RHAU)	A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.17	0.23
	B	NS	NS	NS	NS	NS	0.24	0.17	NS	0.21	NS	0.23	NS	NS	0.25	0.38
	C	NS	NS	0.17	0.24	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

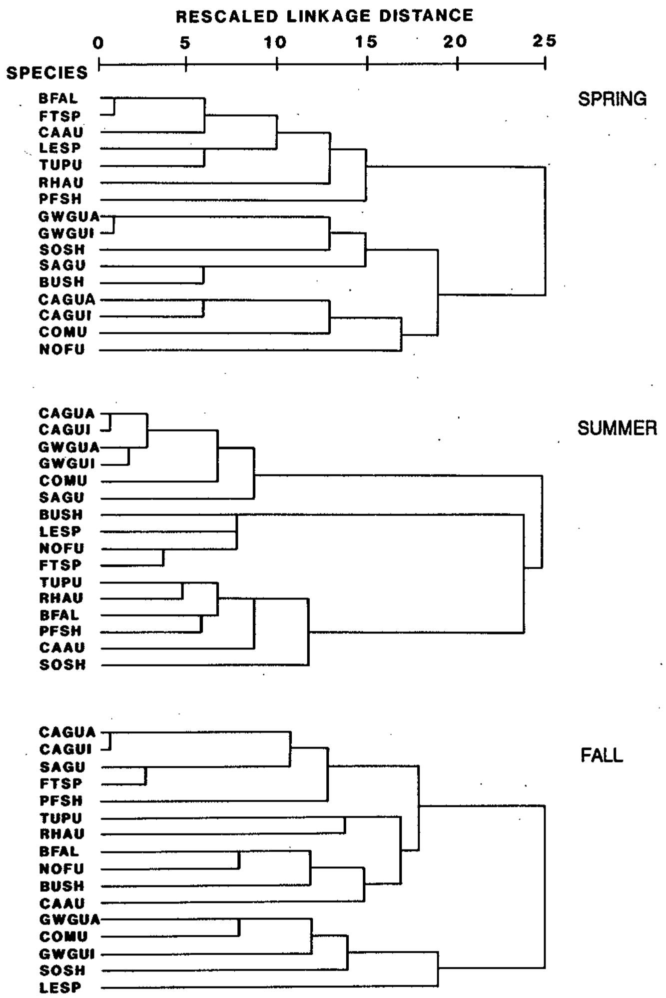
NS = not significant

Glaucous-winged Gulls were the most numerous gulls in spring; they are the only gulls nesting on the west coast of Vancouver Island and begin to occupy their nesting colonies at that time. By August, Glaucous-winged Gulls disperse from their colonies farther inshore. California Gulls are the most numerous birds on the west coast in late summer and fall (Vermeer et al. 1989). These gulls begin to arrive on the British Columbia coast in large numbers in July, mostly from colonies in the Canadian Prairie provinces, where they breed by the tens of thousands (Vermeer 1970). On the west coast, California Gulls feed extensively on fish offal and other organic matter discarded by trawlers (Vermeer et al. 1989). Sabine's Gulls are common off the west coast of Vancouver Island from spring through fall (Vermeer et al. 1987a). They are the most pelagic of all the gull species and visit the offshore waters and banks of Vancouver Island during their migration between Arctic nesting grounds and wintering quarters in Peru.

Northern Fulmars were most numerous in fall, as perhaps at that time they have dispersed from their nesting colonies in Alaska. In the fall, fulmars are attracted to the presence of many fish trawlers on the west coast. Fork-tailed and Leach's storm-petrels are numerous breeders on the British Columbia coast (Vermeer et al. 1983). That Fork-tailed Storm-Petrels were most numerous in spring and Leach's Storm-Petrels in summer may relate to their nesting chronology. The former start nesting in spring and the latter in summer (Vermeer et al. 1988). Both species feed offshore, but the two storm-petrels come inshore when visiting their nesting colonies. Leach's Storm-Petrels were less common in the surveyed region than Fork-tailed Storm-Petrels, perhaps as Leach's Storm-Petrels feed primarily beyond the shelf, whereas Fork-tailed Storm-Petrels inhabit the colder shelf waters (Gould 1983; Vermeer and Rankin 1984; Morgan et al. 1991).

That Cassin's Auklet was one of the two most numerously observed alcids is not surprising, as that species is the most abundant nesting seabird on the west coast (Vermeer et al. 1979, 1983). Common Murres are uncommon nesting alcids on the west coast of Vancouver Island, but their high densities at sea may be explained by their dispersal in late summer and fall from their large breeding colonies in Oregon to feed extensively upon Pacific herring *Clupea harengus pallasi* (Vermeer et al. 1987b, unpubl. data). Rhinoceros Auklets

Figure 3
Dendrograms showing the degree of co-occurrence of pelagic bird species off the west coast of Vancouver Island in the spring, summer, and fall of 1988 (see Table 4 for codes; A = adult, I = immature)



and Tufted Puffins were commonly observed. Those two alcids nest along the west coast of Vancouver Island as well as in northwestern Washington, immediately south of the study region.

6.2 Relationships with physical parameters

Different water types, as partially determined by SSS and SST, exist within the surveyed region. Inshore waters in the spring are characterized by much lower SSS than offshore waters (Fig. 1). Lower inshore SSS in spring probably reflects extensive freshwater runoff from British Columbia rivers. In the summer and fall, river runoff is much reduced, and there is less of a difference between inshore and offshore SSS. SST was much higher offshore than inshore in both summer and fall (Fig. 1).

Although we observed many significant correlations of birds with water depth, distance from land, SSS, and SST, we will not discuss individual correlations, as those variables frequently correlated with one another. Several combinations of correlations of variables that may represent water types containing certain prey communities are considered. Inverse correlations between birds and depth, distance from land, SSS, and SST suggest species that prefer to feed over inner shelf waters low in SSS and SST. Glaucous-winged and California gulls and Common Murres fall in that category. On the other hand, positive correlations between birds and the above four variables suggest species that prefer to feed in the warm, saline waters farther offshore. Buller's Shearwater, Black-footed Albatross, and Leach's Storm-Petrel are examples of the latter.

Table 5
Correlations between the presence of birds and both fish boats and cetaceans off the west coast of Vancouver Island, 1988

Species	Chi-square statistics: Birds/boats (35 transects with boats)	Birds/cetaceans (76 transects with cetaceans)
Adult Glaucous-winged Gull	5.64	2.61
Immature Glaucous-winged Gull	17.50 *	2.21
Adult California Gull	35.41 *	5.41
Immature California Gull	36.98 *	3.89
Sabine's Gull	3.33	6.23
Sooty Shearwater	7.53	1.36
Pink-footed Shearwater	1.53	1.50
Buller's Shearwater	0.16	1.11
Black-footed Albatross	0.36	1.42
Northern Fulmar	1.26	7.37
Fork-tailed Storm-Petrel	3.59	15.36 *
Leach's Storm-Petrel	4.22	1.80
Common Murre	1.93	10.65 *
Cassin's Auklet	0.40	0.69
Tufted Puffin	0.25	4.34
Rhinoceros Auklet	0.00	0.45

* $P < 0.05$

Sabine's Gull, Pink-footed Shearwater, Northern Fulmar, Fork-tailed Storm-Petrel, Cassin's Auklet, and Tufted Puffin fall somewhere between these two categories. Those species (other than Sabine's Gull) were associated with relatively cold and saline water in summer, at which time they were observed feeding over Swiftsure Bank, near Vancouver Island (Morgan et al. 1991). In other seasons, those species inhabited warmer and more saline waters at the outer shelf. Sabine's Gulls also fed over Swiftsure Bank in summer and in waters farther offshore in spring and fall, but we observed no correlation between that species and SSS or SST (Table 3).

Rhinoceros Auklets differed from the pattern of the above six species, in that they positively correlated with SSS but inversely with SST in spring (Table 3). We suggest that Rhinoceros Auklets probably foraged during the spring in areas of upwelling characterized by cold and highly saline surface waters. That Rhinoceros Auklets forage in such areas is supported by Vermeer (1979), who observed that Rhinoceros Auklets fed primarily upon bluethroat argentines *Nansenia candida*, a bathypelagic species that came to the sea surface in areas of upwelling on the west coast of Vancouver Island in the summer of 1978.

Different nesting populations of Rhinoceros Auklet have been observed to feed on different prey species at inshore and offshore locations during the same season. For example, the Pacific saury *Cololabis saira* is an abundant warm-water and offshore fish species (Inoue and Hughes 1971). In late summer, sauries were an important prey of Rhinoceros Auklets nesting on offshore Triangle Island at northwestern Vancouver Island, but not of those auklets nesting on islands surrounded by cooler inshore waters. Juvenile Pacific herring generally inhabit inshore waters near Vancouver Island and were a primary prey of Rhinoceros Auklets nesting inshore (Vermeer and Westrheim 1984).

6.3 Co-occurrence of bird species

Different seabird species may be attracted to the same water types because of the presence of certain prey communities. Birds may feed either on the same prey or on different organisms within the same communities. For example, although Rhinoceros Auklets and Tufted Puffins foraged on the same fish (sandlance, rockfish, sauries) in the same water types (Vermeer 1979), Cassin's Auklets, which also occurred there, primarily fed on the copepod *Neocalanus cristatus* and on the euphausiids *Thysanoessa spinifera* and *Euphausia pacifica* off the west coast of Vancouver Island (Vermeer 1981, 1984).

In addition to the attraction of seabirds to water types, mixed-species flocks develop in response to localized food concentrations. For example, mixed feeding flocks (primarily Common Murre and California and Glaucous-winged gulls) were frequently observed over the inner shelf in summer, where they probably fed upon Pacific herring (Vermeer 1982; Vermeer et al. 1989). Chilton and Sealy (1987) suggested that Common Murres enhance the foraging of surface-feeding gulls, as the diving murres concentrated fish schools near the surface. In the fall, Common Murres and Glaucous-winged Gulls still co-occurred over the inner shelf, but not in association with California Gulls, perhaps as the latter fed farther seaward on offal near trawlers and on Pacific sauries near fishing vessels at night (Vermeer et al. 1989).

Leach's Storm-Petrel is a well-known forager of the open ocean and shelf break, whereas the Fork-tailed Storm-Petrel feeds mainly over the shelf and shelf break (Vermeer and Rankin 1984; Vermeer et al. 1988) and, to a lesser extent, over the open ocean. Fork-tailed and Leach's storm-petrels were observed to co-occur mainly over the shelf break (Morgan et al. 1991), where both species may feed on similar foods, such as *Paracallisoma coecus* amphipods and myctophid fish (Vermeer et al. 1988). Black-footed Albatrosses, Buller's Shearwaters, and Northern Fulmars generally co-occurred with both storm-petrel species at the shelf break (Morgan et al. 1991). Little information exists on the diet of Black-footed Albatrosses and Buller's Shearwaters off British Columbia, whereas the diet of fulmars appears to consist chiefly of squid inhabiting waters at and beyond the shelf break (Vermeer et al. 1989).

Sooty Shearwaters are known to feed upon Pacific herring over banks of the inner shelf (KV, unpubl. data), as well as on Pacific sauries farther offshore (Chu 1984). The feeding of Sooty Shearwaters on both herring and sauries may explain their co-occurrence with both typical inshore (e.g., Common Murres, Glaucous-winged Gulls) as well as farther offshore (e.g., Northern Fulmars, Pink-footed Shearwaters) foraging birds. No information exists on the diet of Pink-footed Shearwaters off British Columbia.

6.4 Relationship of birds with fish boats and cetaceans

California Gulls were observed to be the dominant species at every foreign fishing vessel off the west coast of Vancouver Island (Vermeer et al. 1989) and off Washington (Wahl and Heinemann 1979) in the fall. Hence, it is no surprise that the occurrence of that species was highly correlated with that of fish boats. Many Glaucous-winged Gulls also fed near fish boats off Vancouver Island, but they were much less numerous than California Gulls. Of the Glaucous-winged Gulls near boats, immatures predominated. A possible reason is that immatures have difficulty competing with adults near shore and may seek out fish boats farther offshore. Sanger (1973) and Harrington (1975) observed that immature Glaucous-winged Gulls occurred somewhat more seaward than adults.

Many gull species have been observed to be associated with fishing vessels. Wahl and Heinemann (1979) reported significant correlations between fishing vessels and California, Glaucous-winged, Western *Larus occidentalis*, and even Sabine's gulls off Washington.

Significant correlations between seabirds and cetaceans undoubtedly reflect feeding relationships like those between seabirds and fish boats. We observed that Fork-tailed Storm-Petrels significantly co-occurred with Dall's porpoises and humpback whales, the two most numerous cetaceans encountered. Because Fork-tailed Storm-Petrels, Dall's porpoises, and humpback whales feed upon both plankton and fish (Leatherwood and Reeves 1983; Vermeer and Devito 1988), their association may be the result of porpoises or whales bringing prey to the surface. The inverse correlation between Common Murres and cetaceans suggests that murres either avoid cetaceans or feed in different habitats.

Many, if not all, seabirds probably feed opportunistically with cetaceans. Harrison (1979) reported that at least nine marine bird species fed upon food that was brought to the surface by gray whales *Eschrichtus robustus* in the northern Bering Sea. The Glaucous Gull *Larus hyperboreus* was the most prominent species, but phalaropes and auklets were also frequently seen near whales. Harrison's observations do not indicate, however, that the above seabirds were significantly associated with gray whales. One of the most frequent and numerous species we observed feeding in close proximity to cetaceans was the Sooty Shearwater. Many Sooty Shearwaters, however, also fed at other locations where no cetaceans were present; hence, no significant correlation was observed between Sooty Shearwaters and cetaceans.

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Marine bird populations and habitat use in a fjord on the west coast of Vancouver Island

Kees Vermeer and Ken H. Morgan

1. Abstract

Marine bird populations in Alberni Channel were surveyed monthly from September 1987 through August 1988. The number of birds was lowest in June and July (5–8 birds/km^2), increased in August, September, and October (28–54 birds/km^2), was highest from November through February (91–126 birds/km^2), and decreased again from March through early May (49–54 birds/km^2). The five most numerous species were Western Grebe *Aechmophorus occidentalis*, Surf Scoter *Melanitta perspicillata*, Barrow's Goldeneye *Bucephala islandica*, Glaucous-winged Gull *Larus glaucescens*, and California Gull *L. californicus*. Average densities of these species in the channel were 8.0, 26.3, 11.1, 12.8, and 7.7 birds/km^2, respectively. Birds occurred in six habitats at the following average densities (birds/km^2): open water (15.5), rocky shores without logs (76.4), rocky shores with logs (110.7), estuaries with bays (327.5), estuaries without bays (165.2), and bays without estuaries (125.8).

Bird numbers in Alberni Channel were compared with densities in other fjords and over the adjacent continental shelf. Composition and seasonal changes of marine birds in Alberni Channel generally reflected those in other British Columbia fjords, but not in Alaskan fjords, which are characterized by tidewater glaciers that have many nesting Black-legged Kittiwakes *Rissa tridactyla*. Observed differences and similarities in bird composition between Alberni Channel and the adjacent shelf are thought to result from differences in physical and chemical parameters, which in turn determine availability and type of prey.

2. Résumé

Les populations d'oiseaux de mer dans le chenal Alberni ont été dénombrées chaque mois de septembre 1987 à août 1988. Le nombre d'oiseaux était à son plus bas en juin et juillet (de 5 à 8 par km^2), a augmenté en août, septembre et octobre (de 28 à 54 par km^2), a atteint son maximum de novembre à février (de 91 à 126 par km^2) et a de nouveau diminué de mars au début de mai (de 49 à 54 par km^2). Les cinq espèces les plus nombreuses étaient le Grèbe élégant *Aechmophorus occidentalis*, la Macreuse à front blanc *Melanitta perspicillata*, le Garrot de Barrow *Bucephala islandica*, le Goéland à ailes grises *Larus glaucescens* et le Goéland de Californie *L. californicus*. Pour ces espèces, les densités moyennes de population étaient respectivement de 8,0, 26,3, 11,1, 12,8 et 7,7 individus par km^2. Les oiseaux fréquentaient six habitats, et leurs densités moyennes de population, exprimées en individus par km^2, étaient les suivantes: eau libre, 15,5; littoraux rocheux sans grumes, 76,4; littoraux rocheux avec grumes, 110,7; estuaires avec baies, 327,5; estuaires sans baies, 165,2, et baies sans estuaires, 125,8.

Les densités de population dans le chenal Alberni ont été comparées avec celles dans d'autres fjords et au-dessus du plateau continental adjacent. La composition et les changements saisonniers des populations d'oiseaux marins dans le chenal étaient généralement les mêmes que dans les autres fjords de la Colombie-Britannique, sauf dans ceux de l'Alaska, qui sont caractérisés par des glaciers de marée où nichent bon nombre de Mouettes tridactyles *Rissa tridactyla*. Les différences et les similitudes observées dans la composition des populations d'oiseaux entre le chenal Alberni et le plateau continental adjacent étaient probablement dues aux différences dans les paramètres physiques et chimiques qui, à leur tour, déterminaient l'accessibilité aux proies et leur type.

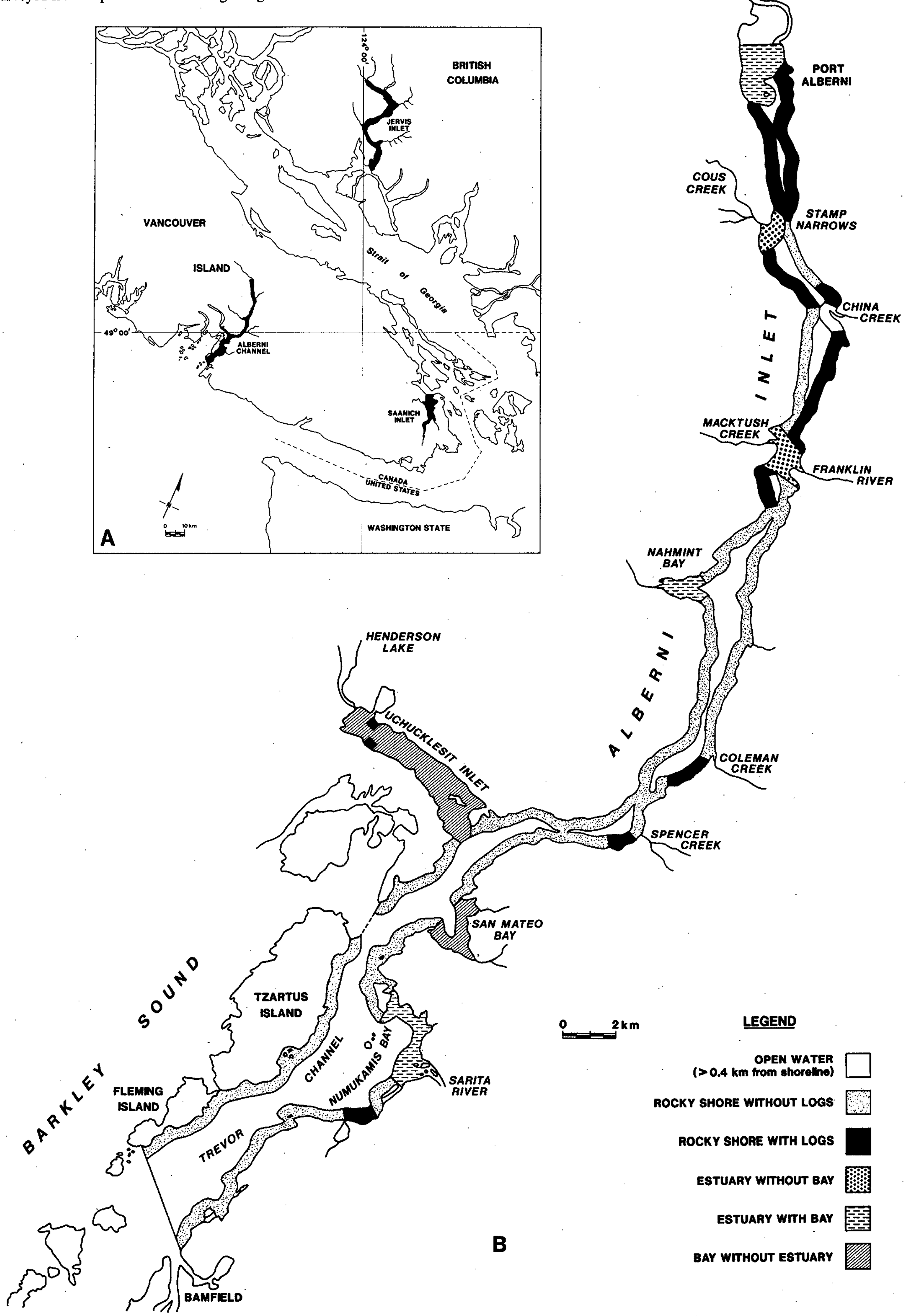
3. Introduction

Brown et al. (1975) reported on seabird use of several fjords in Chile, and Hogan and Irons (1988) on the use of a fjord in south-central Alaska. Hartley and Fisher (1936) and Lydersen et al. (1985) investigated the diet of seabirds in a fjord in Spitsbergen. No quantitative information appears to be available on bird populations inhabiting the extensive fjord systems in Norway (R.T. Barrett, Tromsö, Norway, pers. commun.). In British Columbia, however, detailed information is available on the seasonal use of two fjords by water bird populations. Morgan et al. (1987) investigated the seasonality and bird composition of Saanich Inlet, the only fjord on the east coast of Vancouver Island, over a nine-month period, and Vermeer (1989) surveyed the bird populations in Jervis Inlet, a mainland British Columbia deep fjord, during one year.

We investigated the water bird populations of Alberni Channel, a fjord on the west coast of Vancouver Island (Fig. 1). Our objectives were as follows:

(1) to determine seasonal changes in the composition of bird populations;
(2) to examine seasonal changes in habitat use by bird populations;
(3) to compare bird use of a fjord on the west coast of Vancouver Island with that of two Strait of Georgia fjords (Jervis and Saanich inlets, Fig. 1);
(4) to compare bird use of fjords with and without tidewater glaciers; and
(5) to compare bird use of the Alberni Channel with that of the adjacent continental shelf.

Figure 1
A. Location of three fjords—Alberni Channel and Jervis and Saanich inlets—where bird populations have been investigated in British Columbia.
B. Different habitats of Alberni Channel in which marine birds were surveyed from September 1987 through August 1988.



4. Description of study area

The study region consisted of Alberni Inlet and Trevor Channel, which together comprise a fjord entering the Pacific Ocean; we term it "Alberni Channel" (Fig. 1). Alberni Channel is the longest (55 km) of the 10 fjords on the west coast of Vancouver Island, and its waters generally average about 150 m in depth, with a maximum depth of 356 m. The channel is bordered by a forested shoreline. The Somass River enters at its head and forms a large delta of silt and mud in the channel. Other smaller deltas occur along the length of the channel. Estuaries are here defined as either "estuaries with a bay" or "estuaries without a bay," depending upon whether they are located within a bay or protrude directly into the channel. Two large bays without estuarine deltas, Uchucklesit Inlet and San Mateo Bay, enter Alberni Channel; they are termed "bays without estuaries." Most of the channel shoreline is rocky; the deltas constitute only about 9% of the surface area of the channel. Logs are stored extensively along the shoreline; these logs are processed in the Port Alberni Paper Mill located at the head of the channel.

The physical oceanography of British Columbia fjords has been described by Pickard (1961, 1963). The most significant influence determining the oceanographic character in Alberni Channel, as well as that in Jervis and Saanich inlets, is the freshwater runoff from rainfall. The greatest runoff occurs from late autumn to spring. The river runoff into Alberni Channel has its annual peak in winter, and there is a second, lesser peak in May. The shape and location of the channel and the inflow of fresh water that gives rise to the low-salinity surface layer identify the estuarine character of the channel.

5. Methods

Alberni Channel was surveyed by boat for one day, or two successive days, each month from September 1987 through August 1988. In May, the channel was surveyed twice. All marine birds on the water, along the shore, and in flight were counted in all portions and along the whole length of the channel (Appendix 1). The surveys began at the Somass River estuary and continued along the eastern shore to Bamfield near the channel mouth; the return route covered the other (western) shore back to the Somass River estuary. Each survey lasted about 12 hours during fall, spring, and winter and 6–8 hours, depending upon the number of birds present, in summer. The surveys were conducted at boat speeds ranging from 15 to 20 knots (28–37 km/h), with stops as necessary to count aggregated birds.

Alberni Channel was divided into six habitat types, consisting of the open water zone (the water surface beyond 0.4 km from the shoreline) and the following five coastal zones: rocky shores without logs, rocky shores with logs, estuaries with bays, estuaries without bays, and bays without estuaries. These divisions were effected to determine whether certain bird groups and species used shores with logs more than they did those without logs and estuaries with bays more than they did estuaries without bays or bays without estuaries. All birds were counted in the six habitats separately. The water surface area of the six habitats, as well as that of the total area of the channel, was measured with a planimeter on a 1:40 000-scale hydrographic chart of the channel (No. 3672). The surface areas of the six habitats are as follows: open water 42.0 km^2, rocky shores without logs 32.2 km^2, rocky shores with logs 12.6 km^2, bays without estuaries 8.4 km^2, estuaries with bays 6.5 km^2, and estuaries without bays 2.7 km^2, for a total of 104.4 km^2. Bird densities are shown as the numbers of birds per square kilometre of water surface area.

We also compared marine bird composition and species abundance in Alberni Channel with those found in Jervis and Saanich inlets and with those of the continental shelf off the channel mouth. Details on marine bird composition and on relative species abundance over the shelf in this area from March through November have been given by Vermeer et al. (1987).

6. Results

6.1 Seasonal changes in bird numbers and densities

The largest numbers and the highest densities of birds were seen from November through February. Numbers and densities were low in March through early May; they further dwindled to a small fraction of winter counts in late May through August (Table 1). Of the four major groups of birds found, waterfowl were most numerous from November through May, and gulls were most numerous from July through October (Fig. 2). Loons, grebes, cormorants, and auks were found in low numbers.

Seasonal variation in densities of the most numerous bird species seen in Alberni Channel is shown in Table 2. In the loon, grebe, and cormorant category, the Western Grebe *Aechmophorus occidentalis* was by far the most numerous species and had its highest densities from October through the beginning of May. Of the waterfowl, the Surf Scoter *Melanitta perspicillata* outnumbered all other waterfowl species combined and had its highest density from December through April. Barrow's Goldeneye *Bucephala islandica* was the next most numerous duck and had its highest densities from December through February. The three *Bucephala* species—Barrow's Goldeneye, Common Goldeneye *B. clangula*, and Bufflehead *B. albeola*—were among the last waterfowl species to arrive in the channel in the fall (Table 2).

Of the gulls, the California Gull *Larus californicus* was most numerous in late summer and early fall, whereas it was scarce or absent from December through the beginning of May. Thayer's Gull *L. thayeri* was seen from November through February. Two gull species, the Glaucous-winged Gull *L. glaucescens* and the Mew Gull *L. canus*, were present throughout the year. The Glaucous-winged Gull, which is the only gull that nests in the marine habitat of British Columbia, had its highest densities in the channel from September through February. This likely reflects the postbreeding dispersal from nesting colonies to Vancouver Island shores in August (Vermeer 1963). Of the auks, the Common Murre *Uria aalge* was the main species present. Murre populations were densest from October through March, but the Marbled Murrelet *Brachyramphus marmoratus*, which was the second most common auk, outnumbered murres in April and May.

6.2 Bird densities related to habitat

The largest habitats in Alberni Channel are open water and rocky shore zones with and without logs, comprising 83% of the total water habitat; the estuaries with and without bays and bays without estuaries make up the remaining 17%. The largest number of birds was observed along rocky shorelines without logs (Table 3). However, bird densities were higher along rocky shores with logs and in bays and estuaries, whereas the open water zone had the lowest densities. The higher density along rocky shores with logs than along those without was primarily the result of many gulls resting on logs (Fig. 3). Gulls and waterfowl in particular contributed to the high densities in

Table 1
Number of species, number of birds, and bird densities observed in Alberni Channel, September 1987 through August 1988

Month	No. of bird species	No. of birds	No. of birds/km^2
September	22	5 626	53.9
October	25	5 180	49.6
November	33	12 130	116.2
December	35	13 209	126.5
January	36	11 674	111.8
February	30	9 518	91.2
March	32	5 563	53.3
April	32	5 671	54.3
Early May	27	5 141	49.2
Late May	25	1 521	14.6
June	18	544	5.2
July	16	861	8.2
August	14	2 925	28.0

Figure 2
Seasonal changes in the composition of major groups of marine birds in Alberni Channel

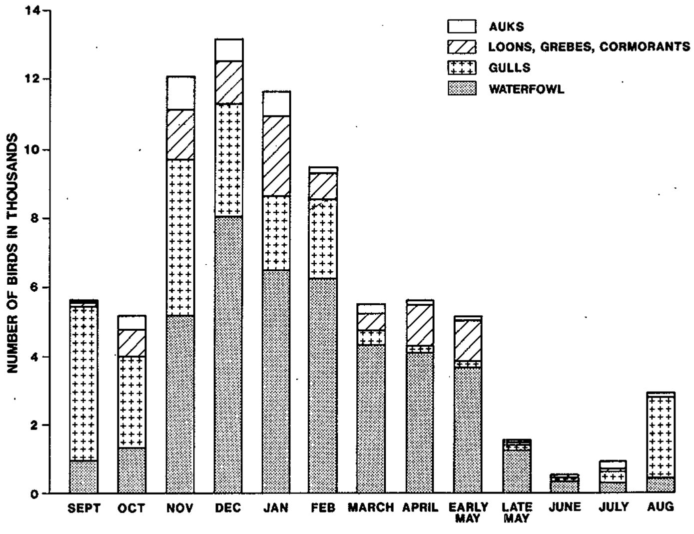


Table 2
Seasonal variation in densities of the 24 most common bird species observed in Alberni Channel from September 1987 through August 1988

Species	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	Early May	Late May	June	July	Aug.
	No. of birds/km^2 [a]												
Common Loon	0.01	0.15	0.19	0.26	0.14	0.10	0.14	0.28	0.29	0.09	0.17	0.03	0.03
Western Grebe	1.12	6.06	10.32	7.76	18.97	4.91	3.11	9.95	9.66	0.24	0.00	0.00	0.00
Red-necked Grebe	0.01	0.10	0.39	0.50	0.53	0.29	0.60	0.30	0.47	0.03	0.00	0.00	0.00
Horned Grebe	0.05	0.32	0.57	0.56	0.65	0.47	0.80	0.22	0.14	0.02	0.00	0.00	0.00
Double-crested Cormorant	0.07	0.08	1.02	0.71	0.39	0.51	0.42	0.14	0.11	0.00	0.04	0.02	0.03
Brandt's Cormorant	0.10	0.72	0.64	0.92	0.80	0.54	0.12	0.00	0.04	0.07	0.04	0.02	0.00
Pelagic Cormorant	0.09	0.20	1.01	1.18	0.89	0.58	1.04	1.06	0.49	0.22	0.11	0.10	0.01
Mallard	2.20	0.45	2.71	2.95	1.48	0.65	0.95	0.69	0.41	0.22	0.11	0.03	0.20
American Wigeon	1.99	0.57	1.84	0.10	0.11	0.00	0.28	0.81	0.00	0.00	0.00	0.00	0.00
Greater Scaup	0.00	0.24	0.54	0.16	0.46	0.99	1.08	0.93	1.49	0.22	0.00	0.00	0.00
White-winged Scoter	0.00	1.26	7.09	2.56	1.26	0.90	0.77	0.01	0.24	0.16	0.04	0.00	0.00
Surf Scoter	2.62	8.98	28.23	44.99	41.73	41.24	23.22	22.71	22.84	9.66	2.32	0.10	1.48
Barrow's Goldeneye	0.00	0.00	7.60	18.34	13.40	12.01	9.90	9.53	6.73	0.98	0.07	0.00	0.00
Common Goldeneye	0.00	0.00	0.07	0.69	0.47	0.53	0.44	0.46	0.15	0.01	0.00	0.00	0.00
Bufflehead	0.00	0.00	1.23	4.96	2.29	2.70	3.19	2.17	1.48	0.04	0.00	0.00	0.00
Common Merganser	0.93	0.78	0.05	0.13	0.27	0.18	0.93	1.10	1.44	0.44	0.47	1.75	2.16
Red-breasted Merganser	1.53	0.00	0.19	0.24	0.19	0.15	0.18	0.12	0.12	0.06	0.03	0.00	0.00
Glaucous-winged Gull	10.21	17.54	33.62	25.79	11.33	12.09	1.48	1.80	1.24	0.95	0.32	0.83	4.62
Mew Gull	2.64	0.99	3.65	3.59	1.74	6.41	2.35	0.19	0.53	0.45	0.16	0.01	0.11
Thayer's Gull	0.00	0.00	1.69	1.63	6.89	3.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
California Gull	29.89	4.97	2.50	0.02	0.00	0.00	0.00	0.01	0.00	0.11	0.45	2.57	18.17
Bonaparte's Gull	0.13	1.56	1.47	0.02	0.01	0.00	0.00	0.03	0.00	0.00	0.11	0.05	0.86
Common Murre	0.09	3.93	5.60	4.57	5.17	1.32	1.08	0.39	0.01	0.02	0.04	0.00	0.13
Marbled Murrelet	0.05	0.03	3.55	1.71	1.48	0.53	0.30	0.80	0.94	0.22	0.13	2.04	0.09

[a] Highest densities for each species are underlined.

estuaries with bays. Gull and waterfowl use of bays with estuaries was at least twice as great as that of either bays without estuaries or estuaries without bays (Fig. 3). Waterfowl utilized estuaries with and without bays to a greater extent than did any other bird group. Estuaries with bays showed bimodal use by waterfowl; the largest peak occurred in November through December, and a smaller one from March through May (Fig. 3).

The three most numerous waterfowl species—Surf Scoter, Barrow's Goldeneye, and Bufflehead—were the main users of estuaries (Fig. 4); Barrow's Goldeneye occurred in bays without estuaries much more than did the Bufflehead. Surf Scoters used bays with estuaries more than they did bays without estuaries and estuaries without bays combined. The Western Grebe also showed strong bimodal use of estuaries with bays (Fig. 5). The Western Grebe was the only species that occurred in higher densities in the open water zone than in the rocky shore zone without logs. The Common Murre was found in similar densities in open water and along rocky shores (Fig. 6). The Common Murre and Marbled Murrelet differed from gulls, grebes, and waterfowl in that they primarily used bays without estuaries (Fig. 6).

Average densities of the most common species present in Alberni Channel during maximal use from September through the beginning of May are compared in Table 4. Fourteen species had their highest densities in the estuaries with

Table 3
Comparison of average numbers and densities of birds recorded in different habitats in Alberni Channel during periods of highest utilization (September 1987 through early May 1988)

Habitat	Average no. of birds per survey (± SD)	Average no. of birds/km² (± SD)
Open water	652 ± 675	15.5 ± 16.1
Rocky shores without logs	2436 ± 1173	76.4 ± 35.7
Rocky shores with logs	1395 ± 845	110.7 ± 66.7
Bays without estuaries	1057 ± 640	125.8 ± 76.2
Estuaries with bays	2128 ± 1233	327.5 ± 189.8
Estuaries without bays	446 ± 177	165.2 ± 65.6

Figure 3
Seasonal changes in habitats used by gulls and waterfowl in Alberni Channel

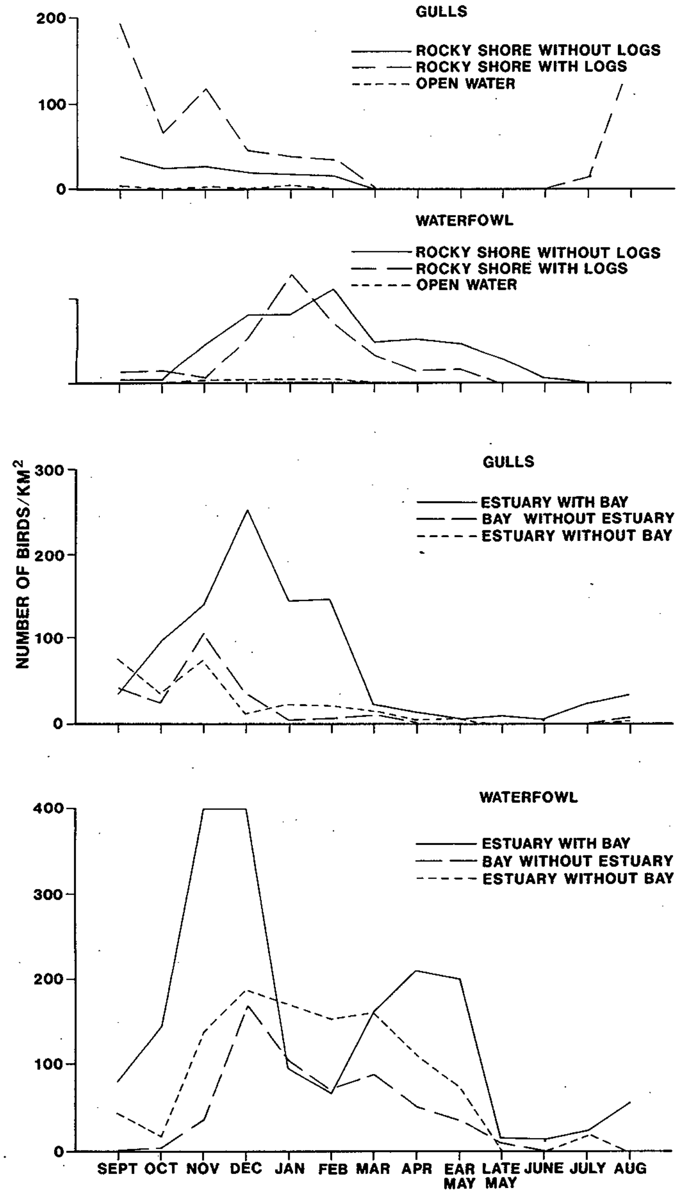
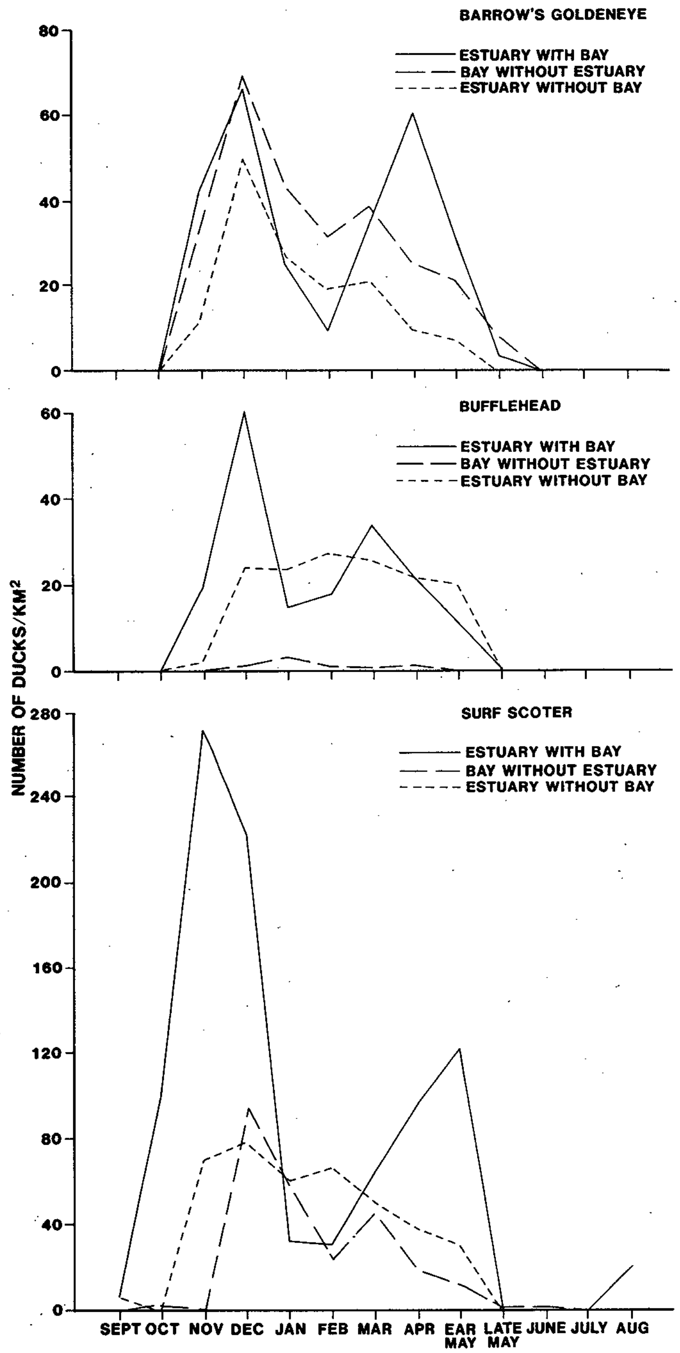


Figure 4
Seasonal changes in habitats used by Barrow's Goldeneyes, Buffleheads, and Surf Scoters in Alberni Channel



bays, six species in bays without estuaries, and four species in estuaries without bays; one species (the California Gull) had its highest density along rocky shores with logs. The relatively high densities in estuaries with or without bays compared with bays without estuaries—for Mallard *Anas platyrhynchos*, American Wigeon *A. americana*, Greater Scaup *Aythya marila*, Common Goldeneye, Bufflehead, Common Merganser *Mergus merganser*, and Red-breasted Merganser *M. serrator*—indicate that estuaries are more important habitats for these species than are sheltered bays. Relatively low densities of Brandt's Cormorant *Phalacrocorax penicillatus*, Common Murre, and Marbled Murrelet in estuaries with and without bays compared with bays without estuaries, on the other hand, suggest that bays constitute more important habitats for these species than do estuaries.

The open water zone of all habitats had the lowest bird densities for all species with the exception of Western Grebe. This is understandable, as intertidal and benthic foraging gulls and waterfowl and bottom-feeding piscivorous birds have little or no access to the deep fjord benthos (Vermeer 1981), whereas Western Grebes frequently prey on fish in the water column (Vermeer and Ydenberg 1989) and are therefore not restricted from feeding in open water.

Figure 5
Seasonal changes in habitats used by Western Grebes in Alberni Channel

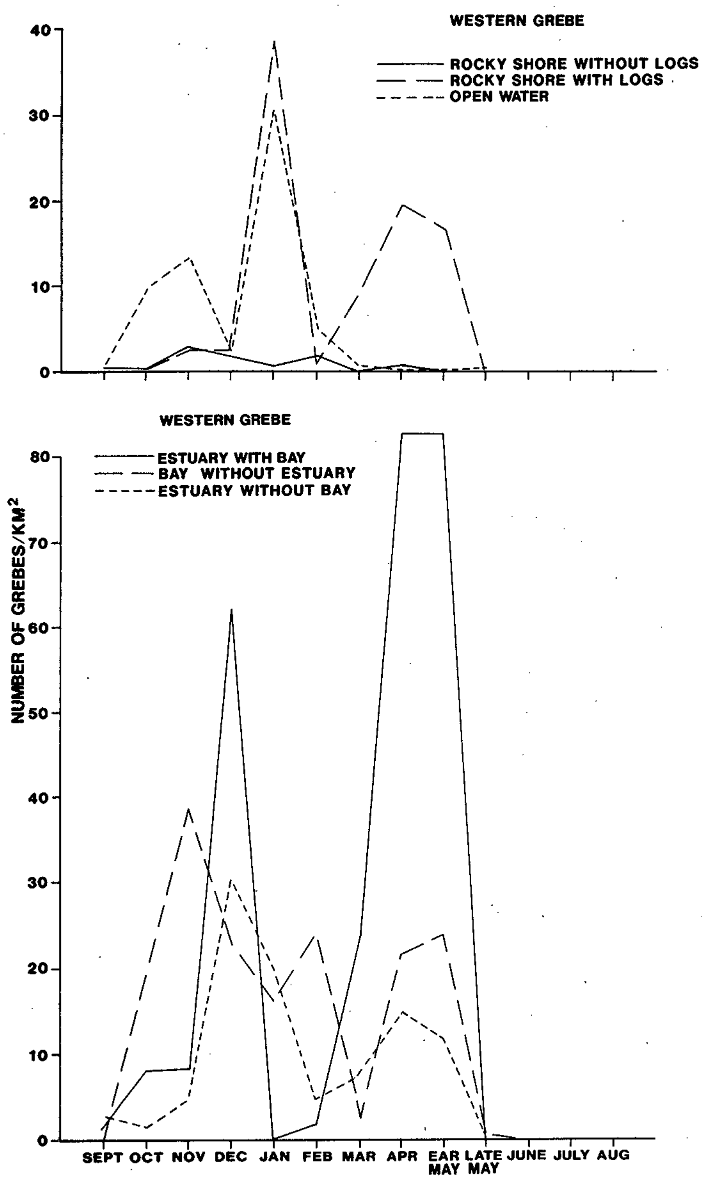
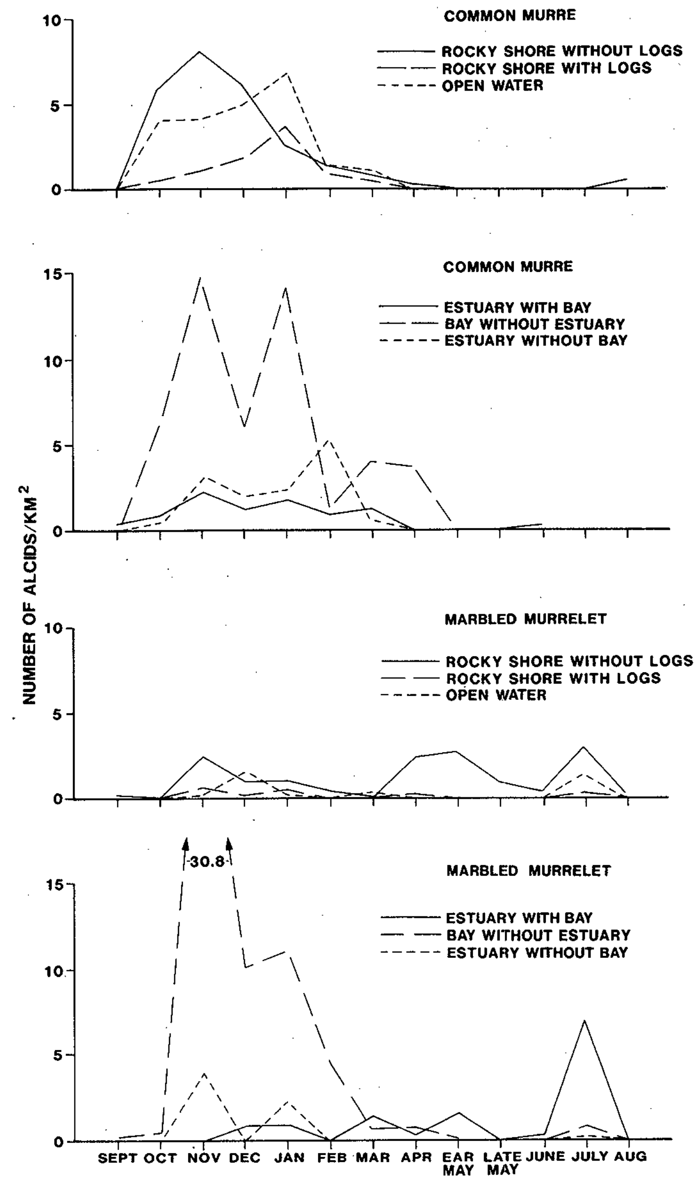


Figure 6
Seasonal changes in habitats used by Common Murres and Marbled Murrelets in Alberni Channel



6.3 Comparison with other British Columbia fjords

The overall seasonality and composition of major bird categories was similar for Alberni Channel and Jervis and Saanich inlets. Birds in these three fjords were scarce in summer. Numbers increased in late summer and early fall, were at a maximum in late fall and winter, and then declined in spring. Gulls were the most numerous birds in late summer and early fall, whereas waterfowl predominated in late fall, winter, and spring. Bird densities during maximal use from September through April were about two to three times higher in Alberni Channel and Saanich Inlet than in Jervis Inlet (Table 5). In all fjords, the numbers of loons, cormorants, and alcids were relatively small compared with those of gulls and waterfowl. Of the grebes, only one species, the Western Grebe, was numerous both in Alberni Channel and in Saanich Inlet; it was relatively scarce, however, in Jervis Inlet. Of the cormorants, Double-crested *Phalacrocorax auritus* and Pelagic *P. pelagicus* cormorants were common in all three fjords, whereas Brandt's Cormorants were common only in Alberni Channel.

In all three fjords, diving ducks were far more numerous than dabbling ducks, geese, and swans. The Surf Scoter and Barrow's Goldeneye had the highest densities in Alberni Channel and Jervis Inlet, whereas Bufflehead and Red-breasted Merganser were most numerous in Saanich Inlet. The White-winged Scoter was as common as the Surf Scoter in Saanich Inlet but was much less numerous than the Surf Scoter in Alberni Channel and was very rare in Jervis Inlet. Of the three *Bucephala* species, the Common Goldeneye was much less numerous than the Barrow's Goldeneye and the Bufflehead in both Alberni Channel and Jervis Inlet. In contrast, the Common Goldeneye was almost as common as the Barrow's Goldeneye in Saanich Inlet.

Glaucous-winged and Mew gulls were present in all three fjords for a longer period of the year than were any other gull species. The Glaucous-winged Gull was the most numerous gull in Alberni Channel and Saanich Inlet, whereas the Mew Gull had the highest density in Jervis Inlet. The California Gull was present in all three fjords but was most numerous in

Table 4
Densities of the 24 most common bird species observed in different habitats in Alberni Channel, September 1987 through early May 1988

Species[a]	Average no. of birds/km² [b] Open water	Rocky shore without logs	Rocky shore with logs	Estuaries with bays	Estuaries without bays	Bays without estuaries	All habitats
Common Loon	0.04	0.22	0.12	0.80	0.33	0.39	0.17
Western Grebe	6.70	0.85	10.20	30.20	11.00	18.90	8.00
Red-necked Grebe	0.01	0.28	0.90	1.00	0.50	0.95	0.35
Horned Grebe	0.00	0.55	0.25	2.20	0.53	0.74	0.42
Double-crested Cormorant	0.06	0.67	0.21	1.20	0.41	0.61	0.38
Brandt's Cormorant	0.11	0.68	0.24	0.34	0.00	0.75	0.43
Pelagic Cormorant	0.07	1.20	0.76	1.30	0.49	1.60	0.73
Mallard	0.01	0.18	0.86	12.10	17.90	0.01	1.40
American Wigeon (Sept.–April)	0.00	0.05	0.11	8.00	7.10	0.00	0.71
Greater Scaup (Oct.–May)	0.05	0.05	0.11	9.40	4.30	0.00	0.73
White-winged Scoter	0.07	6.50	1.20	18.40	1.50	2.50	1.80
Surf Scoter (Oct.–May)	2.20	41.00	23.30	104.60	44.40	28.40	26.30
Barrow's Goldeneye (Nov.–May)	0.00	11.10	14.00	39.60	20.70	39.10	11.10
Common Goldeneye (Nov.–May)	0.01	0.42	0.56	1.10	3.80	0.43	0.40
Bufflehead (Nov.–May)	0.02	0.86	1.10	25.00	20.40	1.00	2.60
Common Merganser	0.00	0.88	0.85	1.80	3.00	1.10	0.64
Red-breasted Merganser	0.00	0.25	0.24	2.20	0.21	0.09	0.30
Glaucous-winged Gull	1.60	9.40	26.60	70.90	12.50	17.70	12.80
Mew Gull	0.47	2.10	4.30	7.80	9.30	4.70	2.50
Thayer's Gull (Nov.–Feb.)	0.07	0.75	12.30	24.70	0.18	1.00	3.40
California Gull (July–Nov.)	0.70	7.00	64.60	12.50	14.30	5.50	7.70
Bonaparte's Gull (June–Nov.)	0.07	0.78	1.40	1.40	0.55	2.70	0.70
Common Murre	2.40	2.70	0.88	0.91	1.60	5.60	2.80
Marbled Murrelet	0.27	1.10	0.17	0.53	0.69	6.50	1.10

[a] Periods briefer than September 1987 – May 1988 are indicated in parentheses.
[b] Highest densities for each species are underlined.

Alberni Channel. Thayer's Gull was common in Alberni Channel but was rare in Saanich Inlet and absent in Jervis Inlet. Bonaparte's Gull *Larus philadelphia* was present in all three fjords.

The Common Murre was the most numerous alcid present in Alberni Channel, and the Marbled Murrelet dominated in Jervis Inlet. The Marbled Murrelet was the second most numerous alcid in Alberni Channel and Saanich Inlet. The Pigeon Guillemot *Cepphus columba* was common in Saanich Inlet but rare in Alberni Channel and Jervis Inlet.

6.4 Comparison with continental shelf

Results of marine bird surveys conducted by Vermeer et al. (1987) over the continental shelf off the mouth of Alberni Channel are briefly summarized here. Two peaks in bird density were observed over the shelf—a minor one in early June and a major one in August and September. The peak in June consisted mostly of Sooty Shearwater *Puffinus griseus*, and that in August–September of Cassin's Auklet *Ptychoramphus aleuticus*, California Gull, and Sooty Shearwater. The California Gull, the most numerous bird seen in September and October, was frequently associated with fishing trawlers (Vermeer et al. 1989). Sabine's Gull *Xema sabini* was the second most numerous gull in September, and Thayer's Gull the second most numerous in October. Thayer's Gull was found only from October through March, being 10 times more numerous than the Herring Gull. The Glaucous-winged Gull and Black-legged Kittiwake *Rissa tridactyla* were also regular visitors to the shelf. Cassin's Auklet and Common Murre were the two most numerous alcids, whereas Marbled Murrelet and Rhinoceros Auklet *Cerorhinca monocerata* were common visitors. The Black-footed Albatross *Diomedea nigripes*, Northern Fulmar *Fulmarus glacialis*, and Fork-tailed Storm-Petrel *Oceanodroma furcata* were also common. Loons, cormorants, and waterfowl were relatively scarce, and no grebes were seen.

The above observations indicate that there are major differences, as well as similarities, in bird composition over the shelf and in Alberni Channel. Major differences were the relative scarcity of loons, grebes, cormorants, and waterfowl over the shelf and the absence of albatrosses, fulmars, shearwaters, storm-petrels, Black-legged Kittiwake, Sabine's Gull, and Cassin's Auklet in the channel. Observed similarities for the shelf and the channel were that the California Gull was the most numerous species in August and September; Thayer's Gull was common from November through February; and the Glaucous-winged Gull, Common Murre, and Marbled Murrelet were relatively common throughout most of the year.

7. Discussion

7.1 Bird composition, seasonal changes, and habitat densities

The observed seasonal changes of birds in Alberni Channel—characteristically highest densities from November through February and lowest densities in summer—have also been observed in other British Columbia inshore waters (Vermeer 1983). The Western Grebe is the most abundant grebe, and the Common Murre and Marbled Murrelet are the most common alcids present in winter in the relatively sheltered waters of the Strait of Georgia. The Surf Scoter is the most numerous waterfowl species along the entire British Columbia coast. Barrow's Goldeneye is abundant along rocky shores, and the Bufflehead is numerous in bays and inlets (Vermeer et al. 1983). Glaucous-winged and Mew gulls are the most common gull species seen throughout the year in coastal British Columbia, whereas the California Gull is only temporarily abundant in late summer and early fall. In brief, the composition and seasonal changes of marine birds observed in Alberni Channel are generally similar to those occurring elsewhere in British Columbia inshore waters.

Table 5
Comparison of average marine bird composition in Alberni Channel and Saanich and Jervis inlets from September 1987 through April 1988

Species	Alberni Channel (% of birds)	Saanich Inlet (% of birds)	Jervis Inlet (% of birds)
Loons	**0.3**	**1.9**	**0.4**
Common Loon	0.2	0.8	0.4
Other loons[a]	0.1	1.1	Tr
Grebes	**10.5**	**33.8**	**1.8**
Horned Grebe	0.5	5.6	0.8
Eared Grebe	0	0.2	0
Red-necked Grebe	0.4	1.6	0.8
Western Grebe	9.6	26.4	0.2
Cormorants	**2.0**	**2.9**	**1.6**
Brandt's Cormorant	0.6	Tr	0
Double-crested Cormorant	0.5	1.2	0.7
Pelagic Cormorant	0.9	1.7	0.9
Waterfowl	**53.5**	**41.0**	**69.6**
Swans and geese	0.4	0.3	0.1
American Wigeon	0.9	2.3	0.3
Mallard	1.8	0.6	1.3
Other dabbling ducks[b]	0.2	Tr	0.3
Surf Scoter	32.7	4.3	34.1
White-winged Scoter	2.1	4.3	Tr
Barrow's Goldeneye	11.0	5.3	30.5
Common Goldeneye	0.4	4.4	0.6
Bufflehead	2.5	8.1	0.8
Common Merganser	0.7	1.4	1.3
Red-breasted Merganser	0.4	7.0	0.1
Other diving ducks[c]	0.4	3.0	0.2
Gulls	**29.0**	**19.1**	**24.1**
Bonaparte's Gull	0.5	0.8	1.7
California Gull	5.7	0.7	0.6
Glaucous-winged Gull	17.3	14.5	8.6
Mew Gull	3.3	3.0	13.2
Thayer's Gull	2.0	Tr	0
Other gulls[d]	0.2	0.1	Tr
Alcids	**4.7**	**1.3**	**2.5**
Common Murre	3.4	0.7	Tr
Marbled Murrelet	1.3	0.3	2.5
Pigeon Guillemot	Tr	0.2	0
Other alcids[e]	Tr	0.1	0
Average no. of birds/month	8571	4708	5080
Average no. of birds/km^2	82.1	72.9	28.7

Tr = <0.1%
[a] Red-throated, Pacific, and Yellow-billed loons.
[b] Cinnamon and Green-winged teals, Gadwall, Northern Shoveler, and Northern Pintail.
[c] Black Scoter, Greater and Lesser scaups, Harlequin Duck, and Oldsquaw.
[d] Herring, Iceland, Ring-billed, and Western gulls.
[e] Ancient Murrelet and Rhinoceros Auklet.

Low bird densities in open water habitat have been generally observed along the British Columbia coast (Robertson 1977; Vermeer et al. 1983). Highest densities of waterfowl species occur in estuaries and bays in other locations in British Columbia (e.g., Vermeer and Levings 1977; Vermeer et al. 1983). Alberni Channel habitats therefore show the same overall trends in bird densities as do other inshore habitats on the British Columbia coast.

7.2 Comparison of habitats

A comparison of Alberni Channel with the two other British Columbia fjords shows that overall bird numbers fluctuate similarly over the season in all three fjords, but that there are differences in densities and species composition. The differences in bird densities between Alberni Channel and Saanich Inlet on the one hand, and between Alberni Channel and Jervis Inlet on the other, relate mainly to the size of estuaries and shallow bays, where most birds congregate. Estuaries and shallow bays made up 16.8%, 12.3%, and 4.1% of Alberni Channel, Saanich Inlet, and Jervis Inlet, respectively. The differences in species composition can be explained by variations in habitat and food availability between fjords. Alberni Channel and Saanich Inlet are shallower than Jervis Inlet and contain shallower and larger bays. Jervis Inlet is probably too deep for foraging by the White-winged Scoter, which was common in Alberni Channel and Saanich Inlet, or by the Pigeon Guillemot, which was common in Saanich Inlet only. The White-winged Scoter feeds mostly on bivalves inhabiting gravel and mud substrates (Vermeer and Bourne 1984), and the Pigeon Guillemot chiefly feeds epibenthically (Drent 1965; Follett and Ainley 1976; Krasnow and Sanger 1986).

Another difference is that the Pacific herring *Clupea harengus pallasi* usually does not spawn in deep waters such as Jervis Inlet but has been known to do so in the sheltered and shallow waters of Alberni Channel and Saanich Inlet. Herring-consuming birds such as Brandt's Cormorant, Common Murre, and Western Grebe follow the movement of herring until the fish spawn in sheltered and shallow waters (Vermeer 1983). This may explain the relative scarcity or absence of these species in Jervis Inlet and their presence in Alberni Channel and Saanich Inlet.

The similarities and differences in the presence of the *Bucephala* species in the three fjords may be explained by food availability. Barrow's Goldeneye, which was numerous in all three fjords, feeds extensively on blue mussels *Mytilus edulis* on fjord walls (Vermeer 1981). However, the Bufflehead and Common Goldeneye, which are numerous in Saanich Inlet and occur in higher densities in Alberni Channel than in Jervis Inlet, feed primarily upon snails, shrimp, and crabs in shallow bays and estuaries (Vermeer 1982).

During August and September, California Gull density was much greater in Alberni Channel than in Jervis and Saanich inlets. This fact probably relates to the general direct migration of the species in late summer from its breeding colonies in the Canadian Prairie provinces to the coast of southwestern Vancouver Island, where it feeds extensively on offal from the offshore fishing fleet (Vermeer et al. 1987).

The absence and scarcity of Thayer's Gull in Jervis and Saanich inlets, respectively, and its common presence in Alberni Channel can be explained by the fact that this gull remains mostly offshore when travelling between its Arctic breeding colonies and the coastal and offshore feeding grounds (Vermeer and Rankin 1984). Thayer's Gull disperses from Alberni Channel in March to feed on herring eggs in major herring spawn areas in adjacent Barkley Sound. Of an estimated 12 000 gulls observed feeding on herring eggs for about two weeks in March 1988, it was estimated that at least half were Thayer's Gulls (KV, pers. obs.). These gulls leave Barkley Sound after the herring has spawned and migrate north to their Arctic breeding colonies. The spawn appears to provide an energy "boost" for the gulls just prior to their spring migration.

7.3 Comparison with fjords with tidewater glaciers

Maximal bird use in Alberni Channel and Jervis and Saanich inlets occurred from late autumn to spring, coinciding with the period of greatest freshwater runoff from rainfall. In contrast, in Prince William Sound, Alaska, most fjords have tidewater glaciers. These fjords have the highest input of fresh water during summer as a result of warm air temperatures and the melting of glacier ice when it comes into contact with relatively warm, saline water masses (Matthews and Quinlan 1975). Hogan and Irons (1988) conducted monthly surveys of marine birds at Port Valdez, Alaska, where a glacier enters

Shoup Bay. Bird densities were highest in summer and lowest in winter, which is the reverse of the seasonal profile of bird use in British Columbia fjords. Most bird use at Port Valdez in summer was by the Black-legged Kittiwake and, to a lesser extent, the Glaucous-winged Gull and Arctic Tern *Sterna paradisaea*. All three species nested on or near an island at the base of a glacier at Shoup Bay. Waterfowl, the second most numerous bird category after larids at Port Valdez, were most abundant in winter. Of the waterfowl, Barrow's Goldeneye and Surf Scoter were most numerous. The most common alcids were the Common Murre and Marbled Murrelet. If one omits the nesting larids, the seasonal bird profile at Port Valdez is not unlike that observed in British Columbia fjords.

The presence of both tidewater glaciers and islands with cliff ledges, on which kittiwakes nest, may influence the seasonal profile of bird use of Prince William Sound fjords. Kittiwakes do not nest in or usually visit British Columbia fjords, where islands with cliff ledges are either scarce or absent and where there are no tidewater glaciers. Glacial activity apparently results in nutrients, which augment phytoplankton growth, entering a fjord (Hartley and Dunbar 1938; Dunbar 1973; Apollonia 1973). Phytoplankton constitutes a food base for zooplankton and fish, upon which kittwakes feed in turn. Zooplankton may also concentrate at glacier river outlets as a result of passive transport by salt water, as suggested by Mehlum (1984). Kittiwakes feed upon concentrations of amphipods and euphausiids at glacial outlets in fjords in Spitsbergen (Hartley and Fisher 1936; Stott 1936; Norderhaug et al. 1971; Mehlum 1984). Arctic cod *Boreogadus saida* is the other main food consumed by kittiwakes in these fjords (Lydersen et al. 1985).

7.4 Comparison with the continental shelf

There are major differences and similarities in bird composition between Alberni Channel and the adjacent shelf, which likely relate to food sources and their availability. Food sources are determined by physical and chemical parameters. One major physical difference is that the benthic substrate in shelf waters, because of their much greater depth, is much less accessible to epibenthic-feeding birds than that in the channel. This may explain the relative scarcity of waterfowl over the shelf. Salinity is another important barrier for waterfowl. For example, mussel-feeding ducks that swallow whole mussels, which have seawater locked between their valves, experience a reduced net energy gain because of the necessity to excrete salt (Nystrom and Pehrsson 1988). Birds other than waterfowl, which feed primarily in estuarine conditions, may also experience similar difficulties.

The absence of albatrosses, fulmars, shearwaters, storm-petrels, and Cassin's Auklets in the channel may be explained by the fact that those species feed chiefly on oceanic foods such as marine epipelagic and mesopelagic fish, cephalopods, and zooplankton (e.g., Ogi et al. 1980; Vermeer 1984; Chu 1984; Sanger 1986; Hills and Fiscus 1988; Vermeer and Devito 1988; Vermeer et al. 1989). These prey often undergo extensive diel migration (e.g., Vermeer and Devito 1988) and are either absent or less common in the channel than on the shelf. Forbes et al. (1990a, 1990b) observed that zooplankton in the surface water of Alberni Channel was less abundant and consisted of smaller species than that observed on the shelf.

The Common Murre visits both the channel and the shelf, perhaps because its main prey—Pacific sandlance *Ammodytes hexapterus* and Pacific herring—commonly occur in both habitats. That California, Glaucous-winged, and Thayer's gulls utilize both habitats may relate primarily to their scavenging habits; pelagic and nonscavenging gulls such as Black-legged Kittiwake and Sabine's Gull generally do not visit Alberni Channel.

Although true pelagic birds generally do not frequent British Columbia fjords, perhaps because of the relatively low surface salinity there, high-salinity fjords in Chile are visited by Wandering *Diomedea exulans* and Royal *D. epomophora* albatrosses, Sooty Shearwaters, and diving petrels (*Pelecanoides* spp.). Brown et al. (1975) suggested that these species visit the fjords because of their preference for conditions associated with high salinity. We observed that the Black-footed Albatross and Leach's Storm-Petrel *Oceanodroma leucorhoa*, which generally feed in deep water and at relatively large distances from shore, were positively and significantly correlated with surface salinity in waters off the west coast of Vancouver Island (Vermeer and Morgan, this volume). These birds are perhaps associated with high-salinity conditions because of the occurrence of their main prey in that environment.

8. Conclusions

It can be concluded that the deep-water habitat along steep rock walls of British Columbia fjords is mainly inhabited in winter by deep-diving ducks such as Surf Scoters and Barrow's Goldeneyes (see also Vermeer 1981), although their highest densities occurred in bays and estuaries. Bay ducks such as White-winged Scoters, Buffleheads, Common Goldeneyes, and Red-breasted Mergansers, as well as Western Grebes, abounded only where large or many bays and estuaries existed. Swans, geese, and dabbling ducks were primarily restricted to estuaries, but even there they made up only a small fraction of the waterfowl present. Loons, grebes (except the Western Grebe), cormorants, and alcids were common but never made up a large component of the fjord bird population. Of the gulls, the Glaucous-winged Gull was numerous in all three and the Mew Gull was abundant in one and common in two fjords during most seasons. The California and Thayer's gulls appeared to be numerous only during autumn and winter, respectively, in Alberni Channel.

Although we provide here aspects on the composition, seasonal variation, and different habitat use by bird species in British Columbia fjords, much is still to be learned about their daily variation in numbers, movements between different habitats, feeding behaviour, and diet. Detailed studies on the association of birds as well as that of their prey with various water types are essential before it can be determined why certain species occur in fjords and others do not. Furthermore, information on the year-round composition, habitat use, and food of birds in fjords in Alaska, Chile, Norway, and elsewhere is necessary before we will be able to fully understand the ecology of birds occupying the world's fjords.

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Appendix 1
Numbers of marine birds for a total of 46 species observed in Alberni Channel from September 1987 through August 1988

	No. of birds												
Species	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	Early May	Late May	June	July	Aug.
Common Loon	1	16	20	27	15	10	15	29	30	9	18	3	3
Red-throated Loon			7	8	3	1	4						
Pacific Loon			15	25	28		2	1	1	12			
Western Grebe	117	633	1077	810	1981	513	325	1039	1009	25			
Red-necked Grebe	1	10	41	52	55	30	63	31	49	3			
Horned Grebe	5	33	60	58	68	49	83	23	15	2			
Double-crested Cormorant	7	8	106	74	41	54	44	15	11		4	2	3
Brandt's Cormorant	10	75	67	96	84	56	13		4	7	4	2	
Pelagic Cormorant	9	21	105	123	93	61	109	111	51	23	11	10	1
Trumpeter Swan			2	49	44	41		3					
Canada Goose	4	29		100			7	2	6	6	60	55	
Mallard	230	48	283	308	155	68	99	72	43	23	12	3	21
American Wigeon	208	60	193	10	11		29	85					
Northern Pintail					1		5	8					
Northern Shoveler	8	5	1				4		13				
Gadwall	3				2								
Green-winged Teal				13	2	1	46	24	8				
Cinnamon Teal									2				
Greater Scaup		25	56	17	48	103	113	97	156	23			
Lesser Scaup					1								
White-winged Scoter		132	740	267	132	94	80	1	25	17	4		
Surf Scoter	274	938	2947	4697	4357	4306	2424	2371	2385	1009	242	10	155
Black Scoter				3	8		2	5	1	2			
Barrow's Goldeneye			793	1915	1399	1254	1034	995	703	102	7		
Common Goldeneye			7	72	49	55	46	48	16	1			
Bufflehead			128	518	239	282	333	227	154	4			
Oldsquaw						1				4			
Harlequin Duck					4	3	10	6	12	14			
Common Merganser	97	81	5	14	28	19	97	115	150	46	49	183	225
Red-breasted Merganser	106		20	25	20	16	19	13	13	6	3		
Hooded Merganser	1			5	4	1	1	4					
American Coot		2	5	13	2	4	6	5					
Glaucous-winged Gull	1066	1832	3510	2692	1183	1262	155	188	130	99	33	87	482
Herring Gull		1	6	10	11	10						20	13
Western Gull			7	2	9	1						1	
Thayer's Gull			176	170	719	361							
California Gull	3121	519	261	2				1		11	47	267	1897
Mew Gull	276	103	381	375	182	669	295	20	55	47	17	1	11
Bonaparte's Gull	14	163	153	2	1			3			12	5	90
Heermann's Gull		30	1										
Iceland Gull										1			
Caspian Tern											3		
Common Murre	9	410	585	477	540	138	113	41	1	2	4		14
Rhinoceros Auklet		3	1										
Marbled Murrelet	5	3	371	179	155	55	31	83	98	23	14	212	9
Pigeon Guillemot				1			6	5					1

Bird populations of estuaries on the southwest coast of Vancouver Island

Kees Vermeer, Ken H. Morgan, Adrian Dorst, and Bruce Whittington

1. Abstract

The species composition and population of water birds were investigated in eight estuaries on the southwest coast of Vancouver Island: Sooke Harbour, Sarita River, Somass River, Barkley Sound estuarine area, and four small estuaries in Clayoquot Sound. The Barkley Sound estuarine area was distinct from the other seven estuaries because of the very large bird population present in March; Surf Scoters *Melanitta perspicillata* and Glaucous-winged *Larus glaucescens*, Mew *L. canus*, and Thayer's *L. thayeri* gulls fed extensively upon herring eggs there. Sooke Harbour estuary had the highest densities of Double-crested *Phalacrocorax auritus* and Pelagic *P. pelagicus* cormorants, American Wigeons *Anas americana*, Mallards *A. platyrhynchos*, Northern Pintails *A. acuta*, Buffleheads *Bucephala albeola*, and Red-breasted Mergansers *Mergus serrator*. All eight estuaries were distinct from one another in bird composition, even the four small estuaries within Clayoquot Sound. The water bird fauna in Somass River estuary appeared impoverished compared with that of the other estuaries, perhaps because effluents from several lumber and pulp mills affected the food base of the water birds. Western Grebes *Aechmophorus occidentalis* and Common Mergansers *Mergus merganser* in the Somass River estuary were highly contaminated with dibenzofurans and dibenzodioxins. In order to maintain the diversity of estuarine birds on the west coast of Vancouver Island, it is recommended that efforts be made to protect all estuaries from further deterioration caused by pollution and human development.

2. Résumé

La population des oiseaux aquatiques et les espèces qui la composaient ont été étudiées dans huit estuaires de la côte sud-ouest de l'île de Vancouver : ceux du havre Sooke, de la rivière Sarita et de la rivière Somass, la zone estuarienne de la baie Barkley et quatre petits estuaires de la baie Clayoquot. La zone estuarienne de la baie Barkley était différente des sept autres estuaires en raison du nombre considérable d'oiseaux qui la fréquentaient en mars; des Macreuses à front blanc *Melanitta perspicillata*, des Goélands à ailes grises *Larus glaucescens*, des Goélands cendrés *L. canus* et des Goélands de Thayer *L. thayeri* s'y nourrissaient abondamment d'oeufs de hareng. C'est dans l'estuaire du havre Sooke que les densités de population des espèces suivantes étaient le plus élevées : le Cormoran à aigrettes *Phalacrocorax auritus*, le Cormoran pélagique *P. pelagicus*, le Canard siffleur d'Amériqué *Anas americana*, le Canard colvert *A. platyrhynchos*, le Canard pilet *A. acuta*, le Petit Garrot *Bucephala albeola* et le Bec-scie à poitrine rousse *Mergus serrator*. Les huit estuaires, même les quatre petits de la baie Clayoquot, différaient tous les uns des autres du point de vue de la composition de la population d'oiseaux. La population d'oiseaux aquatiques de l'estuaire de la rivière Somass semblait appauvrie comparativement à celle des autres estuaires, peut-être parce que leur base alimentaire était altérée par les effluents de plusieurs scieries et usines de pâtes. Dans cet estuaire, le Grèbe élégant *Aechmophorus occidentalis* et le Grand Bec-scie *Mergus merganser* étaient fortement contaminés par les dibenzofurannes et les dibenzodioxines. Pour maintenir la diversité des oiseaux estuariens de la côte ouest de l'île de Vancouver, il est recommandé de déployer des efforts en vue d'empêcher les estuaires de se détériorer davantage à cause de la pollution et de l'exploitation.

3. Introduction

Estuaries are among the most important feeding habitats of water birds in British Columbia (Butler and Campbell 1987; Campbell Prentice and Boyd 1988; Butler and Vermeer 1989). Butler et al. (1989) recently summarized information on water bird populations in Strait of Georgia estuaries, including six on the east coast of Vancouver Island. Little is known about the status of water bird populations in estuaries on the west coast of Vancouver Island, with the exception of those in one fjord, which were investigated by Vermeer and Morgan (this volume). Information on the latter, however, was presented as part of a study of a fjord as a whole, and not on a separate estuary basis.

To address the lack of information on the status of water birds in west coast estuaries, we investigated the composition and densities of bird species in eight estuaries on the southwest coast of Vancouver Island during each month of the year. The objective of this study was to compare the temporal and spatial distributions of marine birds within and between eight estuaries on the southwest coast of Vancouver Island.

4. Description of study area and methods

The location and surface areas of the eight estuaries are shown in Figure 1. The surveyed areas include all of the intertidal zone (except for the Somass River estuary) and the adjacent subtidal zone; the boundaries of these areas are shown in Figure 2 to facilitate future comparisons.

All estuaries were surveyed by boat once a month over the course of one year, with most surveys conducted during the third week of each month. The Somass and Sarita river estuaries were surveyed from September 1987 through August 1988, the four Clayoquot Sound estuaries and Sooke Harbour estuary from January through December 1989, and the Barkley Sound

Figure 1
Location and size of eight estuaries surveyed for marine birds on the southwest coast of Vancouver Island

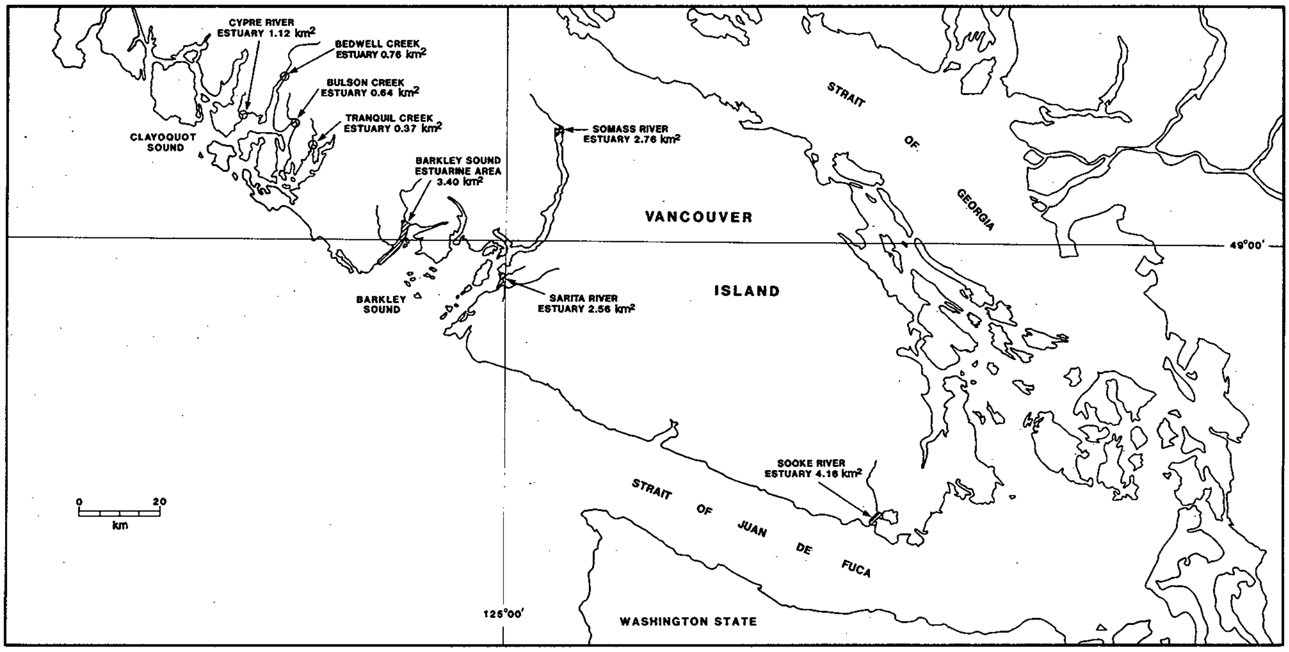


Figure 2
Survey boundaries of eight estuaries on the southwest coast of Vancouver Island

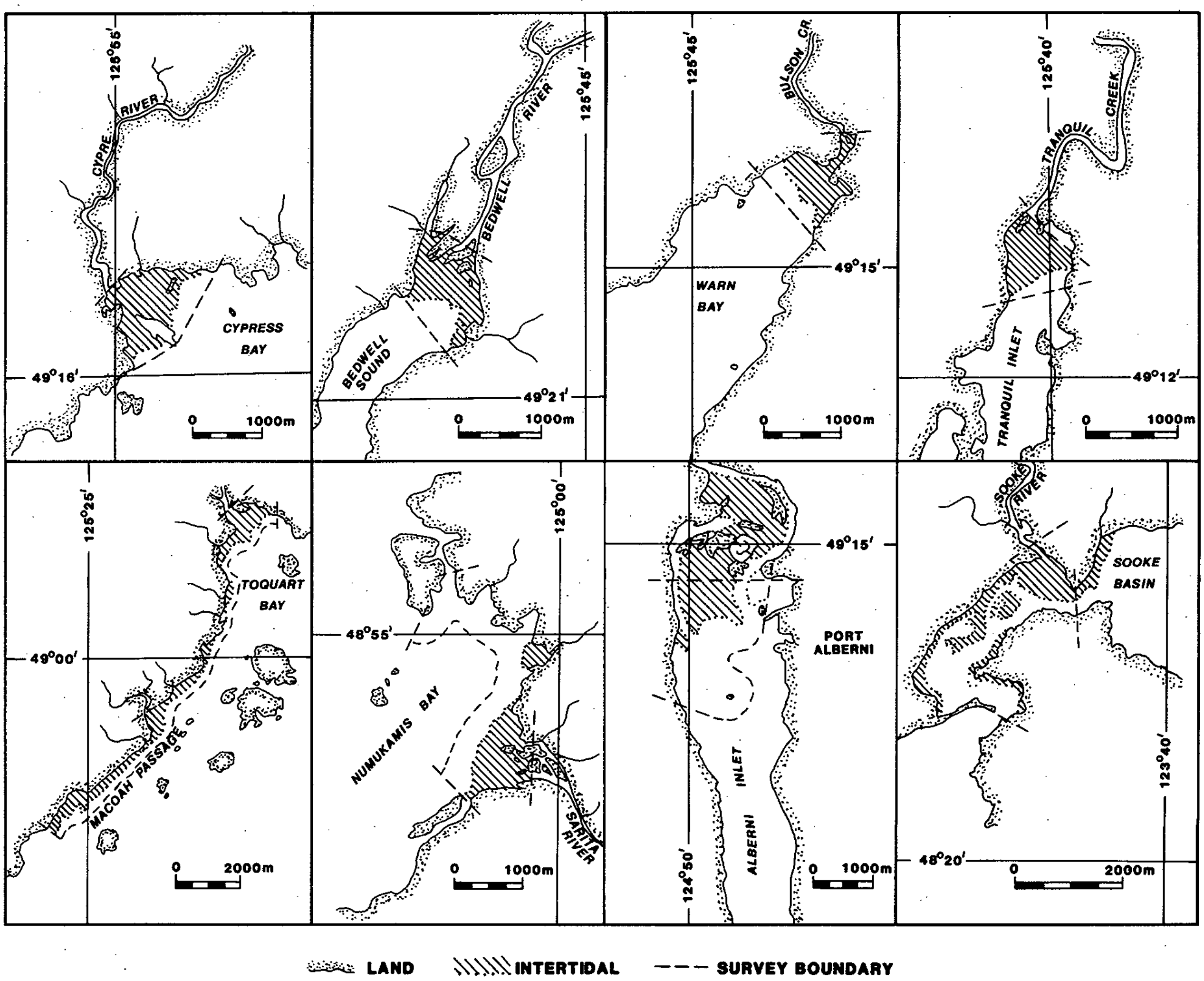


Figure 3
Location and size of three sections of the Somass River estuary surveyed for marine birds in April 1989

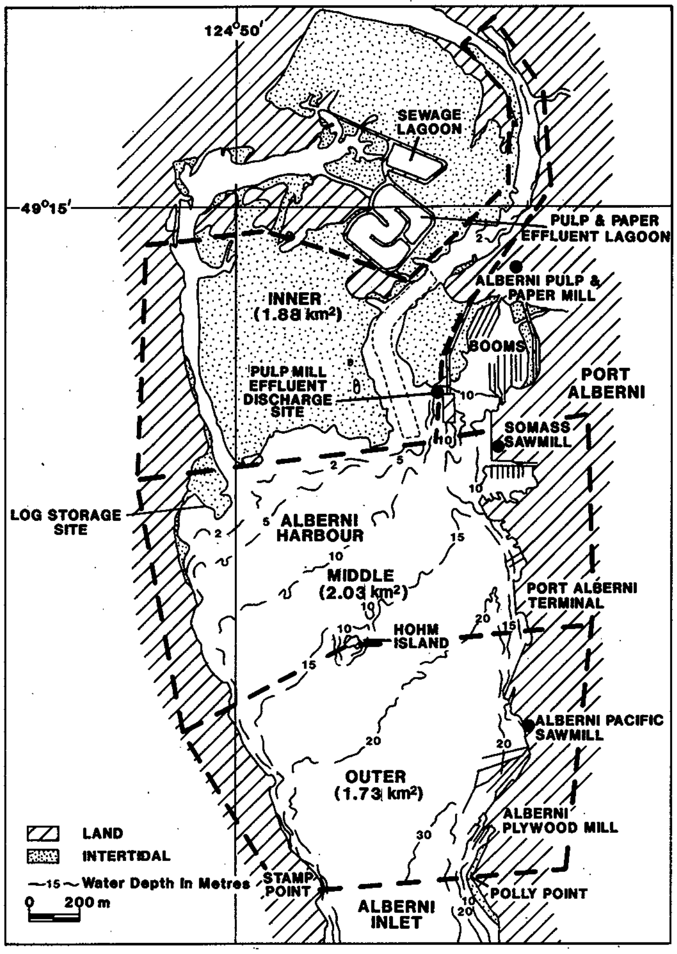
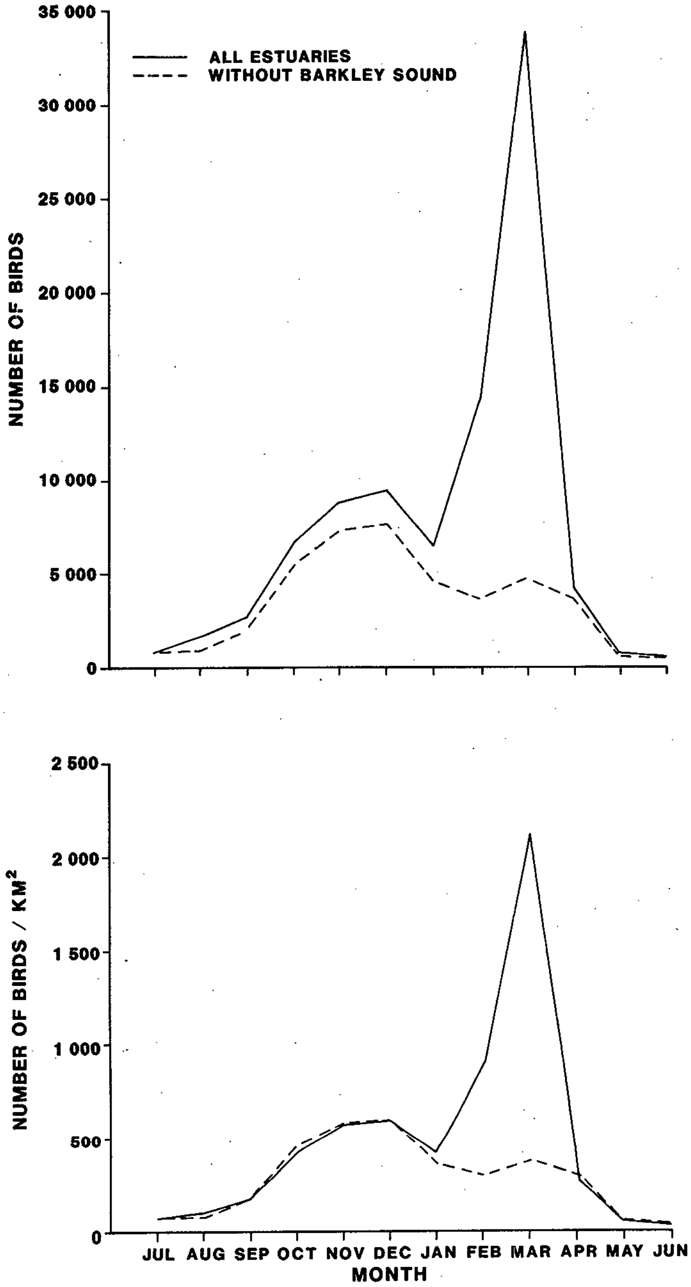


Figure 4
Monthly changes in numbers and densities of marine birds in eight estuaries on the southwest coast of Vancouver Island, with and without the inclusion of the Barkley Sound estuarine area



estuarine area from June 1989 through May 1990. Three separate sections in the Somass River estuary were surveyed at extreme low and high tides during daylight hours on 17 days in April 1988 (Fig. 3).

5. Results

5.1 Overall bird numbers and densities

Two peaks in numbers and densities of water birds occurred: one in November and December, and the other in March (Fig. 4). In seven estuaries, the highest numbers of birds occurred in November–December, whereas the March peak occurred chiefly in the Barkley Sound estuarine area.

5.2 Bird composition and seasonal changes

Of six major groups of birds, gulls and waterfowl were most numerous from September through March (Fig. 5). Peak densities of gulls and waterfowl were observed in Barkley Sound in March. Grebe and cormorant densities were one order of magnitude less, and those of loons and alcids two orders of magnitude less than those of gulls and waterfowl.

Highest loon densities occurred from September through January and consisted mostly of Common Loons *Gavia immer* (Fig. 6). Of the alcids, Common Murres *Uria aalge* and Marbled Murrelets *Brachyramphus marmoratus* were most common. Common Murre densities peaked in October and June, and those of Marbled Murrelets in December and June (Fig. 6). Of the grebes, Horned *Podiceps auritus* and Western *Aechmophorus occidentalis* grebes were most common (Fig. 6). Both grebe species had peak densities in fall and early winter, whereas the Western Grebe had its highest density in April. The April peak resulted chiefly from Western Grebes visiting the Somass River estuary. Red-necked Grebes *Podiceps grisegena* were also common but less numerous than Horned and Western grebes. One Pied-billed Grebe *Podilymbus podiceps* was seen at Sooke Harbour. Of the three cormorant species present, Double-crested *Phalacrocorax auritus* and Pelagic *P. pelagicus* cormorants had the highest densities, mostly from September through November, whereas Brandt's Cormorant *P. penicillatus* was least common.

Of the waterfowl, diving ducks had by far the highest densities, whereas densities of dabbling ducks were generally modest and densities of swans and geese were low. Two species

Figure 5
Monthly changes in densities of major groups of marine birds in eight estuaries on the southwest coast of Vancouver Island

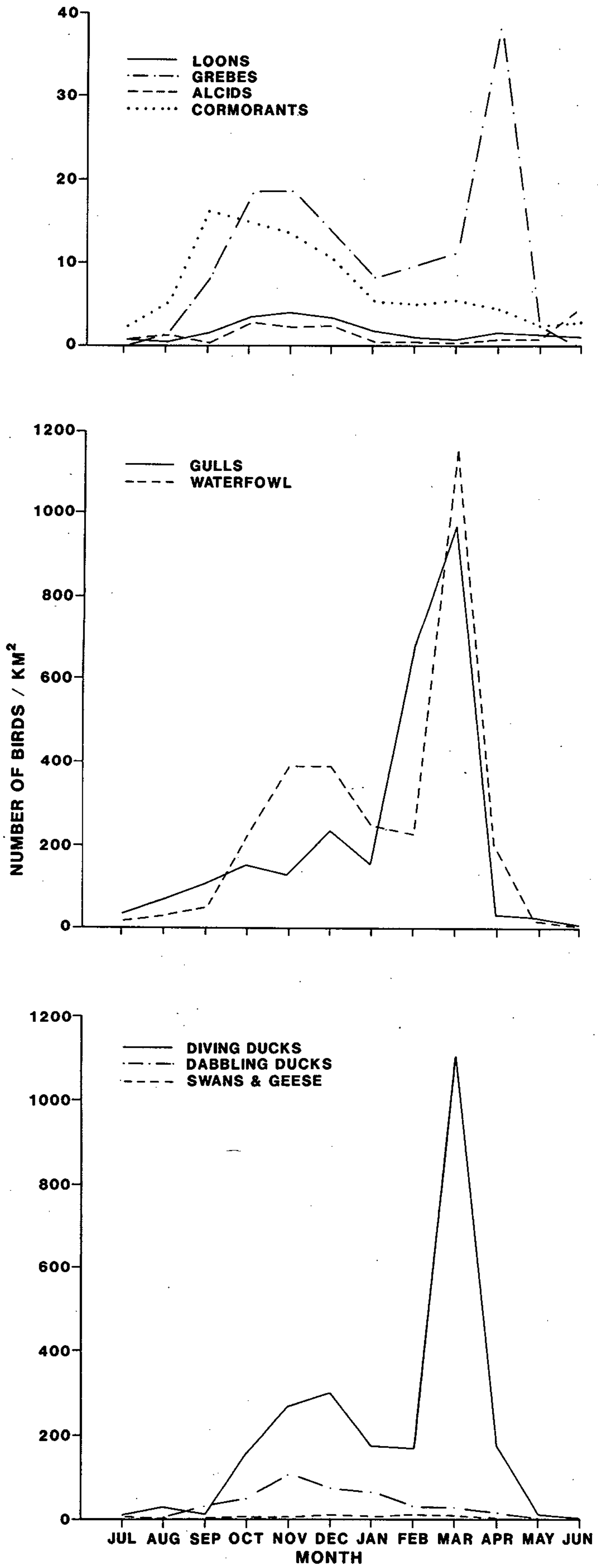
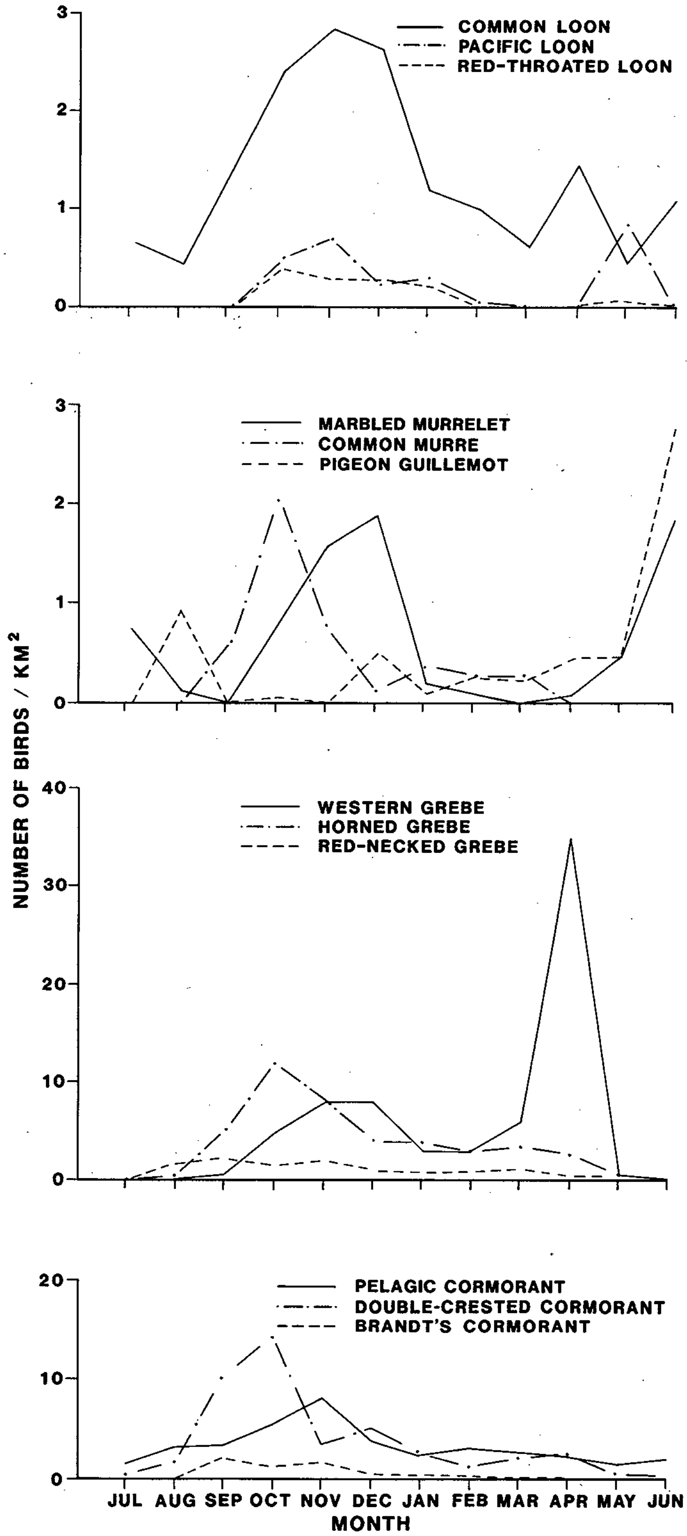
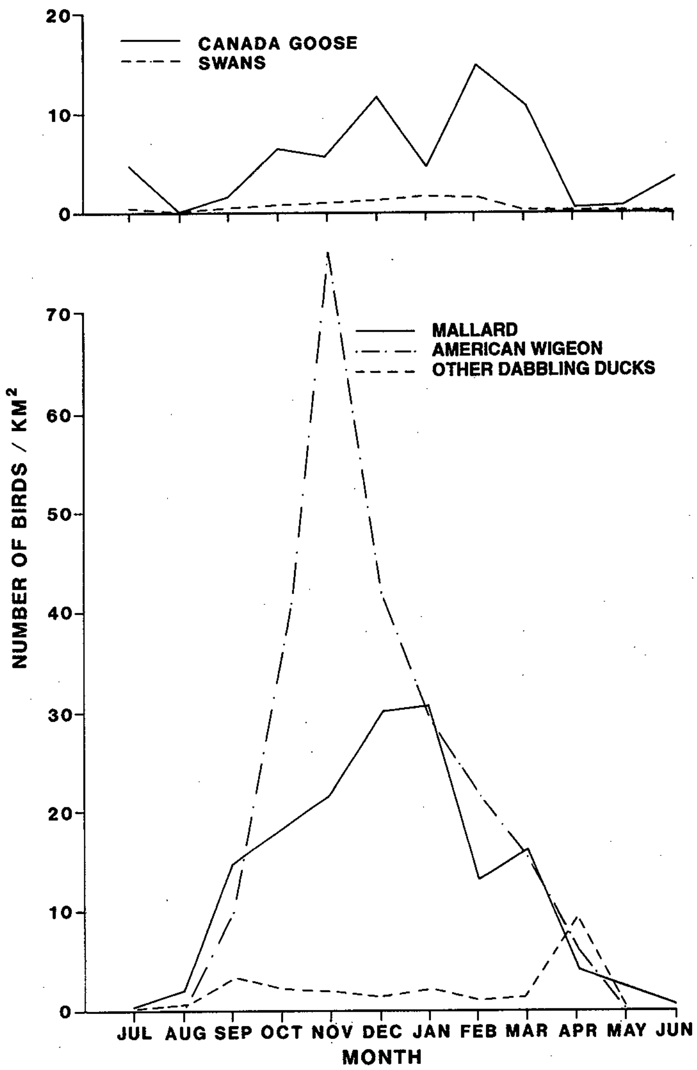


Figure 6
Monthly changes in densities of loon, alcid, grebe, and cormorant species in eight estuaries on the southwest coast of Vancouver Island



of swans visited the estuaries: Mute Swans *Cygnus olor* were observed only at Sooke Harbour, and Trumpeter Swans *Olor buccinator* occurred in all other estuaries (Fig. 7). The Canada Goose *Branta canadensis* was the only goose species encountered. The two most numerous dabbling ducks were the Mallard *Anas platyrhynchos* and the American Wigeon *A. americana*, whose highest densities occurred from October through January (Fig. 7). Other common visiting dabblers were the Northern Pintail *A. acuta* and Green-winged Teal

Figure 7
Monthly changes in densities of swans, geese, and dabbling ducks in eight estuaries on the southwest coast of Vancouver Island

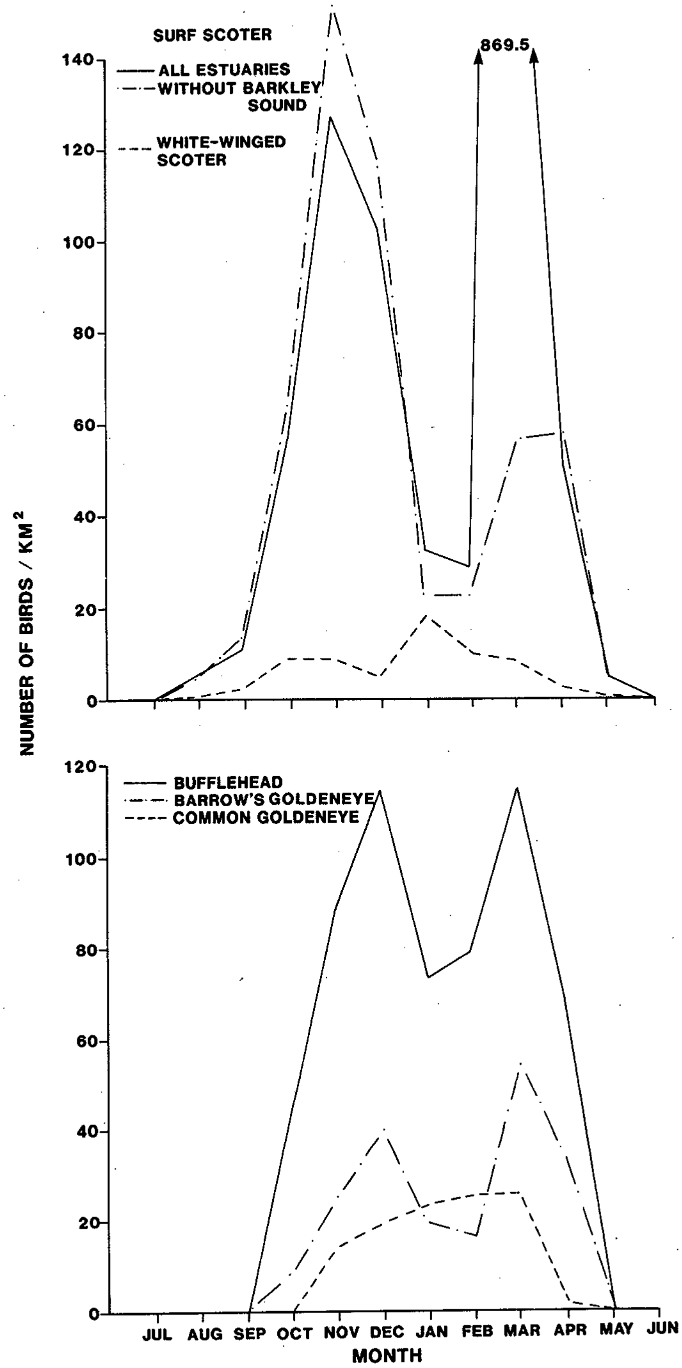


A. carolinensis, whereas the Eurasian Wigeon *A. penelope*, Northern Shoveler *A. clypeata*, Blue-winged Teal *A. discors*, and Gadwall *A. strepera* were observed only in small numbers. Eurasian Wigeons were seen only at Sooke Harbour.

The two most numerous diving duck species were the Surf Scoter *Melanitta perspicillata* and the Bufflehead *Bucephala albeola*. Both species had peak densities in the fall and in March (Fig. 8). Other diving ducks that were common visitors were White-winged Scoter *Melanitta fusca*, Barrow's Goldeneye *Bucephala islandica* (Fig. 8), three merganser species, and Greater Scaup *Aythya marila* (Fig. 9). Harlequin Ducks *Histrionicus histrionicus* and Oldsquaws *Clangula hyemalis* occurred in small numbers, whereas a few Black Scoters *Melanitta nigra* and Lesser Scaup *Aythya affinis* were also seen.

Glaucous-winged *Larus glaucescens* and Mew *L. canus* gulls were the only species that were year-round visitors to the estuaries. Thayer's Gull *L. thayeri* was most common from November, through March, California Gull *L. californicus* from July through November, and Bonaparte's Gull *L. philadelphia* from September through November; Herring Gull *L. argentatus* had low densities in most months, except March (Fig. 10). Glaucous-winged, Mew, and Herring gulls had peak densities in March, whereas Thayer's Gulls were even more numerous in

Figure 8
Monthly changes in densities of Surf Scoters (with and without the inclusion of the Barkley Sound estuarine area), White-winged Scoters, Buffleheads, and Barrow's and Common goldeneyes in eight estuaries on the southwest coast of Vancouver Island



February (Fig. 10). Other gull species occasionally observed were Heermann's *L. heermanni*, Iceland *L. glaucoides*, Ring-billed *L. delawarensis*, and Western *L. occidentalis* gulls.

5.3 Differences between estuaries

The Barkley Sound estuarine area differed from the other seven estuaries because of the influx of thousands of birds in March. The highest densities of Barrow's Goldeneyes, Surf Scoters, and Glaucous-winged, Thayer's, Mew, and Herring gulls occurred in that month.

The Sooke Harbour estuary had the highest densities of all estuaries. Highest densities of Double-crested and Pelagic

Figure 9
Monthly changes in densities of merganser species, Greater Scaups, Harlequin Ducks, and Oldsquaws in eight estuaries on the southwest coast of Vancouver Island

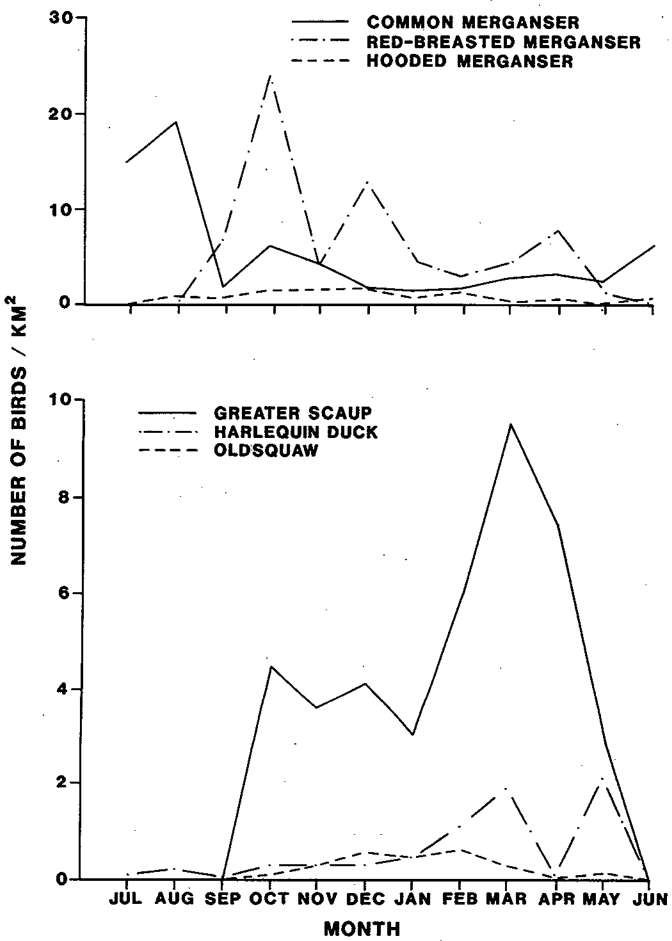
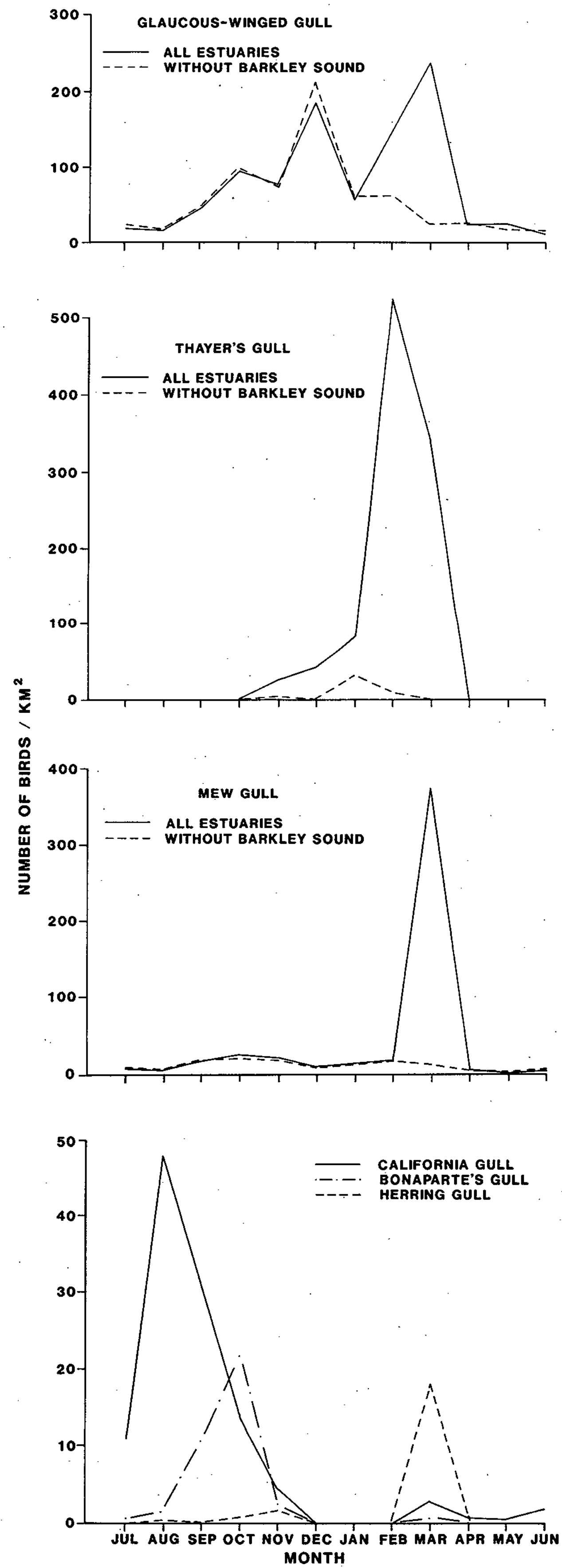


Figure 10
Monthly changes in densities of gull species in eight estuaries on the southwest coast of Vancouver Island, with and without the inclusion of the Barkley Sound estuarine area for the major gull species



cormorants, American Wigeons, Mallards, Northern Pintails, Buffleheads, and Red-breasted Mergansers *Mergus serrator* occurred there (Fig. 11). Mute Swans bred and resided in winter only at Sooke Harbour.

The Somass River estuary was characterized by low densities of loons and Barrow's and Common goldeneyes and the absence of White-winged Scoters. Only Western Grebes and Greater Scaup reached higher densities at Somass River than in the other estuaries (Fig. 12). The Somass River (2.76 km^2) and Sarita River (2.56 km^2) estuaries are similar in size and are located within the same fjord, but their bird composition varied considerably. The Sarita River estuary was extensively used by Barrow's Goldeneyes, Surf and White-winged scoters, and Thayer's Gulls, whereas the Somass River estuary had higher densities of Mallards, American Wigeons, Greater Scaups, Glaucous-winged Gulls, and Western Grebes (Table 1).

The four small estuaries surveyed in Clayoquot Sound also differed considerably in bird composition. Western Grebes were common only in the Bedwell River, Trumpeter Swans in Tranquil Creek, Bonaparte's Gulls in Bulson Creek, and American Wigeons and White-winged Scoters in Bulson Creek and Cypre River estuaries (Fig. 13). There were distinct differences in the proportions of three *Bucephala* species between the four Clayoquot Sound estuaries (Fig. 14). Bufflehead had the highest densities at the Cypre River, Common Goldeneyes at the Bedwell River, and Barrow's

Figure 11
Comparison of densities of Double-crested and Pelagic cormorants, swans, American Wigeons, Mallards, Northern Pintails, Buffleheads, and Red-breasted Mergansers in Sooke Harbour estuary with the combined densities of those species in the other seven estuaries

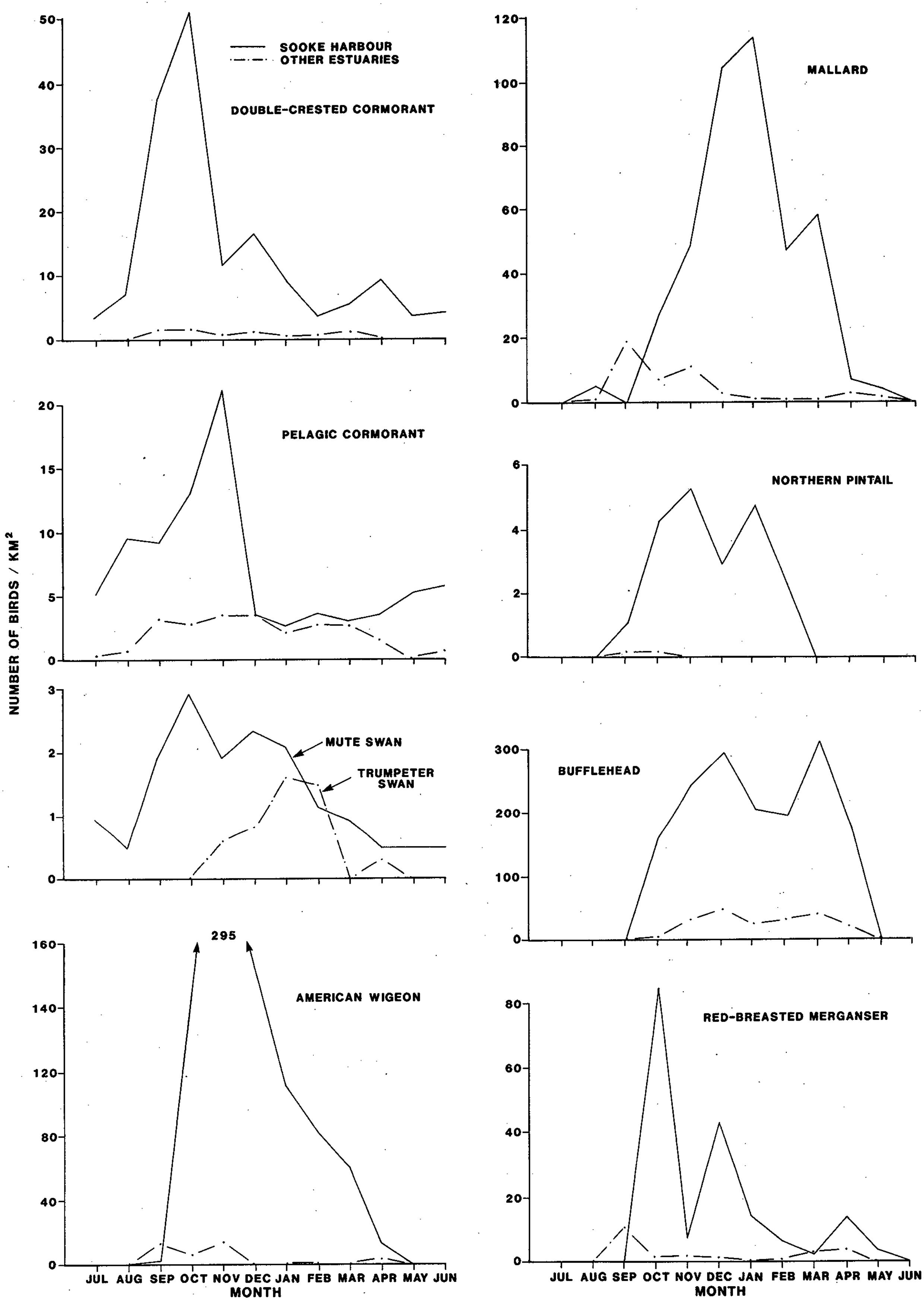
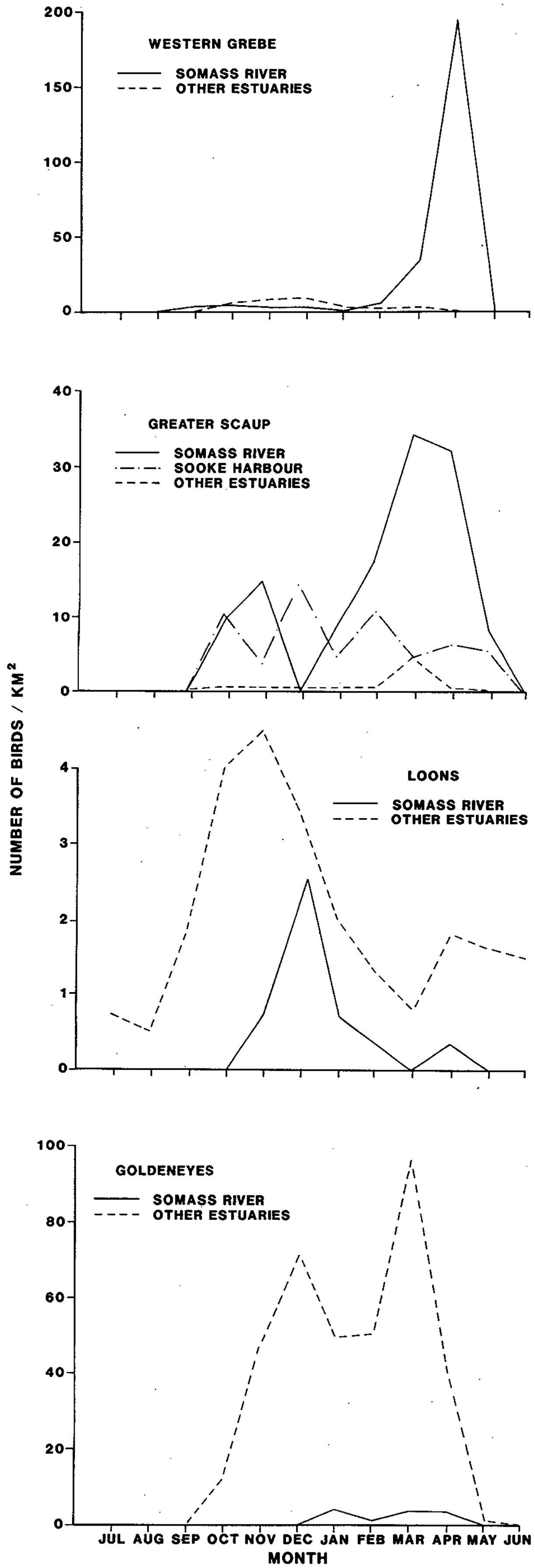


Figure 12
Comparison of densities of Western Grebes, Greater Scaups, loons, and goldeneyes in the Somass River estuary (and Greater Scaups in the Sooke Harbour estuary) with the combined densities of those species in the other estuaries



Goldeneyes at Tranquil Creek; all three species were common at Bulson Creek.

5.4 Differences within the Somass River estuary

The most abundant bird groups using three sections of the Somass River estuary in April 1988 were grebes, gulls, and dabbling and diving ducks (Fig. 15). The highest average densities of all water birds, as well as those of dabbling ducks and gulls, occurred in the inner section near the river mouth (Fig. 15A). Water bird densities averaged higher there at low than at high tide.

Highest average densities of Western and Horned grebes occurred in the middle section, farther from the river at both low and high tides (Fig. 15B). The Red-necked Grebe was the only grebe that used the outer section as much as the middle section (Fig. 15B).

Of the diving ducks, Buffleheads, Common Goldeneyes, Surf Scoters, Greater Scaups, and Common Mergansers were the most numerous species present in the Somass River estuary in April. All species, except the Surf Scoter, had their highest densities at both low and high tides in the inner section of the estuary (Fig. 15C). Middle and outer sections were as important as or more important than the inner section as habitats for Surf Scoters.

6. Discussion

6.1 Overall bird numbers and densities

The large water bird population in the Barkley Sound estuarine area in March was the result of tens of thousands of birds feeding upon herring eggs. The surveyed area in Barkley Sound is one of the largest spawning grounds of Pacific herring *Clupea harengus pallasi* on the west coast of Vancouver Island (Hay et al. 1989); herring regularly spawn there in March. Because of the large number of birds concentrating in Barkley Sound in March, the combined numbers and densities of birds present in the eight estuaries peaked in that month too.

The seasonal composition of the bird population of the estuaries is very different if the Barkley Sound data are omitted; the overall numbers and densities of birds in the other seven estuaries peaked in fall and early winter. The elevation of bird numbers in fall and early winter is typical for the water bird population in estuaries (Vermeer and Levings 1977; Butler et al. 1989) and fjords of the British Columbia coast (Morgan 1989; Vermeer 1989; Vermeer and Morgan, this volume). In British Columbia, the exceptions to this are the herring spawn areas, where water bird numbers peak in March (Vermeer 1981).

6.2 Bird composition and seasonal changes

Loons, grebes, cormorants, and alcids are piscivores; a possible explanation for why those species made up a relatively small portion of the total water bird population is that estuaries, with their generally large intertidal and shallow subtidal gravel, mud, and sandflats, attract predominantly shore and benthic foragers. Western Grebes, which were seen more frequently at the outer edge than inside estuaries, entered the Somass River estuary in large numbers in April, where they fed upon juvenile salmon (Vermeer, this volume), which then leave the Somass River to enter the estuary (B. Hargreaves, pers. commun.).

Gulls and ducks made up the vast majority of birds visiting the estuaries, perhaps as most of them are shore and benthic foragers on marine invertebrates (Vermeer and Ydenberg 1989). Gulls and ducks are also opportunistic foragers; when another temporary and abundant food item becomes available, they switch from their staples to that source. A notable example of such a switch was the large number of

Table 1
Comparison of densities of selected bird species, showing distinct differences in the utilization of the Sarita and Somass river estuaries during the period of maximal bird use (September 1987 through early May 1988)

Species	No. of birds/km²									Average no. of birds/km²
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	
Sarita River										
Western Grebe	–	–	12.5	16.4	–	–	–	–	32.4	6.8
Mallard	–	–	10.2	0.4	3.1	0.8	0.8	2.3	5.5	2.6
American Wigeon	–	–	–	–	–	–	–	–	–	0
Greater Scaup	–	–	–	–	–	–	–	–	0.4	0.04
White-winged Scoter	–	48.0	33.2	25.0	35.9	–	7.0	–	1.2	16.7
Surf Scoter	8.6	234.4	638.7	530.1	48.4	37.5	56.3	221.5	232.0	223.1
Barrow's Goldeneye	–	–	106.3	159.0	56.3	15.6	65.2	139.1	70.3	68.0
Glaucous-winged Gull	–	37.5	65.2	32.8	14.8	139.5	9.0	11.7	5.5	35.1
Thayer's Gull	–	–	8.6	4.7	152.3	48.0	–	–	–	23.7
Somass River										
Western Grebe	2.5	4.3	1.8	1.4	–	4.7	32.6	194.9	165.2	45.3
Mallard	76.8	5.8	27.2	10.9	–	–	0.7	5.1	1.1	14.2
American Wigeon	47.1	21.7	54.3	–	–	–	–	13.0	–	15.1
Greater Scaup	–	9.1	14.5	–	5.4	17.4	34.1	31.9	54.7	18.6
White-winged Scoter	–	–	–	–	–	–	–	0.4	–	0.04
Surf Scoter	5.1	17.8	26.4	2.9	24.3	11.6	81.9	10.9	24.3	22.8
Barrow's Goldeneye	–	–	–	–	3.6	–	4.0	–	–	0.8
Glaucous-winged Gull	38.0	157.6	187.7	500.0	139.1	96.7	9.4	12.3	2.5	127.0
Thayer's Gull	–	–	15.6	4.3	3.6	9.4	–	–	–	3.7

Glaucous-winged, Thayer's, and Mew gulls, as well as Surf Scoters and Barrow's Goldeneyes, feeding upon herring spawn in Barkley Sound in March. Herring spawn was observed in the stomachs of all those species examined for food contents in the Barkley Sound estuarine area in March (Vermeer, this volume).

6.3 Differences between and within estuaries

Differences in species composition and bird densities between estuaries appear to be food related, as evidenced from the large number of gulls and scoters observed feeding upon herring eggs in Barkley Sound in March and the influx of Western Grebes into the Somass River estuary in April, apparently to feed upon juvenile salmon. Higher densities of Barrow's Goldeneyes and Surf Scoters in the Sarita River than in the Somass River estuary, as well as the presence of White-winged Scoters at the former and their absence at the latter, may relate to an abundance of blue mussels *Mytilus edulis* at the Sarita River estuary and the relative scarcity of these mussels at the Somass River estuary (KV, pers. obs.). Blue mussels are staple foods for both Barrow's Goldeneyes and Surf Scoters (Vermeer 1981), as well as being an important prey of White-winged Scoters in British Columbia (Vermeer and Bourne 1984). The relative scarcity of blue mussels at the Somass River estuary may be the result of the estuarine delta being covered with log debris, which smothers mussels and other bivalves, or contamination by effluent from the Port Alberni Paper Mill (Waldichuk 1956; Parker and Siebert 1972). The Sarita River is far from the mill and presumably suffers little or no contamination.

The reasons for high densities of many bird species at Sooke Harbour estuary, as well as the differences in species composition between the four small estuaries in Clayoquot Sound, are not understood, but might be food related. In Sooke Harbour, the high density of cormorants, which perch on beacons and pilings, might also be related to the high number of beacons and pilings present in that estuary.

Differences in bird composition and densities within the three sections of the Somass River estuary are not understood. A detailed study of the diet of the birds in those sections may explain the distribution pattern of the various species. That most water birds use the inner section of the estuary is not surprising, as marine invertebrate prey is more accessible to birds in shallow than in deep water. Morgan et al. (1987) observed a negative relationship between tide height and feeding activity of many species of water birds in Saanich Inlet on the east coast of Vancouver Island. Also, juvenile salmon entering the estuary from the Somass River concentrate at the river mouth and in the inner section and are fed upon by Common Mergansers and Western Grebes before dispersing farther into Alberni Inlet (Vermeer, this volume).

7. Conclusions and recommendations

The investigation of water bird populations on the southwest coast of Vancouver Island shows that each estuary is unique in its bird composition. Because estuaries are among the most important feeding habitats of water birds on the British Columbia coast, each individual estuary is worth preserving from environmental disturbances.

Chemical pollution affects birds in several estuaries on the southwest coast of Vancouver Island. One source of chemical pollution is bleached kraft effluents from the Port Alberni Paper Mill, located at the mouth of the Somass River. Those effluents contain highly toxic dibenzofurans and dibenzodioxins. The highest dioxin and furan residue levels in British Columbia have been found in the livers of Common Mergansers *Mergus merganser* and Western and Red-necked grebes collected from the Somass River estuary in April 1989 (KV, unpubl. data).

Another source of chemical pollution is oil spillage, which was observed to affect birds using the Sooke River estuary. One unexplained oil spill on 23 November 1989 off Whiffin Spit, a barrier head separating Sooke Harbour estuary from Juan de Fuca Strait, contaminated 200 seabirds before drifting into Sooke Harbour to pollute beaches (*Times Colonist*, 24 November 1989). The following species of oiled birds were still observed during our regular survey, four days after the spill: Common Loons, Red-necked Grebes, Buffleheads, Surf Scoters, Red-breasted Mergansers, Glaucous-winged Gulls, Mew Gulls, Herring Gulls, and one dead Common Murre. Hay

Figure 13
Comparison of densities of Western Grebes, Trumpeter Swans, Bonaparte's Gulls, American Wigeons, and White-winged Scoters in four Clayoquot Sound estuaries

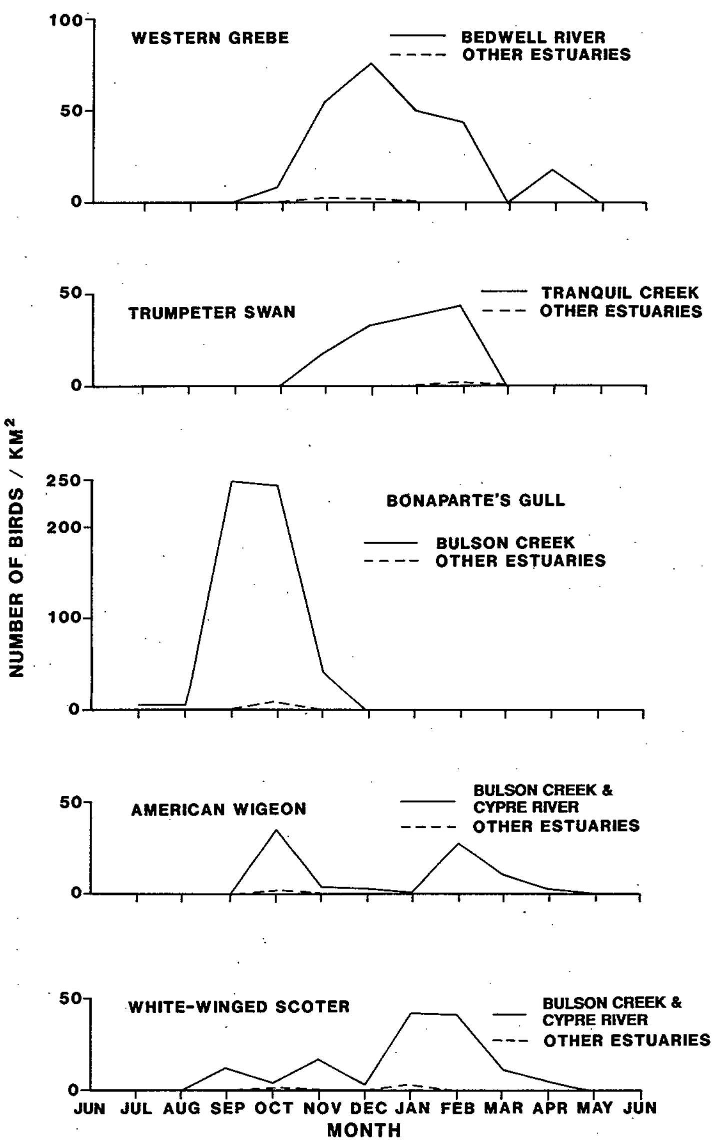
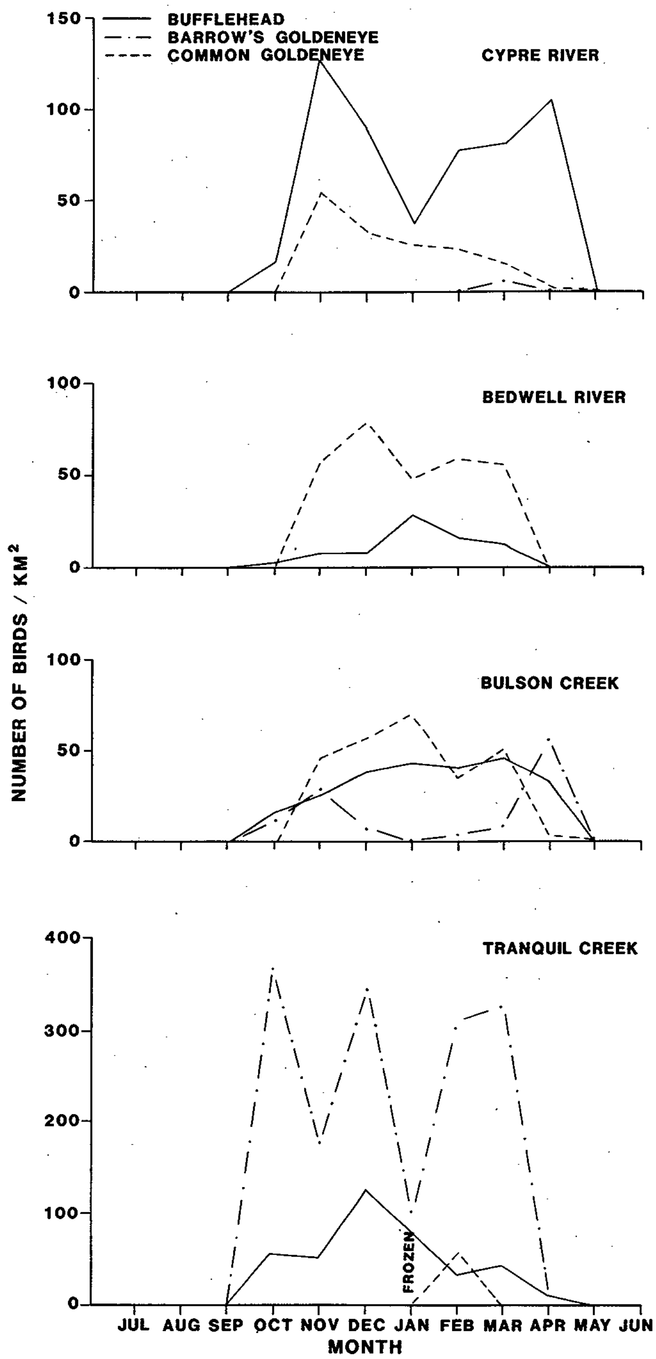


Figure 14
Comparison of densities of three *Bucephala* species in four Clayoquot Sound estuaries



(1987) observed the following oiled birds in Sooke Harbour and vicinity as a result of an oil spill occurring in Juan de Fuca Strait in the first week of January 1986: Yellow-billed *Gavia adamsii* and Common loons, Horned and Eared *Podiceps nigricollis* grebes, Buffleheads, Barrow's and Common goldeneyes, and Common Murres. Many of the birds probably became oiled in Juan de Fuca Strait and sought refuge in Sooke Harbour, whereas others probably were contaminated from the oil that drifted into the Sooke Harbour estuary. As both Sooke Harbour and the Somass River estuaries are frequently used by boaters and have extensive docking facilities, water birds might also become contaminated by oil leaking from boats at those facilities.

Campbell Prentice and Boyd (1988) reported that extensive human development, including log handling and storage areas, pulp mills, and marinas, had led to more than a 30% decline in estuarine habitats along the east coast of Vancouver Island. Although the amount of habitat loss on the west coast is likely to be far less, a study should be undertaken to quantify the historical and present extent of estuaries. Extensive human development in Somass River and Sooke Harbour estuaries has already resulted in significant habitat loss for water birds (pers. obs.). We also recommend that no further development occur in estuaries and that all sources of chemical contamination within estuaries be either significantly reduced or eliminated.

8. Acknowledgements

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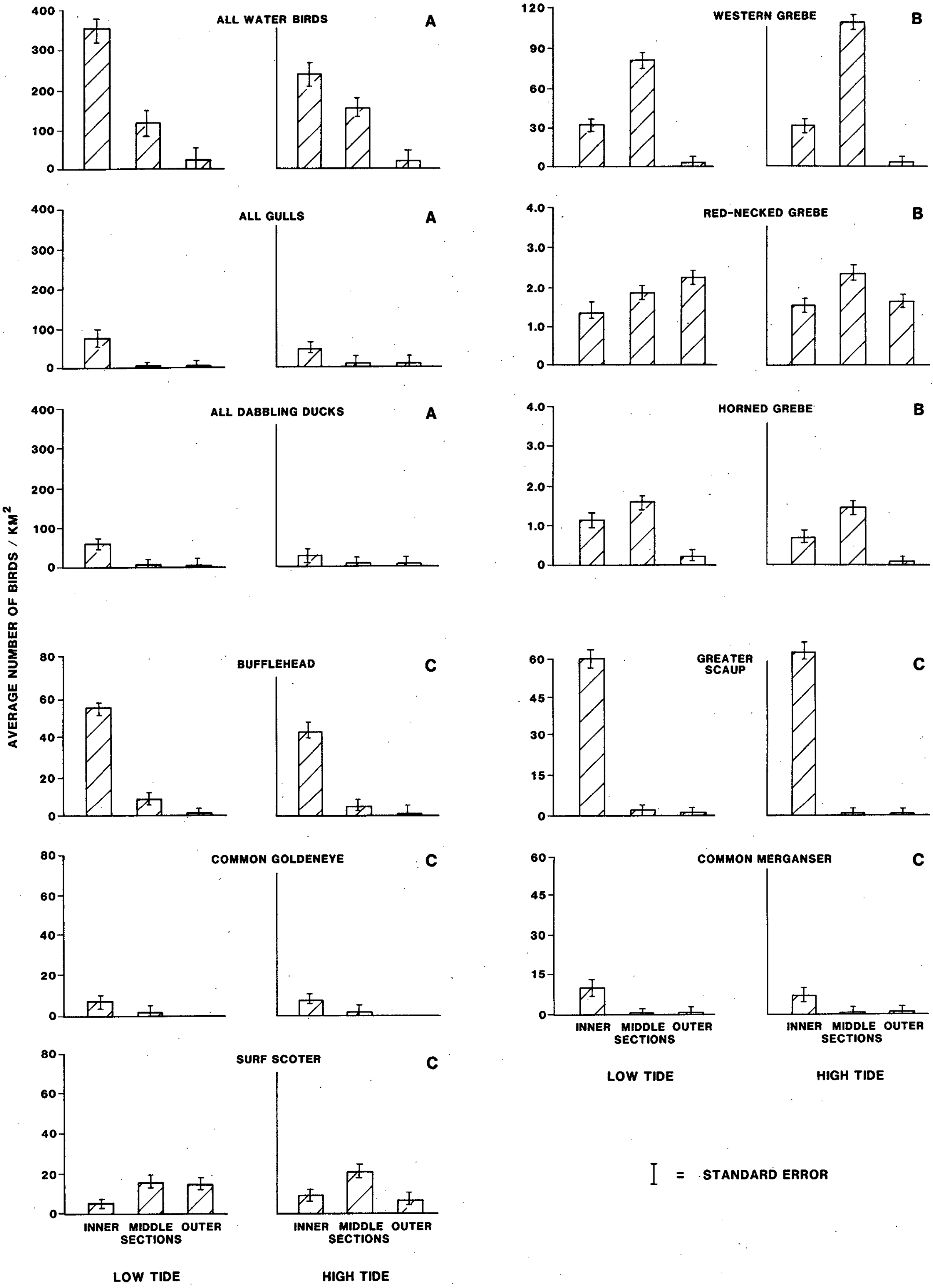
Figure 15
Comparison of densities of water birds in three sections of the Somass River estuary, at both low and high tides: A. Total number of water birds, gulls, and dabbling ducks. B. Western, Red-necked, and Horned grebes. C. Buffleheads, Common Goldeneyes, Surf Scoters, Greater Scaups, and Common Mergansers.



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Seasonal abundance and biomass of birds in eelgrass habitats in Browning Passage on the west coast of Vancouver Island

Robert W. Butler, Adrian Dorst, and Mark A. Hobson

1. Abstract

The Western Sandpiper *Calidris mauri* was the most abundant bird species seen in Browning Passage over a one-year period and was most plentiful in April and August. Shorebirds as a group made up less than 2% of the annual bird biomass. Geese, diving ducks, and dabbling ducks made up nearly 34% of all birds seen through the year and nearly 80% of the bird biomass. They were least abundant in summer. The mean density of birds in Browning Passage in winter (434 birds/km^2) exceeded the mean densities of water birds in inlets and bays and was similar to densities in estuaries in British Columbia. Browning Passage holds the only mudflats on the west coast of Vancouver Island known to support large numbers of shorebirds. Its shorebird and water bird populations exceed the criteria for sites of international significance under the Convention on Wetlands of International Importance especially as Waterfowl Habitat (the "Ramsar" Convention). The mudflats support regionally significant shorebird populations under the criteria of the Western Hemisphere Shorebird Reserve Network.

2. Résumé

Le Bécasseau d'Alaska *Calidris mauri* était l'espèce la plus abondante observée dans le passage Browning sur une période d'un an, et c'est en avril ainsi qu'en août qu'elle était la plus nombreuse. Le groupe d'oiseaux de rivage représentait moins de 2 % de la biomasse aviaire annuelle. Près de 34 % de tous les oiseaux observés pendant l'année étaient des oies et bernaches, des canards plongeurs et canards de surface, et ils représentaient presque 80 % de la biomasse aviaire. Ils étaient le moins abondants durant l'été. En hiver, la densité moyenne de population des oiseaux dans le passage Browning (434 par km^2) était supérieure à celle des oiseaux dans les bras de mer et les baies, mais semblable aux densités observées dans les estuaires de la Colombie-Britannique. Les seules slikkes de la côte ouest de l'île de Vancouver dont on sait qu'elles sont fréquentées par un grand nombre d'oiseaux de rivage se trouvent dans le passage Browning. Ses populations d'oiseaux de rivage et aquatiques sont supérieures aux critères fixés pour les sites d'importance internationale par la Convention relative aux zones humides d'importance internationale particulièrement comme habitats des oiseaux d'eau (la Convention de « Ramsar »). Les slikkes sont fréquentées par des populations d'oiseaux de rivage d'importance régionale, selon les critères du Réseau de réserves pour les oiseaux de rivage dans l'hémisphère occidental.

3. Introduction

The British Columbia coast is an important migration corridor for Pacific coast migrants and the most important wintering area for birds in Canada (Butler and Campbell 1987; Butler and Vermeer 1989). The moderate climate and abundant food supplies attract millions of shoreline birds along the length of the coast. Large numbers concentrate in estuaries in the Strait of Georgia (Butler and Campbell 1987; Butler and Cannings 1989; Butler et al. 1989), and smaller numbers use inlets (Richardson 1971; Morgan 1989; Vermeer 1989; Vermeer and Morgan, this volume). Eelgrass *Zostera marina* beds are important to birds elsewhere on the Pacific coast (reviewed by Phillips 1984), but information on bird use of eelgrass beds in British Columbia is scant. A few studies have shown that eelgrass beds are used by many waterfowl (Vermeer and Levings 1977; Butler and Campbell 1987) and some shorebirds (Butler and Kaiser 1988; Butler et al. 1989).

The aim of this paper is to describe the seasonal abundance and biomass of birds in eelgrass habitat in Browning Passage and compare them with those of other coastal habitats in British Columbia.

4. Study area and methods

4.1 Study area

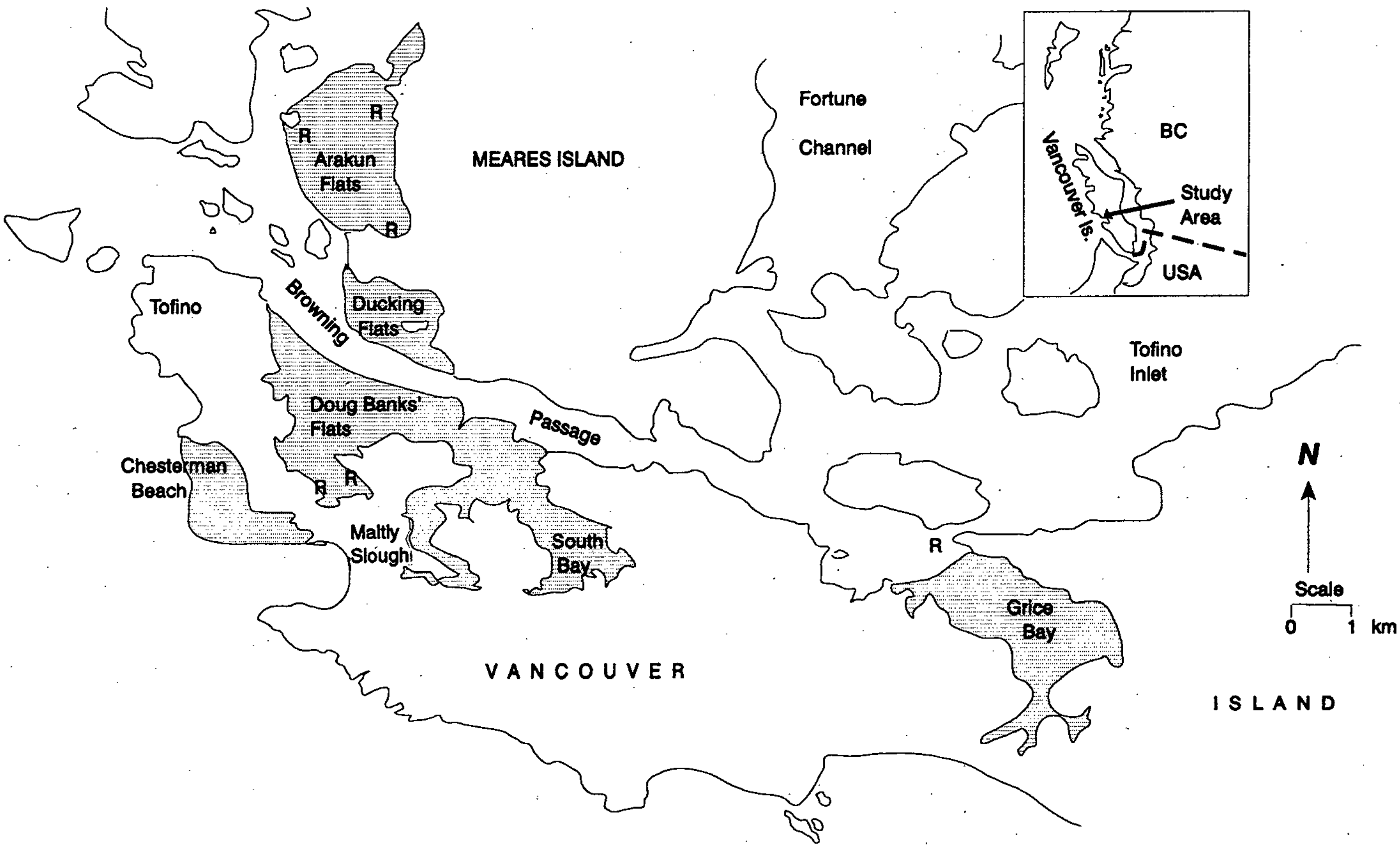
Browning Passage, near the town of Tofino (49°10′N, 125°90′W), is mostly a deep-water channel with mudflat margins (Fig. 1). The six mudflats are known locally as Arakan Flats, Ducking Flats, Doug Banks' Flats, Maltly Slough, South Bay, and Grice Bay. Forests and narrow salt marshes line the upper tide line. About half of the 32-km^2 study area is uncovered during the lowest tides, leaving about 16 km^2 of exposed mudflat. The mudflats are partly covered by dense growths of eelgrass and algae (*Ulva* and *Enteromorpha*). Chesterman Beach is a wave-washed, clean sand beach with tangles of driftwood along the upper tide line.

4.2 Methods

4.2.1 Spring and summer population estimates

Birds were counted from a boat in Browning Passage and from the ground on Chesterman Beach twice each week between 18 April and 26 May 1988, on 13 and 20 July 1988 and on 12 and 29 August 1988, and twice each week between 15 August and 6 October 1989. Flocks with fewer than about 200 sandpipers were counted directly. Flocks exceeding 200 sandpipers were estimated by counting 50 or 100 birds in the

Figure 1
Location of mudflats, beaches, and high-tide shorebird roost sites (R) in Browning Passage



flock and then estimating how many similar-sized groups made up the entire flock.

4.2.2 Fall and winter population estimates

All birds in Browning Passage were counted from Cessna 172, Cessna 185, and Beaver aircraft 3–5 times each month in September 1985 and from November 1985 to April 1986. The airplane flew at an altitude of about 50–75 m. Two observers sat on the same side of the airplane and reported estimates of the size of each flock into a tape recorder. Data were lumped into groups—for example, grebes, dabbling ducks, and gulls—because there was insufficient time to count each species.

4.2.3 Seasonal use of mudflats and eelgrass beds

We determined the mean number of each bird group from the maximum numbers counted each month in spring, summer, autumn, and winter. We estimated the seasonal biomass of each bird group by multiplying the seasonal mean number calculated earlier by the mean mass (Dunning 1984) of each species in that group.

4.2.4 Spatial use of mudflats by shorebirds

We determined how shorebirds were distributed in the habitat in spring and summer by comparing the total number of shorebirds on the area of each of six mudflats in Browning Passage and Chesterman Beach.

5. Results

5.1 Seasonal abundance of birds

5.1.1 Loons, grebes, cormorants, and herons

Loons, grebes, and cormorants used the inlet mostly outside the summer (Table 1). Loons and cormorants were most abundant in December, and grebes in both December and March. The most numerous species in this group were the Common Loon *Gavia immer*, Pacific Loon *G. pacifica*, Western Grebe *Aechmophorus occidentalis*, and Pelagic Cormorant *Phalacrocorax pelagicus*. The Great Blue Heron *Ardea herodias*, the only species of heron we saw, was present year-round and most numerous in September. No local breeding colony has been found. Loons, grebes, cormorants, and herons made up less than 2% of the birds we counted and about 10% of the biomass (Table 2).

5.1.2 Swans, geese, and ducks

Trumpeter Swans *Cygnus buccinator* were recorded in November (5), December (14), January (12), and February (10) (Table 1) and formed less than 1% of the biomass. Thousands of Canada Geese *Branta canadensis* and Brant *B. bernicla* migrate along the west coast of Vancouver Island in April, but few stop in Browning Passage. A few hundred Canada Geese and fewer than 100 Brant were counted in spring. The heaviest use by Canada Geese occurred in autumn (Table 1). Geese made up over 17% of the annual biomass of birds in Browning Passage (Table 2).

Table 1
Maximum numbers of birds counted in Browning Passage in spring, summer, autumn, and winter, 1988–89

	Maximum no. of birds					
Bird group	Spring	Summer	Autumn	Winter	Total	%
Loons	31	2	17	63	113	0.1
Grebes	99	0	62	86	247	0.2
Cormorants	147	0	196	552	895	1.0
Herons	24	75	124	38	261	0.3
Swans	0	0	5	14	19	<0.1
Geese	150	0	1 320	470	1 940	2.1
Dabbling ducks	2 312	840	5 262	3 578	11 992	12.9
Diving ducks	6 619	0	6 435	6 184	19 238	20.7
Gulls	987	2 000	2 482	583	6 052	6.5
Shorebirds	16 000	23 000	13 000	252	52 252	56.2
Total	26 369	25 917	28 903	11 820	93 009	
%	28.4	27.9	31.1	12.7		

Table 2
Percentage of total biomass of birds using mudflats and eelgrass habitats in Browning Passage in spring, summer, autumn, and winter, 1988–89

	% of total				Total biomass	
Bird groups	Spring	Summer	Autumn	Winter	(kg)	%
Loons	1.7	0.3	0.9	2.0	1 365	1.5
Grebes	1.4	0	0.9	1.5	1 102	1.2
Cormorants	2.9	0	2.6	7.7	4 194	4.5
Herons	1.1	12.5	4.2	1.0	2 528	2.7
Geese	7.7	0	30.9	11.2	15 935	17.1
Dabbling ducks	17.7	20.0	16.0	25.0	18 647	20.0
Diving ducks	56.7	0	31.9	48.3	39 099	42.0
Gulls	8.5	53.8	11.6	3.3	8 980	9.6
Shorebirds	2.4	13.4	0.9	<0.1	1 330	1.4
Total biomass (kg)	19 513	4 121	33 824	35 722	93 180	
% total	20.9	4.4	36.3	38.3		

Dabbling ducks were most numerous in November and remained plentiful through winter (Table 1). Diving ducks were abundant through autumn and winter and were most numerous in spring (Table 1). The most numerous species of ducks were the Mallard *Anas platyrhynchos*, Northern Pintail *A. acuta*, American Wigeon *A. americana*, Surf Scoter *Melanitta perspicillata*, and Bufflehead *Bucephala albeolis*. Diving and dabbling ducks were the second and third most numerous bird groups, respectively (Table 1), and held the most (42.0% and 20.0%) biomass of all bird groups through the year (Table 2).

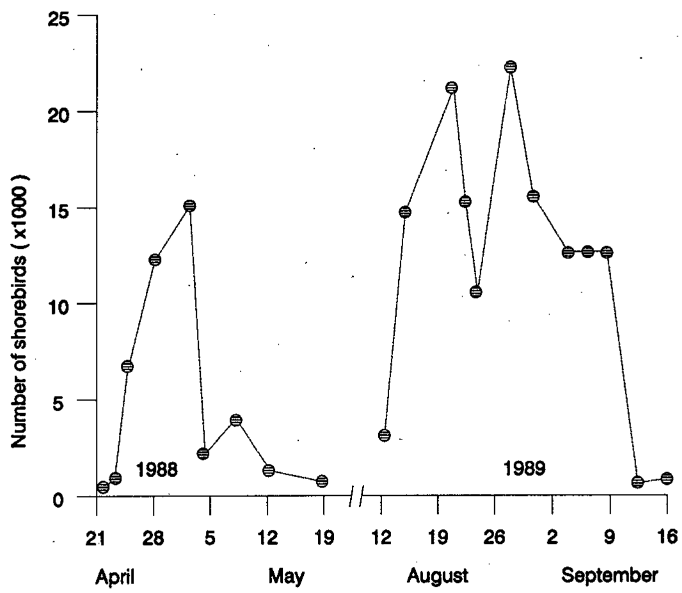
5.1.3 Gulls

Gulls were most prevalent in August and September, when large numbers of California Gulls *Larus californicus* arrived in Browning Passage (Table 1). The California Gull feeds on offal thrown from factory fishing boats along the west coast (Vermeer, this volume). The endemic Glaucous-winged Gull *L. glaucescens* is abundant on nearby Cleland Island but does not visit beaches in Browning Passage until the breeding season ends in August. Mew Gulls *L. canus* arrived in March and April to feed upon Pacific herring *Clupea harengus pallasi* and breed on nearby lakes (Vermeer and Devito 1986). Gulls made up about 7% of the numbers of birds counted (Table 1) and 10% of the biomass in Browning Passage (Table 2).

5.1.4 Shorebirds

More than half the birds seen in Browning Passage were shorebirds (Table 1), but they held less than 2% of the biomass (Table 2). Shorebirds reached a peak of 16 000 birds in April and 23 000 in August (Fig. 2). More than 90% of the shorebirds were Western Sandpipers *Calidris mauri*. Small flocks of Dunlin *Calidris alpina*, Sanderling *C. alba*, and American Black Oystercatchers *Haematopus bachmani* were present between November and April. A Western Sandpiper banded in Panama was seen by D. Axtel on Long Beach a few kilometres south of Browning Passage on 15 May 1990, and a Sanderling banded on the Oregon coast was seen on Long Beach by M. Price and J. Luce on 13 May 1990.

Figure 2
Number of shorebirds counted during low tide on mudflats and beaches in Browning Passage in April and May 1988 and August and September 1989



5.1.5 Other species

We recorded 1–5 Bald Eagles *Haliaeetus leucocephalus* on every visit. Northwestern Crows *Corvus caurinus* became more numerous through the winter. The greatest numbers by month were 60 in September, 150 in November, 125 in December, 410 in January, 100 in February, and 405 in March. One or two Merlins *Falco columbarius* and Peregrine Falcons *F. peregrinus* were present on surveys during the shorebird migration in April and July through September.

5.2 Densities and biomass of birds

The greatest density of birds occurred in April (700/km^2) and August (800/km^2), when the main shorebird migration occurred. Densities were also high in November (500 birds/km^2), when most of the waterfowl returned to the coast. However, the greatest bird biomass occurred in winter (38.3%) and autumn (36.3%) (Table 2). In contrast, only about 21% of the total annual biomass occurred in spring and less than 5% in summer. Diving ducks held most of the seasonal biomass in spring and winter, diving ducks and geese in autumn, and gulls in summer.

About 37% of the total biomass was held by herbivores (geese and dabbling ducks), about 53% was held by invertebrate-feeders (diving ducks, gulls, and shorebirds), and 10% was held by piscivores (loons, grebes, cormorants, and herons) (Table 2).

5.3 Spatial distribution of shorebirds

The numbers of foraging shorebirds were positively and significantly correlated with the area of each mudflat and beach

Table 3
Area and total number of shorebirds counted on six mudflats and one beach near Tofino

Site	Area ha	Area %	No. of shorebirds Total	No. of shorebirds %	Density (no. of birds/ha)
Arakan Flats	433	26.4	148 266	56.1	342.4
Ducking Flats	147	8.9	6 296	2.4	42.8
South Bay	213	13.0	30 057	11.4	141.1
Maltly Slough	229	13.9	30 678	11.6	134.0
Doug Banks' Flats	345	21.0	21 879	8.3	63.4
Chesterman Beach	85	5.2	19 837	7.5	233.4
Grice Bay	182	11.1	7 079	2.7	38.9

(Spearman Rank $r_s = 0.786$, $P = 0.05$). Arakan Flats, the largest mudflat, supported over half of the shorebirds (Table 3). The remaining six mudflats and Chesterman Beach each supported about 2–12% of the shorebirds. Most shorebirds gathered at four roost sites when high tides pushed them off the beaches (Fig. 1).

The abundant (>1000 birds) species were widespread in the study area. Dowitchers (*Limnodromus* spp.), Dunlins, Least Sandpipers *Calidris minutilla*, and Western Sandpipers were seen on all seven sites, Black-bellied Plovers *Pluvialis squatarola* and Greater Yellowlegs *Tringa melanoleuca* on six sites, and Whimbrels *Numenius phaeopus* on four sites. The remaining species were too few in number to determine if they selected certain sites.

6. Discussion

6.1 Seasonal patterns of use

Browning Passage is a migratory staging area for water birds that breed in Alaska and western Canada. Migrants from Alaska include the Canada Goose, Western Sandpiper, Short-billed Dowitcher *Limnodromus griseus*, Northern Pintail, and Green-winged Teal *Anas crecca*. The California Gull and Western Grebe nest in the Canadian prairies. The Surf Scoter, Bufflehead, and Barrow's Goldeneye breed in central British Columbia and the Northwest Territories (American Ornithologists' Union 1983).

Browning Passage is an important wintering area for many western North American species such as loons, grebes, the Trumpeter Swan, dabbling ducks, and diving ducks. Some species that breed locally use the inlet mostly outside their breeding season, including the American Black Oystercatcher, Mew Gull, Great Blue Heron, and Pelagic Cormorant (Hatler et al. 1978; Hartwick and Blaylock 1979; Vermeer and Devito 1986; Butler 1989). The Bald Eagle, Northwestern Crow, and Glaucous-winged Gull are mostly beach predators and scavengers that reside on the west coast.

The increase in numbers of gulls in March (Table 1) coincides with the spawning season of Pacific herring on beaches along the west coast of Vancouver Island. Thousands of water birds gather to feast on herring spawn on the west coast of Vancouver Island (Rodway 1989) and Alaska (Norton et al. 1990) in late winter and early spring. Other birds did not increase appreciably in number in Browning Passage during our winter and spring censuses (Table 1). Our findings suggest that herring did not spawn near Browning Passage when we did our counts or that large numbers of loons, grebes, cormorants, herons, and diving ducks did not immigrate to Browning Passage when herring spawned nearby.

Table 4
Range of bird densities in five coastal habitats in British Columbia

Habitat	No. of studies	Range of densities (birds/km^2)	References
Open water	3	2.4–36.4	Vermeer 1989 Vermeer and Morgan, this volume Morgan 1989
Rocky shore	3	21.7–76.4	Vermeer 1989 Vermeer and Morgan, this volume Morgan 1989
Bays	2	73.2–165.2	Vermeer 1989 Vermeer and Morgan, this volume Morgan 1989
Estuaries	11	96.3–3260	Vermeer 1989 Vermeer and Morgan, this volume Morgan 1989 Butler et al. 1987 Data in Butler and Cannings 1989
Eelgrass	2	434–6690	This study Data in Butler and Cannings 1989

6.2 Significance of Browning Passage to west coast birds

Waterfowl are the primary herbivores in eelgrass beds along the Pacific coast. Eelgrass beds also support large populations of epibenthos, infauna, and nektonic animals that are food for a rich diversity of birds (Phillips 1984). Our results indicate that eelgrass beds in Browning Passage support some of the highest water bird densities in British Columbia (Table 4).

The waterfowl biomass in the estuarine marshes and eelgrass beds of the Fraser River delta is overwhelmingly held by dabbling ducks (85.5%); diving ducks hold only 14.5% (Vermeer and Levings 1977). The opposite is true in Browning Passage, where about one-third of the waterfowl biomass is held by dabbling ducks and two-thirds by diving ducks (Table 2). Browning Passage probably attracts a smaller proportion of dabblers because it lacks the estuarine marshes and farmlands found on the Fraser River delta.

As noted by Butler and Kaiser (1988), the mudflats in Browning Passage are second only to the Fraser River delta in importance as feeding and resting sites for Western Sandpipers in British Columbia. Browning Passage contains the largest eelgrass beds on the west coast of Vancouver Island and deserves adequate protection.

Criteria by which to judge the importance of sites to water birds are set out in two international programs—The Convention on Wetlands of International Importance especially as Waterfowl Habitat (the "Ramsar" Convention) and the Western Hemisphere Shorebird Reserve Network (WHSRN). Criteria for inclusion under the "Ramsar" Convention require a site to support 20 000 water birds annually. Reserve membership in the WHSRN system requires that at least 20 000 shorebirds, or 5% of a flyway population, use the site each year. Clearly, Browning Passage exceeds the criteria required for a Wetland of International Importance under the Ramsar program and a Regional Reserve under the WHSRN program.

7. Acknowledgements

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Summer distribution and abundance of Marbled Murrelets on the west and east coasts of Vancouver Island

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1. Abstract

We surveyed Marbled Murrelets *Brachyramphus marmoratus* along 576 km of transects on the west coast of Vancouver Island and along 590 km of transects on the east coast in May, June, and July 1991. The distribution of Marbled Murrelets was clumped in all surveyed areas. None of the inlets surveyed supported any large numbers of murrelets. Most Marbled Murrelets were located just outside these inlets, in more open waters. In order to adequately determine murrelet abundance in a given area, surveys should be conducted on a regular basis throughout the year.

2. Résumé

Un relevé des Alques marbrées *Brachyramphus marmoratus* a été effectué sur 576 km de transects de la côte ouest de l'île de Vancouver et 590 km de transects de la côte est de l'île en mai, juin et juillet 1991. Les alques étaient réparties par groupes dans toutes les zones examinées. Aucun des bras de mer explorés n'était fréquenté par d'importants groupes d'alques. La plupart des Alques marbrées se tenaient juste à l'extérieur de ces bras, dans des eaux plus libres. Pour bien déterminer le nombre d'alques dans une zone donnée, des relevés devraient être effectués régulièrement durant toute l'année.

3. Introduction

Marbled Murrelets *Brachyramphus marmoratus* are generating much concern in British Columbia because of their association with old-growth forests during the nesting season. During the past few years, research efforts have been initiated to further our understanding of Marbled Murrelet ecology (Rodway et al. 1991; Kaiser et al. 1991; Manley et al., this volume).

Two Marbled Murrelet nests have been located in British Columbia (Manley et al., this volume). Studies in the United States suggest that the species probably nests not in colonies but rather in a dispersed fashion (Simons 1980; Day et al. 1983; Nelson et al. 1987; Marshall 1988; Varoujean et al. 1989; Quinlan and Hughes 1990; Singer et al. 1991). Although survey techniques have been developed to monitor inland murrelet activities (Paton et al. 1988; Nelson 1989), these activities and their relationship to actual numbers of birds utilizing an area are still poorly understood (Rodway et al. 1991), and they cannot yet provide absolute estimates of murrelet abundance. To derive population estimates of Marbled Murrelets, at-sea census techniques have been developed (Robertson 1974; Manuwal et al. 1979; Wahl et al. 1981; Gould et al. 1982; Sealy and Carter 1984; Rodway 1990).

As part of a larger study of Marbled Murrelets on Vancouver Island, we conducted several at-sea surveys. Our objective was to compare the distribution and abundance of Marbled Murrelets along the west and east coasts of Vancouver Island during the breeding season.

4. Methods and study area

We surveyed 576 km of transects along the west coast of Vancouver Island and 590 km of transects along the east coast in May, June, and July 1991. These transects were located nonrandomly within 10 different survey areas (Fig. 1).

Surveys were conducted from a small inflatable boat during daylight hours. May surveys were conducted with three observers, whereas June and July surveys were done with two observers. Most transects followed the shoreline approximately 200 m offshore. All birds seen on each side of the boat were recorded. Transects had no fixed width, although in most cases birds could rarely be detected beyond 200 m.

Place names referred to in the text are from nautical charts. Surveys were divided into transects of varying lengths (1.1–54 km), depending upon shoreline features. We classified the west coast transects into "inlets," "channel or passage," and "open."

Our survey results are presented as the number of birds per kilometre of transect and also by square kilometre, using an assumed width of 400 m per transect.

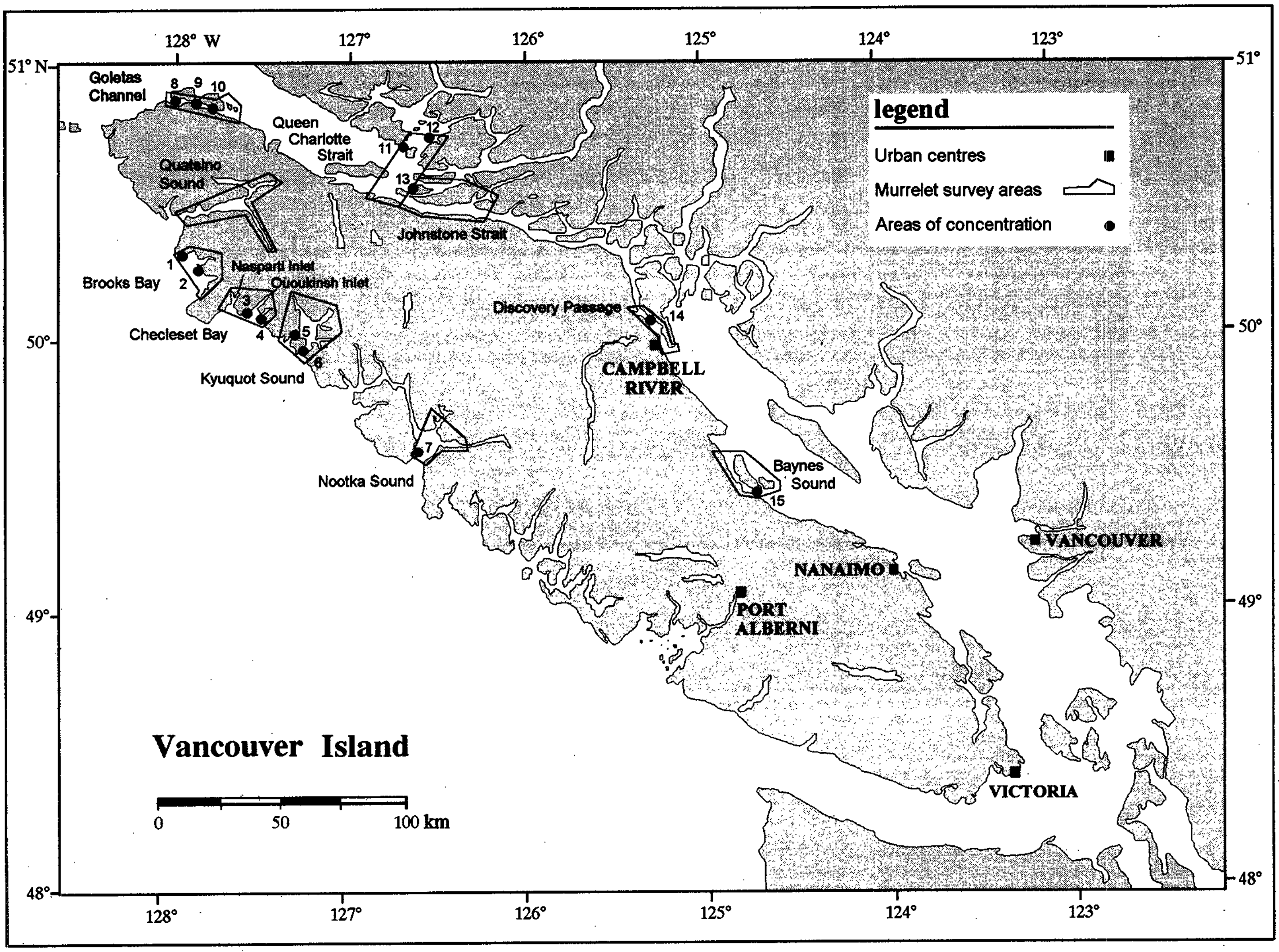
5. Results

5.1 West coast of Vancouver Island

Marbled Murrelets were rarely seen in Quatsino Sound (0.1 birds/km^2), with a maximum of six birds seen during one of the four surveys (Table 1). The Brooks Bay area supported the highest densities of murrelets ($\bar{x}$ = 7.5/km^2) (Table 1). However, Marbled Murrelets were not uniformly distributed throughout this section but concentrated in two areas (Fig. 1, Table 2). Few murrelets were seen in either Klaskino Inlet or Klaskish Inlet. The Checleset Bay area had lower densities of murrelets than Brooks Bay ($\bar{x}$ = 1.8/km^2). Murrelets occurred mainly in two groups of less than 30 birds located outside the inlets. The inside inlets, Ououkinsh and Nasparti, had few murrelets.

Murrelet density averaged 0.4 birds/km^2 in the Kyuquot Sound area. If we exclude the 16 May survey, a maximum of only two murrelets was seen in the remaining eight surveys. The murrelets seen on 16 May were mainly in two groups; comparable numbers were not seen in subsequent surveys of the same area (Fig. 1, Table 2). The inner inlets in the Nootka Sound area (Tlupana, Muchalat, Hisnit) were nearly devoid of murrelets,

Figure 1
Location of survey areas and areas of Marbled Murrelet concentrations observed during the study (see Table 2)



with densities averaging only 0.3 birds/km^2 (Table 1). The large number of Marbled Murrelets seen on 10 July was located between San Raphael Island and Maquinna Point (Fig. 1, Table 2).

5.2 East coast of Vancouver Island

Marbled Murrelet densities were generally higher on the east coast than on the west coast, ranging between 2.0 and 5.6 birds/km^2 in the five areas surveyed (Table 3). In Goletas Channel, most murrelets were seen in the section west-northwest of Shushartie Bay (Location 8–9, Fig. 1). Murrelet densities and the size of murrelet aggregations were lower and smaller in the Queen Charlotte Strait area than in Goletas Channel. Murrelets were seen mostly south of Eden Island (Location 11) and on the north side of Baker Island (Fife Sound, Location 12, Fig. 1). The Johnstone Strait area was adjacent to the Queen Charlotte Strait area, and murrelet densities were similar in both areas (Table 3). However, most murrelets were concentrated along the north shoreline of Hanson Island (Location 13, Fig. 1).

The highest densities of Marbled Murrelets on the east side of Vancouver Island occurred in Discovery Passage ($\bar{x}$ = 5.6 birds/km^2). Most birds were found between Race Point and the mouth of Campbell River (Location 14, Fig. 1). The two surveys in the Baynes Sound area provided different results, with more murrelets being detected during the 25 May survey (115, 3.7 birds/km^2) than during the 4 July survey (15, 0.6 birds/km^2).

5.3 Abundance in fjords, channels, and open water

The west coast of Vancouver Island, with its many fjords, has a more diverse oceanographic environment than the unbroken east coast. Murrelet abundance was lowest in the fjords (inlets), slightly higher in the channels and passages, and highest in open water at the entrance to inlets (Table 4).

6. Discussion

The distribution of Marbled Murrelets was clumped in all surveyed areas. A few locations showed seasonal stability in murrelet numbers, but others did not. Daily, weekly, and monthly variations in Marbled Murrelet numbers have been documented in numerous studies (Carter and Sealy 1984; Sealy and Carter 1984; Morgan 1989; Vermeer 1989; Rodway et al. 1991; Kaiser et al. 1991; Lawrence and Backhouse 1991; Vermeer and Morgan, this volume). This variability is likely related to variations in the timing of the surveys and local prey distribution, as well as, to an unknown extent, survey conditions.

Table 1
Results of boat surveys of Marbled Murrelets along the west coast of Vancouver Island, 1991

Area	Survey date	Transect length[a] (km)	No. of birds	No. of birds/km	No. of birds/km^2
Quatsino Sound	8 May	70.3	0	0.00	0.00
	10 May	94.1	2	0.02	0.05
	17 June	94.1	6	0.06	0.15
	18 June	111.4	5	0.04	0.10
Mean ± SE				0.03 ± 0.01	0.08 ± 0.03
Brooks Bay	20 June	38.5	74	1.92	4.80
	21 June	22.6	15	0.66	1.65
	22 June	46.0	213	4.63	11.58
	15 July	26.4	97	3.67	9.18
	17 July	24.8	100	4.03	10.08
Mean ± SE				2.98 ± 0.74	7.46 ± 1.84
Checleset Bay	27 June	21.8	13	0.60	1.50
	28 June	26.7	21	0.79	1.98
	29 June	35.3	17	0.48	1.20
	23 July	28.9	9	0.31	0.78
	24 July	26.9	24	0.89	2.23
	26 July	35.7	42	1.18	2.95
Mean ± SE				0.71 ± 0.13	1.77 ± 0.32
Kyuquot Sound	14 May	13.6	0	0.00	0.00
	15 May	26.4	0	0.00	0.00
	16 May	79.3	94	1.19	2.98
	19 May	19.3	2	0.10	0.25
	27 May	29.9	2	0.07	0.18
	1 July	29.4	0	0.00	0.00
	2 July	14.3	0	0.00	0.00
	23 July	20.8	2	0.10	0.25
	26 July	20.2	2	0.10	0.25
Mean ± SE				0.17 ± 0.13	0.43 ± 0.32
Nootka Sound	4 May	51.1	2	0.04	0.10
	5 May	66.2	5	0.08	0.20
	14 June	59.5	0	0.00	0.00
	15 June	51.4	15	0.29	0.73
	10 July	55.9	353	6.31	15.78
Mean ± SE without July survey				0.10 ± 0.06	0.26 ± 0.16
Mean ± SE with July survey				1.34 ± 1.24	3.36 ± 3.11

[a] Transect width assumed to be 0.4 km.

Table 2
Marbled Murrelet (MAMU) concentrations detected during the boat surveys[a]

Area	Location	Comments
West coast of Vancouver Island		
Brooks Bay	1	Newton Entrance: 79 MAMU seen on 22 June
	2	Between Heater Pt. and Sapir Pt.: 49 MAMU on 20 June, 102 on 22 June, 84 on 15 July, and 98 on 17 July
Checleset Bay	3	Battle Bay area: 21 MAMU on 28 June and 19 on 24 July
	4	NNW of Cole Rock: 28 MAMU on 26 July but only 4 on 23 July and 3 on 29 June
Kyuquot Sound	5	Between Hohoae Pt. and Chutsis Is.: 37 MAMU on 16 May but 0 on 1 July
	6	N of Volcanic Cove: 19 MAMU on 16 May but 0 on 15 May and 1 July
Nootka Sound	7	Between San Raphael Is. and Maquinna Pt.: 300 MAMU on 10 July
East coast of Vancouver Island		
Goletas Channel	8	Between Jepther Pt. across Tatnall Reefs to Nahwitti Pt.: 95 MAMU on 28 July
	9	Between Shushartie Bay and Jepther Pt: 132 MAMU on 13 July but only 7 on 28 July
	10	W of Lemon Point: 23 MAMU on 13 July but only 1 on 28 July
Queen Charlotte Strait	11	SW of Eden Island: 18 MAMU on 23 May and 28 on 24 June
	12	N side of Baker Island: 62 MAMU on 18 July
Johnstone Strait	13	N side of Hanson Is.: 74 MAMU on 25 June and 58 on 19 July
Discovery Passage	14	Race Point to the mouth of Campbell River: 57 MAMU on 3 July and 66 on 29 July
Baynes Sound	15	Off Mapleguard Pt.: 69 MAMU on 25 May but only 3 on 4 July

[a] Refer to Figure 1 for locations.

Table 3
Results of boat surveys of Marbled Murrelets along the east coast of Vancouver Island, 1991

Area	Survey date	Transect length[a] (km)	No. of birds	No. of birds/ km	No. of birds/ km^2
Goletas Channel	26 June	62.3	33	0.53	1.33
	13 July	83.8	182	2.17	5.43
	27 July	97.7	120	1.23	3.08
Mean ± SE				1.31 ± 0.48	3.28 ± 1.19
Queen Charlotte Strait	23 May	68.1	53	0.78	1.95
	24 June	68.1	55	0.81	2.03
	18 July	82.0	105	1.28	3.20
Mean ± SE				0.96 ± 0.16	2.39 ± 1.38
Johnstone Strait	20 May	64.0	3	0.05	0.13
	25 June	113.2	131	1.16	2.90
	19 July	57.5	69	1.20	3.00
Mean ± SE				0.80 ± 0.38	2.01 ± 0.94
Discovery Passage	3 July	30.7	74	2.41	6.03
	29 July	45.1	92	2.04	5.10
Mean ± SE				2.23 ± 0.19	5.57 ± 0.66
Baynes Sound	25 May	70.7	104	1.47	3.68
	4 July	61.6	15	0.24	0.60
Mean ± SE				0.86 ± 0.62	2.14 ± 1.54

[a] Transect width assumed to be 0.4 km.

None of the inlets surveyed on the west coast of Vancouver Island supported any large numbers of murrelets during summer. Most murrelets were observed just outside these inlets in more open areas. However, Vermeer and Morgan (this volume), who conducted a year-round census of Marbled Murrelets in one fjord on the west coast of Vancouver Island (Alberni Channel), observed that murrelets can occur in certain fjord habitats in much larger numbers in spring, fall, and winter than in summer. Those authors observed 30.8 murrelets/km^2 in Alberni Channel bays during November, which is a much higher density than we observed at any location during our survey.

The obvious patchy and variable distribution of Marbled Murrelets in coastal waters indicates that intensive surveys throughout the year will be necessary to accurately assess the use of a given area by Marbled Murrelets.

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Table 4
Comparison of Marbled Murrelet abundance in inlets (fjords), channels, and open coast[a]

Area	Inlets (fjords)	Channel	Open	Total
Quatsino Sound				
No. of birds	2	4		6
Transect length (km)	75.7	83.7	–	159.4
Density (no. of birds/km [no. of birds/km²])	0.03 (0.08)	0.05 (0.13)		0.04 (0.10)
Brooks Bay				
No. of birds	14		226	240
Transect length (km)	23.5	–	46.2	69.7
Density (no. of birds/km [no. of birds/km²])	0.60 (1.50)		4.89 (12.23)	3.44 (8.60)
Checleset Bay				
No. of birds	5	6	70	81
Transect length (km)	29.0	9.2	41.6	71.7
Density (no. of birds/km [no. of birds/km²])	0.24 (0.60)	0.63 (1.58)	1.68 (4.20)	1.13 (2.83)
Kyuquot Sound				
No. of birds	21	77	2	100
Transect length (km)	70.9	51.9	9.6	132.4
Density (no. of birds/km [no. of birds/km²])	0.30 (0.75)	1.48 (3.70)	0.21 (0.53)	0.76 (1.90)
Nootka Sound				
No. of birds	4	15	352	371
Transect length (km)	98.0	36.2	19.0	153.2
Density (no. of birds/km [no. of birds/km²])	0.04 (0.10)	0.41 (1.03)	18.53 (46.33)	2.42 (6.05)
Total surveyed area				
No. of birds	46	102	650	798
Transect length (km)	289.0	181.0	116.4	586.4
Density (no. of birds/km [no. of birds/km²])	0.16 (0.40)	0.56 (1.40)	5.58 (13.95)	1.36 (3.40)

[a] Maximum area covered and maximum number of murrelets seen on any survey.

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Part IV

Oil pollution and conservation of marine and shoreline birds

The effects of oil pollution on seabirds off the west coast of Vancouver Island

Alan E. Burger

1. Abstract

The annual shipments of oil off the west coast of Vancouver Island include over 300 tankers carrying 26 million cubic metres of crude oil, more than 400 loads of refined petroleum products (approx. 2 million cubic metres) delivered to local ports, and thousands of smaller fuel deliveries. The incidence and estimated risks of oil spills off the coast of Vancouver Island are reviewed. Large spills (>1000 barrels) are likely to affect the area once every 4–5 years, but several hundred minor spills occur annually. Beached bird surveys yielded densities of 0.72 carcasses/km, of which at least 12% were oiled by small, predominantly unreported spills. Under normal conditions, the incidence of oiled birds on the beaches is low relative to beach survey results from other parts of the world, but these data underestimate the actual at-sea mortality because of the characteristics of the beaches and the ocean currents off the island. This has been confirmed by experiments using bird-sized drift-blocks released off the island and studies of carcass persistence on beaches. The effects of the *Nestucca* spill, which killed approximately 56 000 seabirds off Vancouver Island and northern Washington in the winter of 1988–89, are reviewed.

2. Résumé

Les expéditions annuelles d'hydrocarbures au large de la côte ouest de l'île de Vancouver comprennent 26 millions de mètres cubes de pétrole brut transportés par plus de 300 pétroliers, plus de 400 cargaisons de produits pétroliers raffinés (environ 2 millions de mètres cubes) déchargées dans les ports locaux et des milliers de livraisons moins importantes de mazout. L'incidence et les dangers estimés des déversements au large de l'île de Vancouver sont examinés. Selon toute probabilité, un important déversement (de plus de 1 000 barils) touche cette zone une fois tous les 4 ou 5 ans, mais plusieurs centaines de déversements mineurs se produisent chaque année. Le dénombrement des oiseaux échoués sur les grèves a permis d'en arriver à une densité de 0,72 carcasse par kilomètre, et au moins 12 % de ces carcasses étaient mazoutées à la suite de faibles déversements dont la majorité n'avaient pas été déclarés. Normalement, le nombre d'oiseaux mazoutés sur les grèves est peu élevé comparativement aux chiffres obtenus dans d'autres parties du monde pour les oiseaux échoués, mais ces données n'indiquent pas le taux réel de mortalité en mer en raison des caractéristiques des grèves et des courants océaniques au large de l'île, ce qui a été confirmé par des expériences où des objets flottants de mêmes dimensions que les oiseaux ont été lancés à la mer au large de l'île et par des études sur la persistance des carcasses sur les grèves. Les conséquences du déversement du *Nestucca*, qui a tué environ 56 000 oiseaux de mer au large de l'île de Vancouver et du nord de l'État de Washington durant l'hiver de 1988–1989, sont analysées.

3. Introduction

Several million seabirds and waterfowl use the seas and coastal inlets off Vancouver Island for breeding, migration, and overwintering. There have been several census surveys of seabirds at their colonies (Drent and Guiguet 1961; Campbell et al. 1990; Rodway 1991) and at sea (Martin and Myres 1969; Vermeer et al. 1983, 1987, 1989; Morgan et al. 1991; Ford et al. 1991), but information on their spatial and temporal distributions at sea is still rather patchy. There have been no year-round, systematic marine surveys yielding detailed information on the birds' distribution and movements at sea. These birds are, however, exposed to relatively high risks of oiling, both from the offshore tanker traffic bearing Alaskan crude and from the many inshore shipments of petroleum products (Vermeer and Vermeer 1975).

The *Nestucca* spill off Gray's Harbor, Washington, deposited more than 450 t of heavy bunker oil and oily debris along 150 km of shore on Vancouver Island in January through March 1989 (Harding and Englar 1989). More than 3200 oiled carcasses of seabirds were collected on the island (Rodway et al. 1989). Many carcasses were not tallied, and the total number beached on the island was estimated to be 10 000, representing at least 34 300 at-sea deaths (Burger 1991a). With birds found in Washington included, the overall mortality was about 56 000 birds (Ford et al. 1991). This event attracted widespread public attention and led to increased concern and research (e.g., Anon. 1990; Cohen and Aylesworth 1990). Prior to the *Nestucca* event, the risks and consequences of oil spills had not been widely recognized, despite heavy tanker and barge traffic along an exposed, stormy coastline.

This paper reviews the risks and sources of oil spills off Vancouver Island, the evidence for chronic low-level oiling of seabirds, and the effects of major spills on birds. The *Nestucca* spill showed clearly that birds off Vancouver Island could be affected by spills that occurred hundreds of kilometres away, and I have therefore considered oil movements for the broader region of northern Washington and southern British Columbia, in addition to local shipments.

Table 1
Amounts of oil transported by sea per year off southern British Columbia and northern Washington (data from Shaffer et al. 1990)

	Volume (million m^3)	No. of tanker loads	No. of barge loads
Crude oil			
Imports	25.4	333	35
Exports	1.2	14	19
Total (million barrels)	26.6 (167)	347	54
Refined petroleum products[a]			
Total (million barrels)	15.0 (94)	243	4000

[a] About 10% is bunker and heavy oil, 90% is gasoline and light fuels.

Figure 1
Volume and routing of crude oil traffic in southern British Columbia and northern Washington in 1988 (from Shaffer et al. 1990)

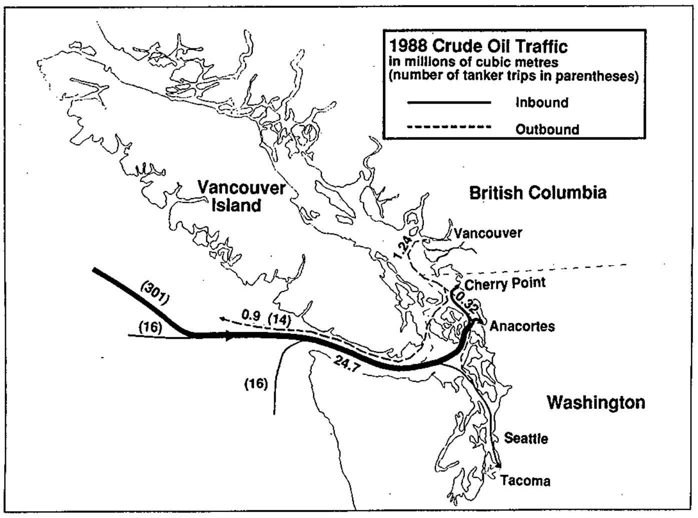


Table 2
Expected intervals (years) between major oil spills from tankers and barges in southern British Columbia and northern Washington, predicted by the status quo risk model of Cohen and Aylesworth (1990)

Spill size (barrels)	Southwest Vancouver Island [a]	Entire region
All oil types		
>1000	40	1.3
>10 000	163	10.7
>100 000	1325	144.8
Crude and bunker oils		
>1000	94	2.5
>10 000	330	20
>100 000	2033	212

[a] These data are derived from risks to a 74-km stretch on the southwest coast of Vancouver Island.

4. Sources and risks of oil pollution

4.1 Movements of oil off Vancouver Island

Oil might be released off Vancouver Island from a variety of sources, including the cargoes of tankers and barges, bilges and fuel tanks of any marine vessel, shore-based fuelling stations, and shore-based industries such as pulp mills. The greatest volume of petroleum, and the greatest risk of spillage, involves shipments of crude oil and refined petroleum products (RPPs) along the coast.

The movements of oil by tankers and barges in northern Washington (i.e., the Olympic coast, Puget Sound, and the Strait of Juan de Fuca) and southern British Columbia (i.e., the southern end of Vancouver Island and the Strait of Georgia) have been reviewed, using data from 1988 and 1989 (Anon. 1990; Shaffer et al. 1990). The volumes of oil shipped in the region are likely to remain similar for several years, with imports from Alaska eventually declining and exports from Vancouver possibly increasing (Shaffer et al. 1990). Movements of crude oil in marine vessels averaged 26 million cubic metres (164 million barrels) annually, consisting largely of imports from Alaska to refineries in northern Washington and smaller exports from the Trans-Mountain Pipeline terminal in Vancouver.

Most of the crude oil is carried by tanker (Table 1). Over 300 tankers bearing Alaskan crude oil pass Vancouver Island to enter the Strait of Juan de Fuca each year (Fig. 1), and many more pass farther offshore en route to the southern states. Approximately 20% of the tankers used in the Alaska trade, which involves rough winter conditions, are classified by the Tanker Advisory Center of New York as "poor" or "fair," below the average for the U.S. fleet (Anderson 1989).

Movements of RPPs average 15 million cubic metres (94 million barrels) per year, mostly carried in barges (Table 1). A relatively small proportion of this traffic (463 loads, or 15% of the loads delivered in British Columbia) occurs off the west coast of Vancouver Island (Shaffer et al. 1990), and bunker and other heavy oils make up only 10% of the volume. Nevertheless, the risk of spills from barges and small tankers making many deliveries of RPPs to coastal depots is high. Shipments of RPPs are likely to increase, tracking population growth in the region (Shaffer et al. 1990).

4.2 Large oil spills: risks and reality

Cohen and Aylesworth (1990) analyzed the risks of oil spills in southern British Columbia and northern Washington, using data on ship movements, port calls, weather and sea conditions, geographic transit risk indices, shipping density, and other pertinent parameters. They included a variety of scenarios, such as changing the sites of loading terminals or shipping methods, but only their status quo model is discussed here. They acknowledge that the factors that contribute to spills are complex and that their risk estimates are imprecise. Nevertheless, their results do offer some insight into the risks faced by birds under current conditions.

The model predicts that the annual risk of a spill exceeding 1000 barrels of any oil type is 0.025 (i.e., once every 40 years) for 74 km of southwest Vancouver Island (Table 2). The risk would be severalfold higher for the entire west coast of the island (minimum linear distance 520 km, excluding fjords and sounds); in addition, spills beyond the coast are also likely to affect it. The risk to the region as a whole (southern British Columbia and northern Washington) was estimated to be once every 1.3 years for a spill of any oil exceeding 1000 barrels and less often for very large spills (Table 2). The heaviest bird mortality is likely to result from spills of heavy crude and bunker oil, and the overall risk of such spills exceeding 1000 barrels is once every 2.5 years for the region as a whole (Table 2). It is impossible to predict from the available information what proportion of oil spills would significantly affect birds off the west coast of Vancouver Island, but a reasonable guess is that a spill exceeding 1000 barrels is likely to affect this region once every 4–5 years, and a slightly larger *Nestucca*-sized spill (5000 barrels) might occur once every 5–10 years.

There have been five major oil spills (>1000 barrels) in the waters off British Columbia and northern Washington in the past 17 years, an average of one every 3.4 years (Table 3). The numbers of birds affected by these spills were variable and, in

Table 3
Major oil spills affecting British Columbia and northern Washington, 1974–91 (data from Cohen and Aylesworth 1990, except where noted)

Vessel	Vessel type	Date	Oil type	Volume spilled (barrels)	Site of spill	No. of birds oiled
Arco Anchorage	Tanker	Dec. 1985	Alaska crude	5 690	Port Angeles, Wash.	4 000[a]
Stuyvesant	Tanker	May 1987	Alaska crude	14 286	150–300 km off northern B.C.	No data
MCN5	Oil barge	Jan. 1988	Glycol, gas oil	1 714	Anacortes, Wash.	No birds reported[a]
Nestucca	Oil barge	Dec. 1988	Bunker C	5 412	Gray's Harbor, Wash.	47 500–68 500[b]
Tenyo Maru[a]	Hake packer	July 1991	Bunker and diesel	~2 000	Finger Bank, 35 km SW of Pachena Pt., B.C.	~4 500[a]

[a] Unpublished data, Washington Department of Ecology.
[b] Ford et al. (1991).

some cases, not fully documented. An estimated total of 4000 birds died from the *Arco Anchorage* spill (Speich 1986), but no bird mortality was reported after the barge *MCN5* spill (Washington Department of Ecology, unpubl. data). Details of the *Nestucca* spill are reviewed below.

The *Tenyo Maru* spill is still under investigation. Fewer than 20 oiled birds were found on Vancouver Island, but at least 4300 dead oiled birds were recovered in Washington, and a further 100 were cleaned and released (Washington Department of Ecology, unpubl. data). Many thousands more did not come ashore, because most of the oil, forming a slick up to 10 × 15 km in area, remained 30 km offshore. The spill coincided with the fledging of murres from colonies in Washington and Oregon and the presence of many thousands of migrant shearwaters and gulls.

The *Stuyvesant* spill was carried offshore; although thousands of birds might have died at sea, this was not investigated. It is unfortunate that oil slicks that do not approach the coast are given low priority by monitoring authorities, even though such slicks undoubtedly affect pelagic seabirds and other marine organisms (Brown 1973).

4.3 Frequencies of smaller spills

Environment Canada considers all spills exceeding 1 t (approx. 7 barrels) as significant. During 1988, spills of this size made up less than 4% (22 out of 574) of marine spills reported, whereas hundreds of other small spills were never reported (Kay 1989a, 1989b). The origin of most of these spills was never established. Seven significant spills of petroleum were reported from the west coast of Vancouver Island between 1972 and 1984, including four of 1–10 t and three of 100–1000 t (Kay 1989a). This suggests that there might be at least 15 reportable spills per year off the west coast of Vancouver Island, assuming that significant spills make up 4% of the reportable total. Hundreds of minor spills of light fuel oils at marine fuel depots and marinas go unreported each year.

5. Mortality of seabirds due to oiling

5.1 Chronic oiling mortality

Monitoring the mortality of seabirds caused by oiling is notoriously difficult because of the fact that relatively few of the affected seabirds usually come ashore, and those that do are often removed by scavengers or lost amongst the jetsam (Ford et al. 1987; Page et al. 1990). The number of birds killed is not necessarily correlated with the size of the spill (Vermeer and Vermeer 1975; National Research Council 1985), and tens of thousands of birds can be killed by a relatively minor spill (e.g., Barrett 1979). Beached bird surveys are routinely used to monitor levels of chronic oiling in seabirds. They have revealed serious rates of mortality, largely attributed to unreported spills, off Belgium (Kuyken 1978), Portugal (Teixeira 1986), Newfoundland (Piatt et al. 1985), California (Stenzel et al. 1988), Britain (Stowe 1982), and the Netherlands (Camphuysen 1989).

Beached bird surveys have been conducted since 1987 on southwest Vancouver Island, but not on other parts of the outer coast. Data are available from 92 surveys, totalling 237 km, at 10 beaches between Tofino and Port Renfrew (Burger 1991b). These data do not include birds recovered during the *Nestucca* cleanup in the winter of 1989. The mean density of carcasses (0.72/km) was higher than that of the shores of southern Vancouver Island (0.24), the Strait of Georgia (0.24), or inland marine waters of Washington (0.26) but lower than in comparable surveys in most parts of the world, including California (2.72), Oregon (2.4–7.5), and exposed beaches of Washington (6.64) (Speich and Wahl 1986; Stenzel et al. 1988; Burger 1991b). Strandings on Vancouver Island showed a strong seasonal trend, with 78% of the carcasses reported in four months: September through December (Fig. 2). This seasonality, due to high mortality among newly independent juveniles and postbreeding moulting birds, has important implications for the impacts of oil spills. Spills in mid- to late winter, such as the *Nestucca* event, will kill birds that might normally have survived the winter, and their effect will thus add to, rather than substitute for, natural mortality (Burger 1991b).

Twelve percent of 172 carcasses from southwest Vancouver Island were obviously oiled, involving at least eight species (Table 4). The actual proportion of oiled birds was certainly higher. Many carcasses were badly decomposed or dismembered when found, making it difficult to determine the cause of death. With the exception of one Western Grebe *Aechmophorus occidentalis* covered in light oil, the birds were affected by heavy bunker or crude oils. Gasoline, diesel, and other light oils are more difficult to detect on carcasses than the heavier oils. Oiled birds were found in most months (Fig. 2). There were no major spills associated with these oiled birds, except for one loon found in January 1986 near Bamfield, which may have been a victim of the *Arco Anchorage* spill (pers. obs.).

Overall, the density of obviously oiled carcasses (0.08/km) was low relative to results from elsewhere in the world (Burger 1991b). A similar low proportion of oiled birds (range <1–2% of beached carcasses) was reported from beach surveys in 1981–83 on the exposed Long Beach Peninsula in Washington (G. Lippert, quoted in Speich and Thompson 1987). However, as discussed below, the ocean and beach conditions of British Columbia seem to lower the probability that birds oiled at sea will be found on the beaches. Increased coverage of beach surveys, spanning several years, is needed to present a more accurate estimate of oiling rates.

Figure 2
Mean monthly densities of unoiled (shaded bars) and oiled seabirds (black bars) found during beached bird surveys on the southwest coast of Vancouver Island, 1987–91. The number of beaches sampled is shown for each month.

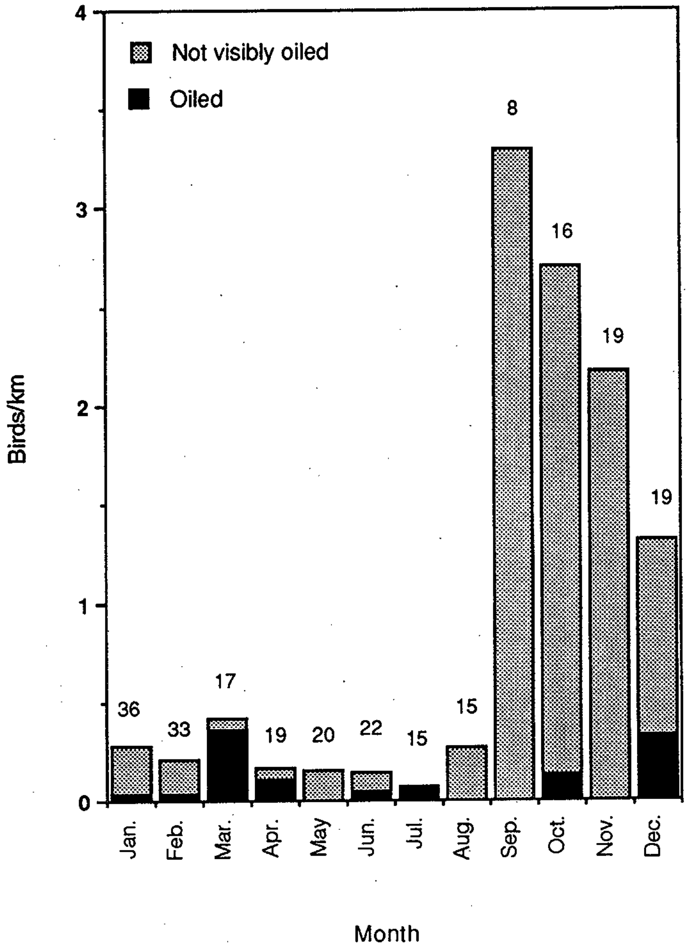


Table 4
Numbers of oiled carcasses found on beaches of southwest Vancouver Island during beached bird surveys, 1987–90 (from Burger 1991b)

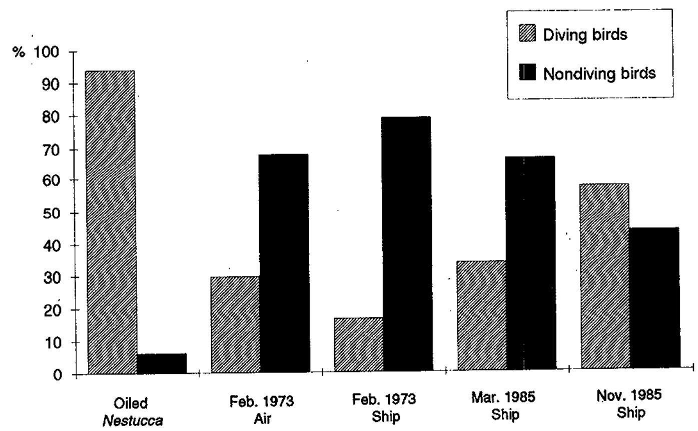
Species	No. of birds oiled	Total no. of birds	% of birds oiled
Pacific Loon	2	3	67
Western Grebe	1	3	33
Cormorant spp.	1	12	8
Glaucous-winged Gull	4	32	13
Common Murre	6	36	17
Rhinoceros Auklet	2	9	22
Ancient Murrelet	1	1	100
Cassin's Auklet	2	10	10
Auklet spp.	1	5	20
Other species	0	61	0
All species	20	172[a]	12

[a] The total includes all carcasses of 27 species.

Table 5
Species oiled by the *Nestucca* spill, December 1988 (data from Rodway et al. 1989; Ford et al. 1991)

	% composition	
Species	Vancouver Island	Washington
Loons	3.0	0.9
Grebes	1.4	8.5
Scoters	6.3	12.1
Common Murre	42.2	72.0
Cassin's Auklet	32.4	0.8
Other alcids	7.6	2.5
Other birds	7.1	3.2
No. of carcasses identified	809	9120

Figure 3
Proportions of diving and nondiving birds among the *Nestucca* spill victims found on Vancouver Island, compared with those recorded in offshore aerial and shipboard surveys in winter off southwest Vancouver Island (from Burger 1991a)



5.2 Effects of the *Nestucca* spill

The barge *Nestucca* spilled 875 000 L (5412 barrels, or 960 m^3) of heavy No. 6 (bunker C) oil off Gray's Harbor, Washington, on 23 December 1988. Oil and oiled birds were first reported on Vancouver Island on 3 January 1989 and continued to be found for the next two months. At least 150 km of shoreline between Victoria and Cape Scott were affected (Harding and Englar 1989; Rodway et al. 1989). The numbers, species, and origins of the birds affected by this spill in Washington and off Vancouver Island have been analyzed in some detail (Rodway et al. 1989; Burger 1991a, 1991c; Ford et al. 1991), and a summary of the data pertinent to Vancouver Island is given here. The direct mortality of birds in Washington and British Columbia was estimated to be between 47 500 and 68 500, with a best approximation of 56 250 birds (Ford et al. 1991).

The species composition of the affected seabirds varied with latitude, with Vancouver Island receiving fewer Common Murres *Uria aalge* and inshore species (e.g., grebes and scoters) and more offshore species (e.g., Cassin's Auklets *Ptychoramphus aleuticus*) than Washington (Table 5). The proportion of inshore species (birds usually found within 500 m of shore) also declined with latitude along Vancouver Island (Burger 1991a). This pattern reflects the path of the oil slick. Inshore species oiled off Washington came ashore in that state, but offshore species oiled off Washington and British Columbia travelled farther before coming ashore on Vancouver Island. Populations of hundreds of thousands of waterfowl, grebes, and loons that winter in inlets and other sheltered waters on Vancouver Island did not appear to suffer significant direct mortality (Rodway et al. 1989; Burger 1991a).

Comparison of *Nestucca* victims with birds recorded during shipboard and aerial transects off Vancouver Island in winter showed that diving birds, and alcids in particular, were affected in greater numbers than expected from the populations at sea (Figs. 3 and 4). Among the alcids, the spill appeared to affect species roughly in proportion to their expected abundance at sea (Fig. 5). Common Murres and Cassin's Auklets were the

Figure 4
Proportions of Procellariiformes, gulls, alcids, and other seabirds among the victims of the *Nestucca* spill found on Vancouver Island, compared with those recorded in offshore aerial and shipboard surveys in winter off southwest Vancouver Island (from Burger 1991a)

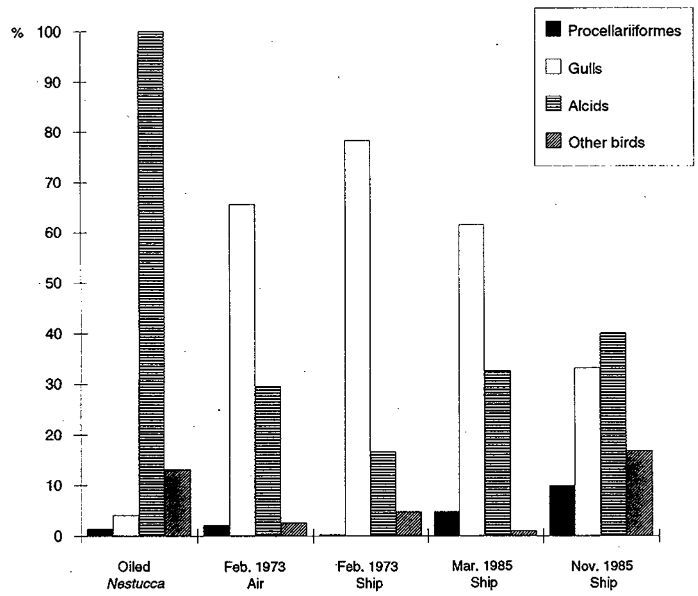


Figure 5
Proportions of Common Murres, mid-sized alcids (Rhinoceros Auklets, puffins, and Pigeon Guillemots), and small auklets (mostly Cassin's Auklets) among the victims of the *Nestucca* spill found on Vancouver Island, compared with those recorded in offshore aerial and shipboard surveys in winter off southwest Vancouver Island (from Burger 1991a)

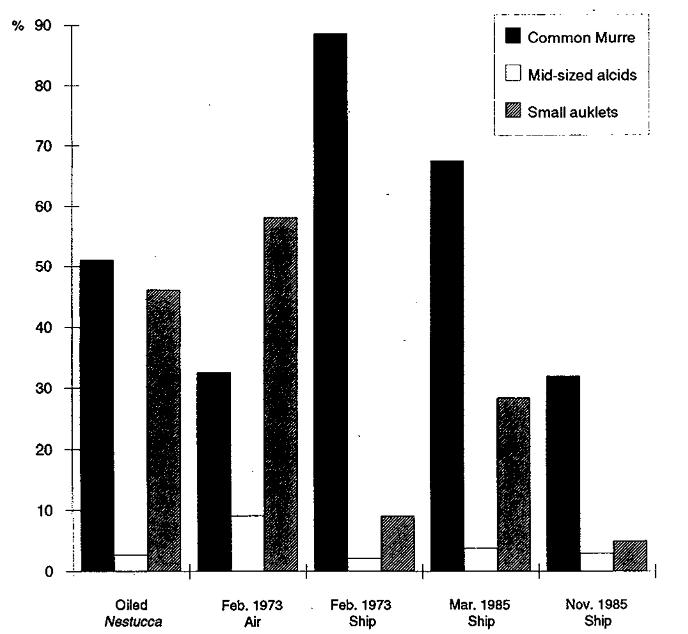
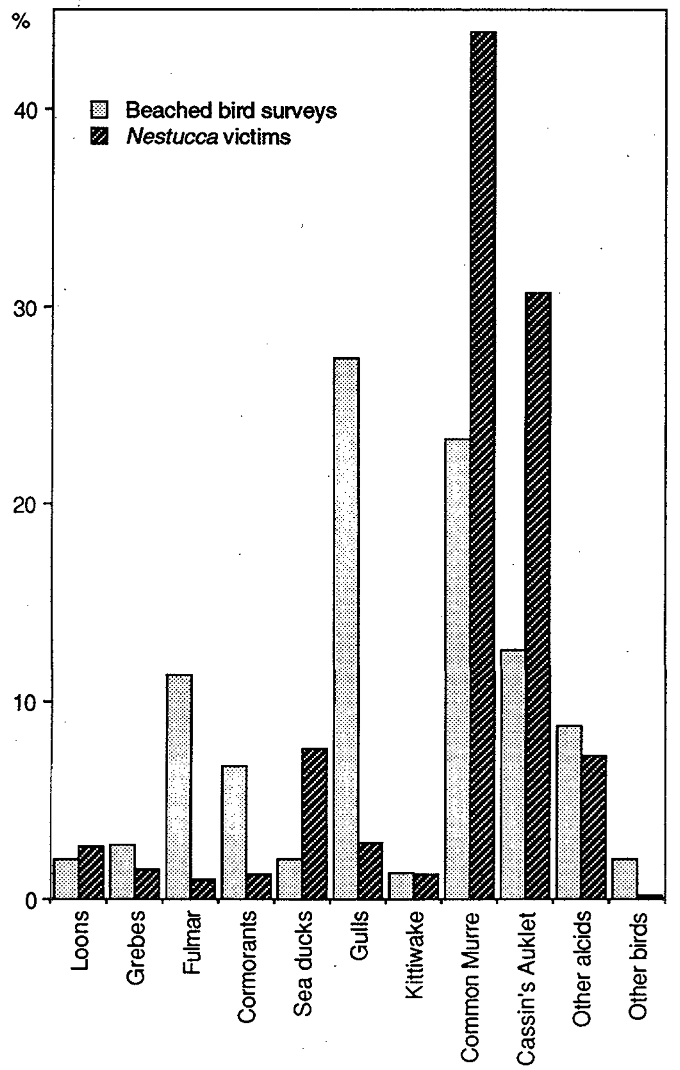


Figure 6
Comparison of the species composition of seabirds found in autumn and winter (September through March) during beached bird surveys (1987–91) on southwest Vancouver Island (Tofino to Port Renfrew) with the *Nestucca* victims found in the same area (January to March 1989)



most abundant alcids over the shelf off Washington and British Columbia in winter (Vermeer et al. 1983, 1989; Ford et al. 1991; Morgan et al. 1991).

A comparison between the *Nestucca* victims found on southwest Vancouver Island (Tofino to Port Renfrew) and the birds reported from beached bird surveys made in autumn and winter (September through March) from the same area shows some striking differences (Fig. 6). The *Nestucca* victims included a greater proportion of sea ducks, Common Murres, and Cassin's Auklets and far fewer aerial foragers, such as Northern Fulmar and gulls, than birds reported from the beached bird surveys.

The high proportion of diving birds, particularly alcids, among the victims is typical of oil spills in temperate northern seas (Hope Jones et al. 1970; Barrett 1979; Camphuysen 1989; Piatt et al. 1990). These birds spend most of their lives on or under the water and appear to get coated with oil as they come to the surface through a slick. Some pelagic fish are known to be attracted to floating objects, and Kerley et al. (1987) suggested that if fish were attracted to surface slicks, then diving birds may pursue them and become oiled. When viewed from beneath, dense oil slicks superficially resemble schools of fish (see photographs in Hodgson and Fobes 1990: 37 and 38), suggesting that the slick itself might attract diving birds.

The effects of the *Nestucca* spill on local populations were difficult to assess for many reasons, including the difficulties of censusing burrowing alcids, the absence of a prior series of complete censuses of colonies in British Columbia, and the problems of separating the spill effects from year-to-year variations in population and attendance at colonies as a result of natural phenomena (e.g., prey availability). In the summer following the spill, the Canadian Wildlife Service censused Common Murres and Cassin's Auklets on Triangle Island, the principal breeding colony of both species in British Columbia. They found no evidence that the spill had affected these populations (Rodway 1990; Rodway et al. 1990). The estimated population of Cassin's Auklets was higher than average because of higher burrow occupancy rates. Numbers of murres were also higher, but this was attributed to a more complete survey of the cliffs than in previous years. Part of the murre colony exhibited breeding failure, but this could not be linked with the spill. Most of the affected murres must have come from colonies in Washington, Oregon, or Alaska, because the spill killed at least 30 000 murres (Ford et al. 1991) and the total breeding population in British Columbia before the spill was thought to be less than 9000 birds (Rodway 1991).

Vermeer, Morgan, and Ewins (this volume) found no strong evidence to link the *Nestucca* spill with recent declines in the breeding populations of Pelagic Cormorants *Phalacrocorax pelagicus* and Glaucous-winged Gulls *Larus glaucescens* off Vancouver Island. These species comprised 0.1% and 1.9%, respectively, of the 841 oiled birds identified on Vancouver Island (Rodway et al. 1989). The loss of cormorants cannot be discounted, however, because some of the areas where cormorants declined might not have been well searched during the cleanup (Vermeer, Morgan, and Ewins, this volume).

The spill had few detectable impacts on inshore habitats used by birds. Rodway (1989a, 1989b) found little change in the behaviour or distribution of birds where eelgrass and other shallow communities had been oiled in Barkley Sound, Tofino, or Grice Bay. Herring failed to spawn in some traditional spawning sites off Stubbs Island, near Tofino, which resulted in far fewer Surf Scoters *Melanitta perspicillata* than usual. Brant *Branta bernicla* appeared to avoid areas where eelgrass had been oiled near Stubbs Island, but their populations and behaviour were otherwise unaffected.

6. Problems in assessing mortality due to oiling

Relatively few of the oiled birds that die at sea are ever found on the beaches (Hope Jones et al. 1970; Bibby and Lloyd 1977; Ford et al. 1987; Piatt et al. 1990). Carcasses at sea may sink or be carried away from the shore by winds and currents, whereas carcasses on the beaches might be covered with sand or jetsam or be washed back to sea and sink. Scavengers might remove carcasses at sea or on beaches. All of these factors affect birds oiled off Vancouver Island, making assessments of overall mortality at sea difficult (Burger 1991a, 1991c; Ford et al. 1991). Experiments addressing some of these problems were completed on this coast after the *Nestucca* spill. These are reviewed below.

6.1 Drift-block experiments off Vancouver Island

Bird-sized wooden drift-blocks were used by Hlady and Burger (1990) to estimate the probability of recovering bird carcasses from a spill off the west coast of Vancouver Island. Equal numbers of blocks the size of large (40 cm long, 701 g), medium (20 cm, 346 g), and small (10 cm, 180 g) alcids were released at sea. About half of the blocks from an inshore release site (<2 km offshore near Seabird Rocks, Pachena Bay) were recovered in both summer and winter. A higher proportion was recovered with onshore winds at the time of release in winter (Table 6). Although recovery rates were positively correlated with block size, this was not statistically significant. Most of these inshore blocks (85% summer; 75% winter) were recovered within 10 km of the release site, but a few travelled several hundred kilometres before coming ashore. A similar series of blocks was released in January 1990 in four batches along a transect 35–116 km long off Barkley Sound in winter to simulate an offshore spill. A month after their release, only 10% of these had been recovered, despite intensive searches and publicity.

Table 6
Recoveries of bird-sized drift-blocks released off the southwest coast of Vancouver Island in summer (June 1989) and winter (January 1990) (from Hlady and Burger 1990)

Release site	Season	No. released	% recovered
Inshore (<2 km offshore)	Summer	300	43
	Winter		
	– onshore wind	150	67
	– offshore wind	150	39
	Total winter	300	53
Offshore (35–116 km offshore)	Winter	300	10

Drift-blocks were more likely to be recovered than oiled seabirds, because they retained their buoyancy for longer, were more conspicuously coloured (red), and were not subjected to scavenging. As a result, these experiments indicate the maximum proportions of carcasses likely to be recovered. The results suggest that, even if a spill occurred very close to shore, only half the victims might be detected. Offshore spills would yield even fewer of the affected birds. A few oiled carcasses on the beaches might be the only indication that hundreds of birds died offshore.

The drift-block experiments demonstrated strong effects of winds and currents. The Vancouver Island Coastal Current, in particular, would have a major effect on the movements and fate of birds oiled over the continental shelf (Thomson et al. 1989). This surface current acts as a powerful conduit, carrying surface objects polewards and parallel with the west coast, but it also acts as a barrier to cross-shelf movement and might prevent oiled carcasses from coming ashore on Vancouver Island. Offshore winds and coastal eddies could also carry carcasses away from the shore. The drifting paths of radio-tagged seabird carcasses off Washington also showed the effects of northerly currents over the shelf (Ford et al. 1991).

6.2 The persistence of carcasses on beaches

Knowledge of the persistence of beached carcasses from one day to the next is essential for estimating the overall mortality (Ford et al. 1987, 1991; Page et al. 1990; Burger 1991a). There are few empirical data relevant to Vancouver Island. The persistence of bird carcasses experimentally placed on beaches near Bamfield, on Vancouver Island, and at other sites on eastern Pacific shores ranged between 0.45 and 0.84 (Table 7). Carcasses on these beaches disappear quite rapidly.

Scavengers were responsible for most of the removals at sites on Vancouver Island and in Washington (Burger 1991c; Ford et al. 1991). Scavengers are common on Vancouver Island and include a variety of mammals (dogs, wolves, raccoons, mink, river otters, and bears) and birds (eagles, gulls, ravens, and crows). Unoiled carcasses might be preferred by scavengers, but even heavily oiled carcasses are opened up and eaten. Most of the *Nestucca* victims on Vancouver Island were completely encapsulated with heavy oil. Nevertheless, 54% had been partly eaten (Burger 1991a, 1991c).

Carcasses might also be washed back to sea or be covered with jetsam or sand and hence go uncounted. Clearly, oiled carcasses that are counted on beaches of Vancouver Island

Table 7
Persistence of bird carcasses on beaches on the Pacific coast, shown as the mean proportion of samples of carcasses remaining on the beach from one day to the next

Site	Birds used	Persistence	Reference
California	Oiled alcids	0.59	Page et al. 1990
Washington	Common Murres	0.74	Ford et al. 1991
Vancouver Island	Intact chickens	0.84	Humphries 1989
Vancouver Island	Chicken portions	0.38	Dale 1989
Vancouver Island	Shearwaters and kingfishers	0.45	Burger 1991c
Alaska	Oiled alcids	0.80–0.84	Piatt et al. 1990

represent only a fraction of the total that come ashore. Varying the daily persistence estimate can have profound effects on models that predict the total number of beached carcasses from irregular beach counts (Ford et al. 1987; Page et al. 1990). For example, daily persistence values of 0.7 and 0.8 produced estimates of 7250 and 11 130, respectively, for the total number of *Nestucca* victims to come ashore on Vancouver Island in 1989 (Burger 1991a, 1991c). Refining such mortality estimates will require more precise measures of persistence, including the effects of seasonal and spatial variations.

6.3 Buoyancy of oiled carcasses

Oiled seabirds generally float for a while after death, but many lose buoyancy and sink. Reports from Great Britain suggest that 11–58% of carcasses sink at sea (Coulson et al. 1968; Hope Jones et al. 1970; Bibby and Lloyd 1977). Victims of the *Nestucca* spill collected off Vancouver Island beaches were found to lose buoyancy over the period 21–60 days following the spill, and many would have sunk if washed back to sea (Burger 1991a, 1991c).

In another experiment, unweathered oiled carcasses collected from a spill off southern Vancouver Island were placed in a seawater tank under very benign wave conditions. Alcids and grebes sank at a rate of 2% and 9% of the original sample per day, respectively (Burger 1991c). When ripped open to simulate scavenging, most of the carcasses sank immediately (67% and 93% of carcasses exposed for three and 32 days, respectively). Carcasses of Common Murres tethered in exposed seas off Coos Bay, Oregon, usually sank in less than a week, and 50% and 90% of a sample of radio-tagged murre carcasses drifting freely off Washington disappeared within 10 and 13 days, respectively (Ford et al. 1991).

These data all suggest that a substantial proportion of oiled carcasses, particularly those oiled offshore, would not come ashore. Oiled birds found on beaches of Vancouver Island clearly represent only a fraction of the birds affected at sea. At least 75% of the *Nestucca* victims that might have beached on Vancouver Island were estimated to have sunk or been carried out to sea by currents and wind (Ford et al. 1991; Burger 1991a).

7. Secondary effects of oiling

Fouling of the plumage leading to hypothermia and waterlogging are probably the most common effects of oiling among seabirds. In addition, ingested oil can result in a wide variety of lethal and nonlethal effects, including gut lesions, liver cell dissociation, kidney tubule necrosis, adrenal hypertrophy and corticosterone stress, hemolysis, disruption of ovarian and ovogenesis functions, mutagenic effects, reduced hatchability of eggs, and altered chick growth (Ainley et al. 1981; National Research Council 1985; Fry and Lowenstine 1985; Leighton et al. 1985; Butler et al. 1988; Boersma et al. 1988). The disruptive effects from even minor contact with oil can persist in seabirds for more than one breeding season (Fry et al. 1986), although this does not always occur (Butler et al. 1988).

Seabirds can ingest oil by preening oiled plumage, scavenging oiled carcasses, eating contaminated prey, or mistaking oil globules for food. Scuba divers reported numerous small tar-balls suspended in coastal waters off Vancouver Island following the *Nestucca* spill (Harding and Englar 1989). Oil globules from undetected or small spills might also aggregate at tidal slicks or ocean fronts where many seabirds forage. Residues of petroleum hydrocarbons have been found in the stomachs of both Leach's *Oceanodroma leucorhoa* and Fork-tailed *O. furcata* storm-petrels in Alaska and Washington, suggesting that they ingested oil droplets (Boersma 1986; Boersma et al. 1988). Storm-petrels appear to be capable of digesting certain long-chain hydrocarbons, possibly because their diets normally include similar natural compounds (Boersma et al. 1988). The long-term effects of low-level, chronic ingestion of oil on these or other species are poorly known.

Continuous monitoring of oil-related toxic effects on seabirds breeding off Vancouver Island would be a complex undertaking, but one that should be considered, given the potentially high risk from large and small spills.

8. Conclusions

Oiling is a significant, persistent cause of mortality among seabirds off the west coast of Vancouver Island. Periodic large spills, such as the *Nestucca* accident, can kill tens of thousands of birds, and the time and place of the spill can greatly alter its impact. Spills can kill mature adults, which normally have high annual survival rates. Spills near major breeding colonies, such as the Scott Islands, where 38% of British Columbia's seabirds breed (Rodway 1991), could have catastrophic effects. Chronic small spills also affect many birds on this coast, but the overall impact is more difficult to assess.

Many of the information needs identified by Wiens et al. (1984) for assessing the sensitivity of seabirds to oil spills have not been adequately addressed in British Columbia—notably, the density and distribution of birds at sea, foraging activity budgets, the dynamics of foraging trips, and the effects of variable food resources and ocean conditions on foraging behaviour. Perhaps the most important information needed to assess mortality from spills is the relationship between the number of oiled birds detected onshore and the actual number affected at sea. This will vary with bird density and wind and ocean conditions, but estimates could be improved with more local research, including radio-tracking drifting carcasses, using drift-blocks, and measuring sinking and scavenging rates. The effects of oil pollution on the populations of birds breeding or wintering off Vancouver Island will remain difficult to monitor, although more frequent systematic colony counts, marine transects, and beached bird surveys would help.

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Environmental disturbance and conservation of marine and shoreline birds on the west coast of Vancouver Island

Ken H. Morgan, Robert W. Butler, and Kees Vermeer

1. Abstract

Loss of habitat and oiling of birds represent two major threats to marine and shoreline bird populations on the west coast of Vancouver Island. Logging of mature and old-growth forests has led to the destruction of the nesting habitat of Marbled Murrelets *Brachyramphus marmoratus*, whereas industrial development of estuaries, mudflats, and spawning grounds of Pacific herring *Clupea harengus pallasi* has diminished feeding habitats for other marine and shoreline birds. Fisheries operations, human disturbance of colonies, and introduced predators, notably raccoon *Procyon lotor* and mink *Mustela vison*, have impacted upon local populations. Management actions and research needs to mitigate these threats are addressed.

2. Résumé

La perte d'habitats et le mazoutage constituent deux importantes menaces pour les populations d'oiseaux de mer et de rivage de la côte ouest de l'île de Vancouver. L'exploitation des peuplements arrivés à maturité et des vieilles forêts a amené la destruction de l'habitat de nidification de l'Alque marbrée *Brachyramphus marmoratus*, tandis que l'exploitation industrielle des estuaires, des slikkes et des frayères du hareng du Pacifique *Clupea harengus pallasi* a diminué les aires de recherche de nourriture d'autres oiseaux marins et de rivage. Les activités halieutiques, la perturbation des colonies par les humains et l'introduction de prédateurs comme le raton laveur *Procyon lotor* et le vison d'Amérique *Mustela vison* ont eu des effets sur les populations locales. Les méthodes d'aménagement et les recherches nécessaires pour atténuer ces menaces sont discutées.

3. Introduction

Nearly half of the 5.7 million marine birds that breed in British Columbia nest on islands off the west coast of Vancouver Island. Thirteen species of marine birds nest on islands along this coastline; the most significant is Cassin's Auklet *Ptychoramphus aleuticus*, of which about three-quarters of the world's population breed on the Scott Islands (Rodway 1991; Rodway et al., this volume). Vermeer (1983) suggested that the diversity of breeding species on the west coast reflected a greater abundance of high-quality foods, as well as more suitable nesting sites, than occurred along the east coast of Vancouver Island. That view is strengthened by Mackas and Galbraith (this volume), who showed that the Scott Islands lie close to the edge of very productive regions of the continental shelf.

The majority of shorebird, waterfowl, and pelagic species that occur along the British Columbia coast are widespread migrants or winter visitors (Vermeer et al. 1983; Butler and Verbeek 1989; Morgan et al. 1991). The mudflats and beaches in Clayoquot Sound are second only to the Fraser River delta in importance to migrating shorebirds in British Columbia (Butler et al., this volume), whereas estuaries, sheltered bays, and inlets along the west coast of Vancouver Island support large numbers of waterfowl (Vermeer, Morgan, Dorst, and Whittington, this volume). The highest densities of shorebirds are attracted to the estuarine and mudflat habitats. Although no site comparable in size to the Fraser River estuary occurs along the west coast of the island, the densities of birds in such habitats is great (Butler et al., this volume). The productive waters of the shelf, especially over banks and at the shelf break, support millions of pelagic birds annually as they pass through British Columbia's offshore waters en route to and from either their northern breeding colonies or their summer feeding grounds (Vermeer et al. 1983, 1989; Morgan et al. 1991; Vermeer, Morgan, and Smith, this volume).

Vermeer (this volume) suggested the establishment of a permanent field station on Triangle Island, as part of an international series of research facilities throughout the North Pacific Ocean. A permanent facility would promote long-term studies of seabirds and serve as a means to monitor the relationships between birds, their prey, and large-scale oceanic and climatic events, such as described by Freeland (this volume).

Vermeer and Rankin (1984) and Rodway (1991) reviewed the threats to marine birds for the entire British Columbia coast. However, we know of no review that has either identified threats to shorebirds or focused specifically on the west coast of Vancouver Island. Here, we summarize the threats to marine and shoreline birds and their feeding habitats along the west coast of Vancouver Island and recommend various management actions and research topics that may help to mitigate those threats.

4. Threats

We have identified two widespread and three localized threats to marine and shoreline birds along the west coast of Vancouver Island. Habitat loss and oil pollution currently represent the greatest threats to the conservation of this avifauna, largely because of their widespread and cumulative effects. Avian mortality and/or reduced reproductive success caused by commercial fisheries, human disturbances, and introduced predators are at present localized.

4.1 Habitat loss and degradation

The loss of nesting, feeding, and roosting habitats likely represents the greatest potential threat to marine and shoreline bird populations on the west coast of Vancouver Island. Humans have modified or destroyed marine and shoreline bird habitats by building settlements, lighthouses, helicopter pads, roads, and radio towers; logging forests; developing industrial and recreational facilities in and adjacent to estuaries and tidal flats; and utilizing lands for agriculture and animal husbandry purposes. The introduction of exotic plants and mammals has further altered nesting or feeding habitats and the functioning of ecosystems, accidentally introduced vegetation has destroyed the endemic flora in some sites, whereas domestic animals have crushed burrows, compacted soil, and caused erosion (Vermeer and Rankin 1984; Vermeer and Sealy 1984).

4.1.1 Effects of loss of forest habitats on the Marbled Murrelet

All seabirds that nest in British Columbia are federally protected by the Migratory Birds Convention Act of 1916, with additional protection afforded through five provincial acts: the Wildlife, Museums, Parks, Ecological Reserves, and Firearms acts. With regard to the protection of seabirds and their habitat, the Ecological Reserves Act has been especially significant; the largest seabird breeding colonies along the west coast of Vancouver Island are protected (Sealy and Carter 1984). However, the Marbled Murrelet *Brachyramphus marmoratus* has eluded protection. This murrelet is the only species of alcid known to nest in trees, possibly exclusively in mature or old-growth forests (Johnston and Carter 1985; Marshall 1988; Manley et al., this volume). We suggest that the Marbled Murrelet is being affected by habitat loss throughout its range more than most other species of marine and shoreline birds.

Marbled Murrelets generally nest solitarily, in a dispersed fashion (Marshall 1988; Savard and Lemon, this volume), which makes it extremely difficult not only to determine crucial nesting areas, but also to derive meaningful population estimates. Marshall (1988) considered that the Marbled Murrelet was at considerable risk, from Washington south, from the continued extraction of old-growth, coniferous forests. Sealy and Carter (1984) predicted that more than 95% of all old growth on productive forest land on Vancouver Island would be gone in less than 50 years.

Marbled Murrelets may select old-growth forests for the following reasons: ease of access to a suitable nesting limb, which may dictate the height of the nest and the nest tree and may require a tree species with an open crown; and the slope, diameter, and vegetative coating of the nest limb (Binford et al. 1975). Immature conifer forests that succeed logged sites are thought to be unsuitable for murrelet nesting because the trees are shorter, have more sloping branches, have smaller trunk and branch diameters, and are generally crowded in even-aged stands with few open crowns and very little epiphyte development (Binford et al. 1975; Sealy and Carter 1984; Marshall 1988).

At-sea daytime counts of Marbled Murrelets, such as reported by Sealy and Carter (1984) and Savard and Lemon (this volume), have been conducted in part to locate nesting areas. It has been noted (Sowls et al. 1980) that murrelets are generally observed at sea during the breeding season, along coastlines that are dominated by old-growth forests. We suggest that localized concentrations of murrelets may simply reflect opportunistic foraging situations, more so than feeding areas adjacent to nest sites. Carter and Sealy (1984) showed that murrelets will forage in different locations at night than during the day. This suggests that the relationships between (and significance of) murrelet daytime feeding areas and adjacent forest habitats require further investigation.

4.1.2 Loss of estuarine and mudflat habitat

It is widely accepted that estuaries and mudflats, especially those that support large beds of eelgrass (*Zostera* spp.), are among the most important feeding habitats of marine and shoreline birds (Phillips 1984; Butler and Campbell 1987; Butler and Vermeer 1989; Vermeer, Morgan, Dorst, and Whittington, this volume). Butler et al. (this volume) showed that the large eelgrass beds near Tofino support some of the highest densities of shorebirds in British Columbia. They determined that those mudflats were second only to the Fraser River delta in importance to Western Sandpipers *Calidris mauri*, and they urged strongly that those habitats be protected.

The estuarine areas along the north shore of Barkley Sound are important seasonal foraging habitats for tens of thousands of marine birds, primarily when Pacific herring *Clupea harengus pallasi* spawn nearby (Vermeer, Morgan, Dorst, and Whittington, this volume). Haegele and Schweigert (1989) estimated that, in March 1988, marine birds—primarily gulls (*Larus* spp.) and scoters (*Melanitta* spp.)—consumed approximately 271 t of spawn along the north shore of Barkley Sound. This annual spawning may be especially important to Thayer's Gull *Larus thayeri*, which breeds only in Arctic Canada. Although this species winters as far south as Mexico (Campbell et al. 1990), it is uncommon to rare from Washington through California (T. Wahl and K. Briggs, pers. commun.). The southeast and southwest coasts of Vancouver Island seem likely to be the centre of abundance for this species in the winter. Many thousands of Thayer's Gulls overwinter in the Barkley Sound/Alberni Inlet area, where they feed upon the abundant herring spawn in February and March (Fig. 10 in Vermeer, Morgan, Dorst, and Whittington, this volume).

Although the Barkley Sound estuarine habitats are adjacent to a part of Pacific Rim National Park, the foreshore and surrounding forests have not escaped degradation; most of the coastline has already been clear-cut (KHM and KV, pers. obs.). What long-term effects the resultant increased runoff and siltation will have upon the herring, and ultimately upon the birds, are unknown. In addition, a log dump and storage facility adjacent to the Toquart River estuary has undoubtedly degraded, to an unknown extent, the immediate area.

Campbell Prentice and Boyd (1988) stated that extensive development has dramatically reduced the amount of estuarine habitat on the east coast of Vancouver Island. The amount of estuarine habitat that has so far been lost along the west coast is much less (Vermeer, Morgan, Dorst, and Whittington, this volume).

4.2 Oil pollution

The millions of marine and shoreline birds that utilize the offshore, coastal, and inlet waters along the British Columbia coast are continuously exposed to high risks of oiling from offshore tanker traffic and inshore shipments of petroleum products (Burger, this volume). Large numbers of birds are most at risk when they are concentrated in relatively small areas, such as at highly productive feeding areas, at communal roosting sites, and around nesting colonies. Some of these sites include the shallow banks offshore of Barkley Sound (i.e., Amphitrite, La Pérouse, and Swiftsure banks; Morgan et al. 1991); Browning Passage (Butler et al., this volume); shorelines adjacent to herring spawning areas (Vermeer, Morgan, Dorst, and Whittington, this volume); Gillam, Solander, and Cleland islands (Vermeer, Morgan, and Ewins, this volume); and the

Scott Islands (Rodway et al., this volume). This serious threat to the marine and shoreline bird populations on the west coast of Vancouver Island is discussed in detail in Burger (this volume), and the nature and extent of the problem will not be dealt with further here.

4.3 Fisheries and other human disturbances

Over the past decade, there has been considerable attention drawn to seabird mortalities caused by the offshore, foreign drift-net fishery (King 1984; DeGange et al. 1985; Atkins and Heneman 1987; Jamieson and Heritage 1987; Jones and DeGange 1988; Gjernes et al. 1990; D. Johnson, T. Shaffer, and P. Gould, unpubl. data). For example, it has been estimated that the North Pacific gill-net fishery kills as many as 400 000 Sooty Shearwaters *Puffinus griseus* annually (Gjernes et al. 1990) and more than 17 500 Laysan *Diomedea immutabilis* and 4400 Black-footed *D. nigripes* albatrosses each year (D. Johnson, T. Shaffer, and P. Gould, unpubl. data).

Data from British Columbia, Alaska, and the Atlantic coast suggest that near-shore fishing activities generally kill far fewer birds than offshore fisheries, although high mortalities have occurred near major nesting colonies (King et al. 1979; Carter and Sealy 1984; Piatt et al. 1984).

Because near-shore mortalities have been relatively low, they have not been considered as potential threats to the conservation of marine birds. However, as near-shore mortalities are likely sustained annually, on perhaps the same population of birds, the cumulative effect could be more severe than expected (Carter and Sealy 1984). Cobb (1976) showed that, for a colony of murres *Uria* spp. in England, the continuous toll inflicted by near-shore fishing was highly significant and greatly outweighed the numbers killed in oil spills.

Several fisheries along the west coast may indirectly result in the deaths of birds. The majority of the harvesting of goose barnacles *Pollicipes polymerus* takes place on small islands along the west coast (Bourne, this volume). When the harvesters beach their boats on a gull, cormorant, or American Black Oystercatcher *Haematopus bachmani* nesting island, the attending adults generally flush from their nests (KHM, pers. obs.). Predators such as Bald Eagles *Haliaeetus leucocephalus*, Northwestern Crows *Corvus caurinus*, Common Ravens *C. corax*, and Glaucous-winged Gulls *Larus glaucescens* take advantage of the easy access to eggs or young (Drent and Guiguet 1961; Verbeek 1982; Vermeer and Morgan 1989). In addition to exposing the eggs and chicks to inclement weather, the young birds that have moved on to a foreign territory risk being killed by other adults of their species. As the barnacle harvesters traverse the island, the burrows of many species of birds may be accidentally collapsed, either crushing the adults and/or nest contents or causing the adults to desert.

Most seabirds are extremely sensitive to human disturbances during the breeding season; Manuwal (1978) and Vermeer (1978) reported high levels of burrow desertion by Tufted Puffins *Fratercula cirrhata* caused by daytime visits and helicopter landings. High levels of desertion of adult seabirds caused by investigators visiting the colonies have been observed (Lensink 1984; K. Vermeer, K.H. Morgan, G.E.J. Smith, and F. Goodfellow, unpubl. data).

Bourne (this volume) states that scoters are one of the main reasons preventing the development of a blue mussel *Mytilus edulis* culture industry in British Columbia. Most mariculture operations probably suffer from some sort of avian predation, and it is also likely that most operators employ certain measures to reduce or prevent such losses. Rueggeberg and Booth (1989) reported that numerous species of birds become entangled in submerged nets or aerial antipredator nets and subsequently drown. In addition, many operators either poison or shoot birds in an attempt to reduce predation.

4.4 Introduced predators

It is assumed that the introduction of mink *Mustela vison* and raccoon *Procyon lotor* to Cox and Lanz islands greatly reduced the seabird breeding populations of the islands (Rodway et al., this volume). Fox (1990), in his review of the methods available and the estimated costs of removing alien mammalian predators from selected seabird colonies along the British Columbia coast, recommended that kill-trapping would be the most efficient means of ridding Cox and Lanz islands of raccoons and mink. If black rats *Rattus rattus* were to reach any of the major breeding colonies along the west coast of Vancouver Island, the consequences to seabirds could be drastic. Rats are thought to be responsible for the extirpation of Cassin's Auklets and population declines of Ancient Murrelets *Synthliboramphus antiquus* from at least one colony in the Queen Charlotte Islands (Bertram 1989).

5. Recommendations

5.1 Marbled Murrelets

The dependence of Marbled Murrelets on coastal old-growth forests as nest sites requires further study. We suggest that future research should address the following:

(1) Derive a meaningful estimate of the total provincial Marbled Murrelet population and identify marine areas of concentration based upon day and night surveys, during and outside of the nesting period.
(2) Determine the relationships between coastal foraging areas (daytime and nighttime) and nesting areas.
(3) Determine the preferred tree species, heights, canopy closure, branch angle and diameter, and quantity (and type?) of epiphytic growth suitable for nesting.
(4) Determine the optimal stand size and shape that will maintain current breeding populations.

5.2 Estuaries and mudflats

As estuarine and mudflat habitats along the west coast appear to be extremely important to migrating and wintering marine and shoreline birds, we recommend the following:

(1) Studies should be initiated to quantify the amount of estuarine habitat that is still available and to identify current and proposed industrial uses.
(2) Crucial areas (e.g., Browning Passage) should receive federal or provincial protection.
(3) The seasonality, distribution, species composition, and populations of marine and shoreline birds utilizing these habitats need to be assessed.
(4) Detailed feeding studies should be initiated in a variety of estuarine and mudflat habitats so that we can determine the avifaunal carrying capacities of different prey organisms and densities, the response of the prey organisms to various forms of habitat degradation, and seasonal and annual variability in prey availabilities.

5.3 Oil pollution

In order for resource managers to make more meaningful assessments of the impacts of oil pollution on birds, we make the following recommendations (adapted from Wiens et al. 1984 and Piatt et al. 1990):

(1) We must continue to monitor breeding colonies to

determine the size, period of occupancy, and age structure of the population and its annual variability.

(2) We need to increase our understanding of where (and upon what) seabirds feed; determine their at-sea distribution, especially during the nonbreeding season; further explore the relationships between oceanographic phenomena and seabird distribution; and investigate age-specific survivorship.

(3) Beached bird surveys must be continued and expanded to establish baseline trends for levels of chronic pollution, to assess the effects of major spills, and to serve as early-warning signals of increasing levels of chronic pollution.

(4) We need to improve our understanding of the proportion of birds that wash ashore on a species-specific basis, during all seasons and for both offshore and inshore spills.

5.4 Fisheries and human disturbances

Although it is assumed that avian mortalities caused by fisheries and other forms of human disturbance are limited, the assumptions need to be verified. Consequently, we suggest that the following research needs be addressed:

(1) We need to identify, quantify, and attempt to mitigate the avian mortalities related to fisheries, mariculture, and other disturbances.

(2) Access to all major colonies must be controlled (perhaps through a warden program during the breeding season), and the impacts of human disturbances, including investigator effects on the colonies, should be addressed.

(3) A permanent, multidisciplinary research facility on Triangle Island should be established to monitor seabirds and their food and to serve as an early warning of changes in prey type and/or availability caused by overexploitation and/or large-scale oceanic and climatic events.

5.5 Introduced predators

To further our understanding of the impacts of introduced predators on seabirds, the following research needs should be addressed:

(1) Surveys of introduced predators should be conducted concurrently with studies on major seabird nesting islands to prevent serious problems from developing.

(2) During breeding colony surveys, if mammalian predation is observed, attempts should be made to identify the predator involved and to determine the extent of predation, such that informed decisions can be made concerning remedial actions.

(3) The level of predation occurring on Cox and Lanz islands by mink and raccoon should be quantified. Because of the islands' proximity to Triangle Island, removal of these predators should be considered.

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