Seabird distribution off British Columbia and Washington

Terry R. Wahl,[1] Ken H. Morgan,[2] and Kees Vermeer[3]

[1]3041 Eldridge, Bellingham, WA 98225
[2]Canadian Wildlife Service, P.O. Box 340, Delta, B.C. V4K 3Y3
[3]Canadian Wildlife Service, c/o Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C. V8L 4B2

Abstract

Surveys of British Columbia and Washington offshore seabirds have been limited seasonally and geographically. Though few direct analyses of distribution and abundance relative to biologic and oceanographic processes have been done, birds appear to concentrate at fronts, outflows, areas of upwelling, and seasonal prey concentrations. Overall numbers generally decrease with depth, presumably reflecting productivity and food availability. Numbers appear to vary greatly from year to year, with differences especially noticeable during abnormal oceanographic "events."

Résumé

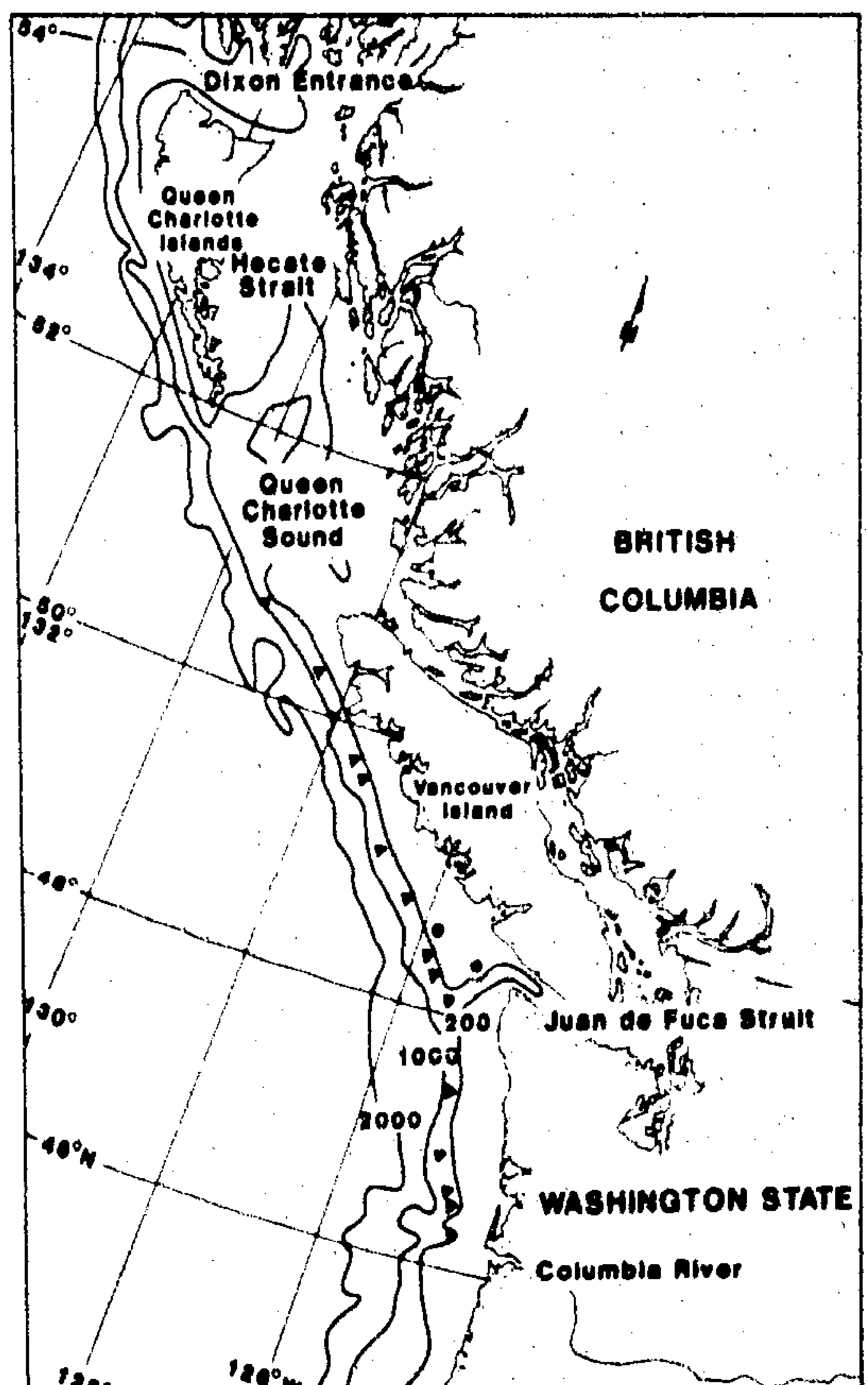
Les relevés des oiseaux marins pélagiques, effectués au large de la Colombie-Britannique et de l'État de Washington, sont limités sur le plan des saisons et des régions. Malgré le peu d'analyses concrètes de la distribution et de l'abondance en fonction des processus biologiques et océanographiques, il semble que les oiseaux se concentrent aux fronts océaniques, aux lieux de débit sortant, aux lieux de remontée des eaux profondes et aux lieux de rassemblement des proies saisonnières. Leur nombre total diminue parallèlement à la profondeur de l'eau, comme il en va vraisemblablement de la productivité et de la disponibilité de la nourriture. Le nombre d'oiseaux marins semble varier considérablement d'une année à l'autre. Les écarts sont remarquables lorsque surviennent des épisodes océanographiques exceptionnels.

1. Introduction

The varied oceanography of the offshore waters (essentially between 20- and 2000-m depth) of British Columbia and Washington (Fig. 1) reflects the area's complicated coastal bathymetry and circulation. Spanning about 900 km in latitude from the Columbia River to Alaska's southeast border, the continental shelf is relatively narrow (up to about 60 km wide), and cut by a number of deep submarine canyons. Shallow offshore banks are located off southern British Columbia and northernmost Washington.

The coastal circulation is complex and seasonally variable in current flows, freshwater inputs, and upwelling (Thomson 1981; Hickey 1989; Landry et al. 1989). The region is not directly associated with the easterly flowing Subarctic Current (Thomson 1981). This current system divides about 1000 km offshore into the southeasterly flowing California Current, which barely affects the Washington continental shelf

Figure 1
Major features of British Columbia and Washington offshore region
▶ = location of major canyons; • = location of offshore banks. Depth contours in metres.



region (Thomson 1981; Hickey 1989), and the Alaska Current, which flows to the northeast and then north off the shelf, west of the Queen Charlotte Islands (Thomson 1981). The Davidson Current, which is perhaps the surface manifestation in winter of the northward-flowing California Undercurrent (Thomson 1981), is a feature of offshore waters, inshore of the California Current.

The character of coastal/continental shelf waters is strongly influenced by the freshwater input from winter rains and summer snowmelt. These vary seasonally and between years (Thomson 1981; Carpenter and Peterson 1989). The outflow from major rivers (Thomson 1981), principally the combined Nass–Skeena, the Fraser, and the Columbia, drains large quantities of fresh water and sediment into estuaries, the transitional waters of the Strait of Juan de Fuca, Queen Charlotte Sound, Hecate Strait, and Dixon Entrance, and eventually into continental shelf and oceanic waters. Offshore, the low-salinity plume from the Columbia River extends southwest far offshore from Oregon in summer, and to the north off Washington in winter (Barnes et al. 1972). From this input and relatively low surface evaporation, Favorite et al. (1976) named the broad region offshore British Columbia and Washington with measurably dilute surface water the "Dilute Domain."

Seasonal, wind-driven upwelling is important to the productivity of the region, though it is highly variable from year to year (Bakun 1973). It occurs from about April to September and generally decreases with latitude. The wind-driven upwelling zone generally occurs 6–10 km offshore (Hickey 1989), and Landry and Lorenzen (1989) reported large standing stocks of zooplankton from about 10 km offshore to at least mid-shelf in summer off Washington. Off southwestern Vancouver Island there are two broad fronts of primary production over the open continental shelf (Brinkhurst 1987). A mixture of seaward-moving estuarine water from the Strait of Juan de Fuca and low-oxygen, nutrient-rich California Undercurrent water is entrained in a band some 65 km long and approximately 20 km wide. This constant supply of nutrients in the summer months contributes to primary production at the inshore front and is responsible for maintaining the offshore front which parallels the 80-m depth contour, some 35 km offshore. Production and biomass of species decrease with depth and/or distance offshore. For example, phytoplankton pigment biomass over the shelf was 8–12 times greater than over the continental slope and in oceanic waters off Washington (Perry et al. 1989). In addition, the California Undercurrent abuts the shelf along its entire margin, producing a weak upwelling and supplying nutrients to the surface waters in the vicinity of the outer canyons. This weak upwelling crosses the shelf and is entrained into the wind-driven upwelling regime of the inner shelf (Hickey 1989).

Sea surface temperature of the shelf region ranges from about 6–10°C in winter to about 10–16°C in summer; summer highs of up to 18°C depend on the extent of irregular intrusions of warm oceanic waters (Thomson 1981). Following the first fall storms in September, the water column becomes mixed and the summer surface temperature pattern of warm offshore/cold shelf waters breaks down.

2. Methods

Comprehensive seabird surveys have been limited until very recently. Sanger (1965, 1970, 1972) and Martin and Myres (1969) reported early observations. Most subsequent data for offshore waters have resulted from surveys conducted on ships of opportunity. Data from many of these systematic studies have been used for descriptive purposes here. The methods of data acquisition, platforms, effort, and habitat classifications used have differed considerably in the various surveys. The resultant density calculations have been derived from both line transect counts and fixed-width transect counts. Some pertinent surveys of adjacent inshore areas also exist (e.g., Savard 1979; Wahl et al. 1981; Vermeer et al. 1983). Geographic coverage has been greatest off southern Washington, and off southwestern Vancouver Island and northern Washington, though, even there, seasonal coverage is uneven and winter data are minimal.

Although long-term oceanographic studies have been conducted off southern Washington (Pruter and Alverson 1972; Landry and Hickey 1989), few seabird data have been collected. Seabird associations with mesoscale features have been identified and characterizations of seasonal populations drawn, but correlations between seabirds and oceanographic features have been quantified in very few cases.

3. Results and discussion

3.1. Faunal overview

Some 38 seabird species (Table 1) occur regularly over continental shelf waters (to 2000-m depth). Another 17 species, casual visitors from oceanic or inshore habitats, have been recorded from the continental shelf area (Table 2). Additionally, a large number of species of waterfowl, shorebirds, and passerines migrate through the region.

3.2. Geographic and seasonal variations

Although the overall species composition is similar throughout the British Columbia–Washington offshore region, there are some differences from north to south, most likely related more to breeding distributions (both coastally and inland) than to latitude *per se* (Hunt and Schneider 1987).

To characterize variations, we have divided the year (after Wahl 1984) into six "seasons." These seasons are: early spring = March, April; late spring = May; summer = June; early fall = July, August; late fall = September, October; winter = November–February. These corresponded generally with patterns of migrations, breeding and wintering periods, as well as the timing of an early September weather change.

3.2.1. Early spring

Nine species (listed as Abundant or Common in Table 1) make up most of the regional seabird population, with an additional 16 occurring in smaller numbers. Fork-tailed and Leach's storm-petrels (*Oceanodroma furcata* and *O. leucorhoa*) arrive to breed after being virtually absent all winter, alcids move in from nearshore wintering regions and from areas offshore, Black-footed Albatross *Diomedea nigripes* numbers increase, and Laysan Albatrosses *D. immutabilis* and Northern Fulmars *Fulmarus glacialis* decrease.

3.2.2. Late spring

Sooty Shearwaters *Puffinus griseus* arrive from the southern hemisphere between late April and early May, and, based on available data, move through the region to concentrate in northern areas, such as Dixon Entrance, the waters west of the Queen Charlotte Islands, Queen Charlotte Sound, and Hecate Strait (Vermeer and Rankin 1984, 1985; Wahl 1984; Vermeer et al. 1987; Morgan et al. 1991). The influx of phalaropes, jaegers, and many species of gulls and terns elevates the diversity of birds to almost fall levels.

Table 1
Seasonal status of seabirds occurring regularly in British Columbia and Washington offshore waters. Seasons: ES = March–April, LS = May, S = June, EF = July–August, LF = September–October, W = November–February. A = abundant (observed regularly in large numbers in appropriate habitat); C = common (observed regularly in moderate numbers); U = uncommon (observed less frequently or in small numbers); R = rare (not always seen in season, small numbers).

Common name	ES	LS	S	EF	LF	W
Black-footed Albatross	U	C	C	C	C	U
Laysan Albatross	R	R	R	R	R	U
Northern Fulmar	C	U	U	C	C	A
Mottled Petrel	U	R	R	R	R	R
Pink-footed Shearwater		C	C	C	C	
Flesh-footed Shearwater		U	U	U	U	
Buller's Shearwater			U	U	C	
Sooty Shearwater	U	C	A	A	A	U
Short-tailed Shearwater	U				U	U
Fork-tailed Storm-Petrel	U	C	C	C	C	R
Leach's Storm-Petrel	U	C	C	C	C	R
Red-necked Phalarope		A		A	A	
Red Phalarope		C		C	U	U
Pomarine Jaeger	R	U	U	C	C	U
Parasitic Jaeger		U		U	C	
Long-tailed Jaeger		R		C	U	
South Polar Skua		R	U	U	U	
Bonaparte's Gull		U				
Mew Gull	U	R			U	C
California Gull	R	U	C	A	A	U
Herring Gull	C	U			U	C
Thayer's Gull	U				U	C
Western Gull[a]	C	C	C	C	C	C
Glaucous-winged Gull	C	C	C	C	C	C
Glaucous Gull	U	U				U
Black-legged Kittiwake	C	U	U	U	U	C
Sabine's Gull		C		C	U	
Common Tern					U	
Arctic Tern		C		C	U	
Common Murre	C	C	C	A	A	A
Thick-billed Murre	R	R	R	R	R	R
Pigeon Guillemot	C	R	R	U	R	R
Xantus' Murrelet			U	U	U	
Ancient Murrelet	C	C	C	U	U	U
Cassin's Auklet	C	C	A	A	A	C
Rhinoceros Auklet	C	C	A	A	A	C
Tufted Puffin	U	U	C	C	U	U
Horned Puffin	R	R	R	R	R	R

[a]Uncommon off British Columbia.

3.2.3. *Summer*

In June, with little or no migration taking place, species richness declines, with about 13 species dominating. Albatrosses and shearwaters reside offshore, adding to populations of storm-petrels, gulls, and alcids breeding in the region. In addition, variable numbers of nonbreeding fulmars and Black-legged Kittiwakes *Rissa tridactyla* are present. From northern Vancouver Island to the Alaskan border, storm-petrels and alcids are especially abundant (Table 3), likely reflecting the much greater availability of nesting habitat than exists farther south. In addition to other numerous nesting alcids, Ancient Murrelets *Synthliboramphus antiquus* breed in the northern area almost exclusively, and small numbers of Thick-billed Murres *Uria lomvia* and Horned Puffins *Fratercula corniculata* are there exclusively. The southwest coast of Vancouver Island and northern Washington also has offshore islands and rocks which provide seabird nesting habitats, particularly for storm-petrels, cormorants, gulls, and alcids. The southern coast of Washington has no offshore islands, and nesting populations are made up almost entirely of Double-crested Cormorants *Phalacrocorax auritus*, gulls, and Caspian Terns *Sterna caspia*, which nest on islands in estuaries.

Table 2
Species of seabirds observed inshore or offshore of British Columbia and Washington. R = regularly seen, C = casual, — = not recorded.

Species	Inshore	Offshore	Reference
Short-tailed Albatross *Diomedea albatrus*	—	C	Gruchy et al. 1972
Shy Albatross *Diomedea cauta*	—	C	Slipp 1952
Solander's Petrel *Pterodroma solandri*	—	C	Wahl, unpubl. data
Manx Shearwater *Puffinus puffinus*	—	C	Wahl, unpubl. data
Black-vented Shearwater *Puffinus opisthomelas*	—	C	Campbell et al. 1990
Wilson's Storm-Petrel *Oceanites oceanicus*	—	C	Wahl, unpubl. data
Red-billed Tropicbird *Phaethon aethereus*	—	C	Flahaut 1947
Brandt's Cormorant *Phalacrocorax penicillatus*	R	C	Wahl, unpubl. data
Brown Pelican	R	C	Wahl, unpubl. data
Laughing Gull *L. atricilla*	C		Wahl, unpubl. data
Franklin's Gull *Larus pipixcan*	C	C	Wahl, unpubl. data
Heermann's Gull	R	C	Wahl, unpubl. data
Ring-billed Gull	R	C	Wahl, unpubl. data
Red-legged Kittiwake *Rissa brevirostris*	C	C	Wahl, unpubl. data
Caspian Tern	R	C	Wahl, unpubl. data
Marbled Murrelet *Brachyramphus marmoratus*	R	C	Wahl, unpubl. data
Parakeet Auklet *Cyclorrhynchus psittacula*		C	Jewett et al. 1953; Morgan et al. 1991; Wahl, unpubl. data

Table 3
Populations of seabirds breeding on the outer coasts of British Columbia and Washington

Species	British Columbia[a]	Washington[b]
Fork-tailed Storm-Petrel	1 526 238[c]	5 000
Leach's Storm-Petrel		36 000
Brandt's Cormorant	126	560
Double-crested Cormorant		2 150
Pelagic Cormorant	2 700	7 640
Glaucous-winged Gull	30 000	16 500[d]
Caspian Tern		7 902
Common Murre	5 620	3 000[e]
Thick-billed Murre	70	
Pigeon Guillemot	8 400	330
Marbled Murrelet	45 000[f]	2 400[g]
Ancient Murrelet	543 000	
Cassin's Auklet	2 354 000	88 000
Rhinoceros Auklet	680 000	24 200
Tufted Puffin	77 000	22 700
Horned Puffin	50	
Total	5 273 209	211 302

[a] From Rodway, in Vermeer 1989
[b] Speich and Wahl 1989 (most recent data from 1982)
[c] Both species combined
[d] Includes Western Gull
[e] Post-1983 estimate (U.S. Fish and Wildlife Service, unpubl. data); estimate prior to 1983 El Niño–Southern Oscillation event was 30 900 (Speich and Wahl 1989).
[f] Ewins et al., this volume
[g] S.M. Speich, Wahl, and D.A. Manuwal, unpubl. data.

A few Ring-billed Gulls *Larus delawarensis* nest there, along with many Western *Larus occidentalis* and Glaucous-winged *L. glaucescens* gulls. Western Gulls nest in numbers only from the central Washington coast south. The offshore distribution of breeding species, whether uniform or related to distance from colonies, has not been described for the entire British Columbia–Washington region. Offshore populations of nonbreeding species may be essentially similar throughout the region. although the movement in May and June of extremely large numbers of Sooty Shearwaters into Hecate Strait may be unique. The limited data indicate that fewer Sooty Shearwaters occur off Washington than British Columbia in June, but that numbers off Washington peak during spring and fall (Wahl 1984. unpubl. data; Vermeer et al. 1987). Xantus' Murrelet *Synthliboramphus hypoleucus*, which breeds from southern California through Baja California, is less rare in southern Washington offshore waters than in British Columbia. although the species has been observed there (Morgan et al. 1991).

3.2.4. Early fall

During the July–August period the seabird populations off Washington and British Columbia include young birds raised both in the region and farther north and, along with the late fall period, likely contain the largest total populations of the year, along with the greatest number of species (20). Offshore summer populations are supplemented by early migrants, including small numbers of Buller's Shearwaters *P. bulleri* (Wahl 1985), increased numbers of Sooty Shearwaters, phalaropes, jaegers, and gulls, especially California Gulls *L. californicus*, which arrive on the coast in July from inland nesting areas. Northward migration of murres from Oregon and/or California begins, with adults and chicks moving slowly north along the Washington coast. Huge flocks of birds forage in southern Washington estuaries starting in August. When warm, oceanic water intrudes over the continental shelf, Leach's Storm-Petrels may forage closer to shore than usual. If this oceanographic condition does occur, it usually breaks down in early September.

3.2.5. Late fall

Numbers of migrating phalaropes, jaegers, Sabine's Gulls *Xema sabini*, and Arctic Terns *S. paradisaea* decrease, though this is the season with the most (20) Abundant and Common species (according to definitions in Table 1) present during the year. Gull populations also increase over early fall, with most Herring *L. argentatus* and Thayer's *L. thayeri* gulls appearing in October. Although shearwater populations in the northern areas are notably smaller in the fall than in the spring (Vermeer and Rankin 1984, 1985), shearwater numbers peak off Vancouver Island and northern Washington prior to migration. Some Sooty Shearwaters penetrate the Strait of Juan de Fuca, and many others forage near shore and in Grays Harbor and Willapa Bay in the south (Wahl 1984; Vermeer et al. 1987). Alcids—murres and Rhinoceros Auklets *Cerorhinca monocerata*—also forage inshore, and migrating murres move all the way into the Strait of Georgia, Puget Sound, and other inland marine waters for the winter.

3.2.6. Winter

From November to March most of the shearwaters and storm-petrels are absent, and populations include only about 10 numerous species, including Northern Fulmar, gulls, and alcids. Gull populations contain local residents, along with large numbers of Mew *L. canus*, Herring, Thayer's, and Glaucous-winged gulls and Black-legged Kittiwakes. Ancient Murrelets and Rhinoceros Auklets disperse offshore and south for the winter, whereas Tufted Puffins *Fratercula cirrhata* move to mid-ocean. Many individuals of a number of species that breed both within the region and outside of it move to winter in sheltered inland waters.

3.3. Population estimates

Almost all of the approximately five million seabirds breeding in the region (Table 3) forage offshore (>20-m depth), with only cormorants, Caspian Terns, and some gulls foraging predominantly near shore (<20-m depth). A large proportion of the breeding population consists of storm-petrels and small alcids, and the vast majority of these breed in British Columbia.

Nonbreeding populations are poorly understood. Although seasonal standing stocks have been roughly estimated for parts of the study area, the estimates perhaps reflect survey coverage more than true seasonal peaks. Maximum spring numbers of about 1.4 million are possible for Dixon Entrance (93 000 from censuses but with 1.4 million nesting nearby; Vermeer and Rankin 1985), 2.2 million for the coastal waters west of the Queen Charlotte Islands, and 6.5 million in Queen Charlotte Sound and Hecate Strait (Vermeer and Rankin 1984). Off southern Washington peak early fall numbers of about 1.2 million (excluding inshore populations) have been estimated (Wahl 1984). No estimate of the seasonal populations off southwestern Vancouver Island has been made. These projections are subject not only to problems of censusing and small sample size but also to the use of averages which understate maximal numbers. For example, a major portion of the alcids which breed in British Columbia (about 3.5 million adult Ancient Murrelets, Cassin's Auklets, and Rhinoceros Auklets [Table 3] plus young and nonbreeders) transit Washington's offshore waters during migrations. Similarly, large numbers of fulmars and kittiwakes originating in Alaska pass through the region to winter off Oregon and California.

Some geographic differences in abundance of nonbreeding species (e.g., large flocks of Sabine's Gulls concentrating off southern British Columbia; Vermeer et al. 1987; Campbell et al. 1990) probably relate to foraging opportunities. Bonaparte's Gulls *L. philadelphia* occur off southern Washington and are only infrequently encountered off the British Columbia coast, perhaps reflecting migrations to and from inland nesting areas via the Fraser River. California Gulls are abundant from Vancouver Island south (Wahl 1975, 1984; Vermeer et al. 1987) but have not been reported for Dixon Entrance (Vermeer and Rankin 1985), suggesting fall migration from the interior to coastal waters via the Fraser and Columbia rivers.

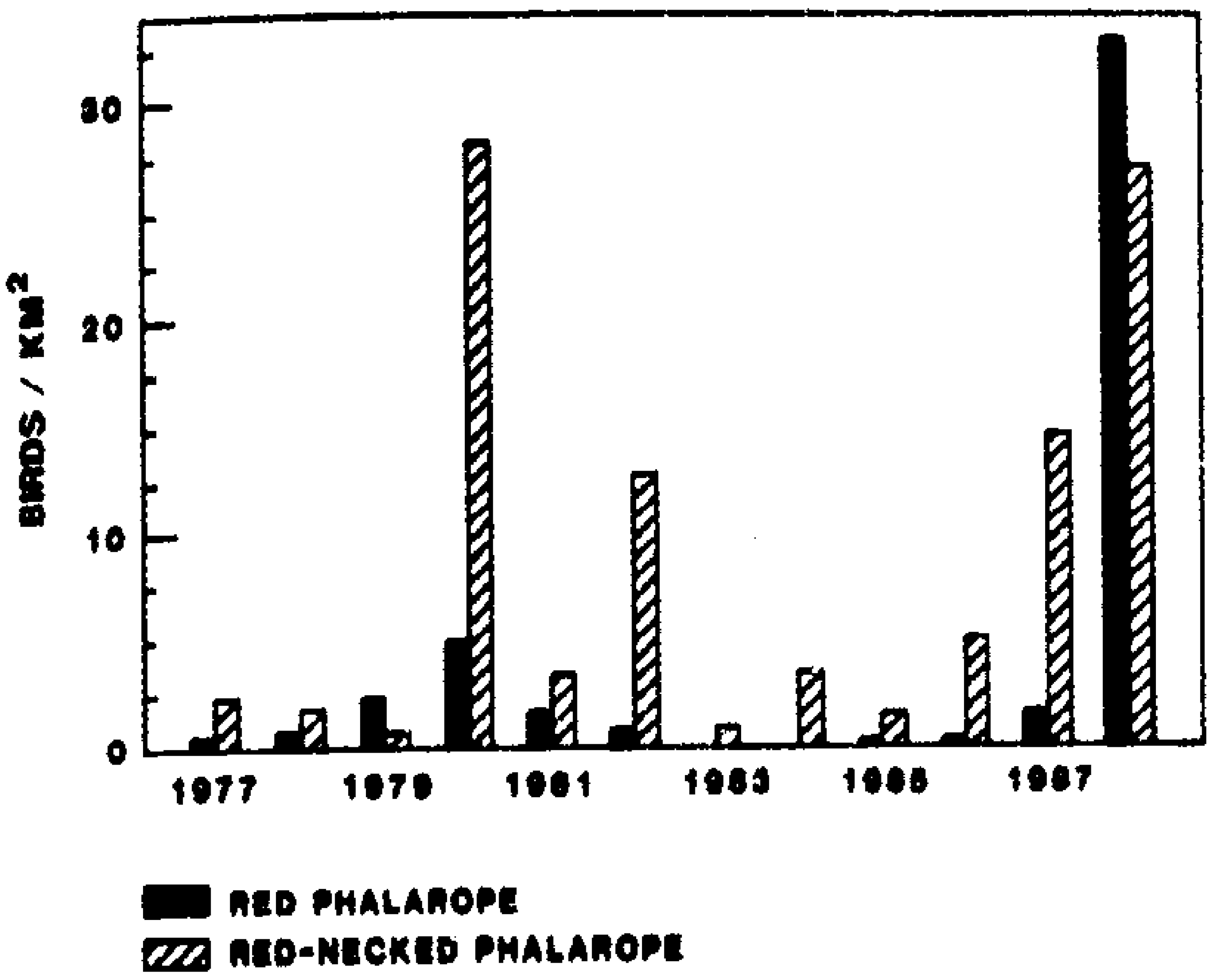
3.4. Year-to-year variation

Only a limited area of the offshore waters off southern British Columbia and Washington has been surveyed over a period of years. Surveys elsewhere were done during only one, two, or three years, with minimal sampling at best, so "average" conditions are unknown. Even off southern Washington interannual differences in most species numbers were not statistically significant because of patchiness and variations in census data (Wahl, unpubl. data), though differences were intuitively apparent in many cases. Extremes stand out, however, for a number of species (e.g., phalaropes: Fig. 2), especially in years of major oceanographic anomalies.

3.5. Proximity to nesting areas

Birds appear to be seasonally more abundant offshore from nesting colonies than in areas far from nest sites. For example, Ancient Murrelets have been observed off Washington, where few if any breed. However, great numbers breed in northern British Columbia and, though numbers have been seen offshore in April–May, low numbers have been observed in pelagic waters at other times. Some "offshore"

Figure 2
Annual Abundance Indices of phalaropes in July–October off southern Washington (Wahl, unpubl. data). Abundance Index = birds observed/km² weighted by habitat area. RNPH = Red-necked Phalarope; REPH = Red Phalarope.



species may forage during the nesting season in nearshore habitats rather than offshore. For example, during limited surveys off the entrance to the Strait of Juan de Fuca in summer, Tufted Puffins were abundant in the immediate area of a colony, whereas few if any were found foraging offshore. Farther from colonies, off the southern coast of Washington, adult puffins at the same season were distributed farther offshore to the edge of the continental shelf, though numbers were low (Wahl, unpubl. data).

3.6. Use of nearshore waters

Sooty Shearwaters forage in huge numbers in shallow nearshore waters during August–September when northern anchovies *Engraulis mordax* are present in southern Washington (Wahl 1984). Also in Washington, the migration of Common Murres from Oregon along the coast takes place in both nearshore and offshore waters. Similar movements have been observed off California (DeSante and Ainley 1980; Briggs et al. 1987). Many murres winter over the continental shelf, but large numbers pass through the area to winter in inland marine waters (Wahl et al. 1981). Rhinoceros Auklets, which winter offshore and mainly south of the region, forage in very large numbers in nearshore waters when prey is abundant there (Wahl, unpubl. data). Conversely, nearshore resident species sometimes use offshore waters. On several occasions, groups of Pigeon Guillemots *Cepphus columba* were observed offshore of Washington in the fall, possibly migrating north from Oregon or California to winter in inland waters of Washington and British Columbia (Wahl, unpubl. data).

3.7. Major inlets off the open ocean

In northern British Columbia, very large numbers of shearwaters forage seasonally in Dixon Entrance, Hecate Strait, and Queen Charlotte Sound (Savard 1979; Vermeer and Rankin 1984, 1985; Campbell et al. 1990). Fulmars and some other offshore species also enter Dixon Entrance in the fall, but other offshore species like Buller's Shearwater do so rarely (Morgan et al. 1991). Farther south, the Strait of Juan de Fuca is used regularly by large numbers of migrating and wintering murres (Wahl et al. 1981) and Red-necked Phalaropes *Phalaropus fulicarius* in spring and fall, but by only relatively small numbers of other oceanic species.

3.8. Oceanic waters offshore

During the summer, seabird populations within the split of the Subarctic Current into the California and Alaska current systems (see Favorite et al. 1976) and lying offshore of the region appear to be relatively small. In addition, the species mix differs notably from those species found in either the adjacent oceanic water masses or the slope, shelf, and coastal waters to the east (Wahl et al. 1989). This suggests that, in the summer, at least, there is little interchange with populations nearer the coast.

3.9. Associations with physical and biological processes

3.9.1. Fronts

Quantitative data are minimal, but observations and anecdotal reports show that a number of species, especially phalaropes, concentrate at drift lines and at current boundaries, similar to other areas (Briggs et al. 1984).

3.9.2. Estuarine outflows

Large numbers of birds (e.g., Sooty Shearwaters, California Gulls, and Cassin's Auklets *Ptychoramphus aleuticus* in July–August) concentrate to forage in tidal fronts off the entrance to the Strait of Juan de Fuca. The combination of feeding opportunities at fronts within the Strait of Juan de Fuca outflow and over shallow offshore banks explains the large, regionally unique concentrations of Sabine's Gulls off southwestern Vancouver Island (Vermeer et al. 1987).

3.9.3. Sea surface temperature

Distribution of seabirds seldom appears to be related to local sea surface temperature *per se*. Even extreme sea surface temperatures in the region still fall within a narrow range relative to the large-scale differences found over the North Pacific Ocean (Wahl et al. 1989). Presence of greater numbers of certain species (e.g., Buller's Shearwater; Ainley 1976) during years of "warm" water and the distribution and abundance of some other regularly occurring species during years of major anomalies such as El Niño–Southern Oscillation events (Wahl, unpubl. data) are likely related to large-scale temperature patterns reflecting productivity.

Vermeer et al. (1992), however, found strong correlations (positive or negative) between sea surface temperatures and the occurrence of many species (e.g., Black-footed Albatross, Northern Fulmar, Pink-footed Shearwater *P. creatopus*, Buller's and Sooty shearwaters, Fork-tailed and Leach's storm-petrels, Glaucous-winged and California gulls, Common Murre, Cassin's and Rhinoceros auklets, and Tufted Puffin) off Vancouver Island. Fork-tailed Storm-Petrels tend to occur primarily over the outer continental shelf, inshore of the front separating colder, "green" water from warmer, "blue" water offshore where Leach's Storm-Petrels occurred (Wahl, unpubl. data). Surveys off British Columbia in warm offshore waters indicate that there are few birds there other than low numbers of Leach's Storm-Petrels and Black-footed Albatrosses (Morgan et al. 1991).

3.9.4. Effects of depth

Off southern Washington there is a relatively regular bathymetric transition from the nearshore 20-m depth contour to oceanic waters. Farther north, patterns of distribution relative

Figure 3
Density Indices of birds by depth off southern Washington in May, 1972–1988 (no samples >2000 m) (Wahl, unpubl. data). Density Index = birds observed/km².

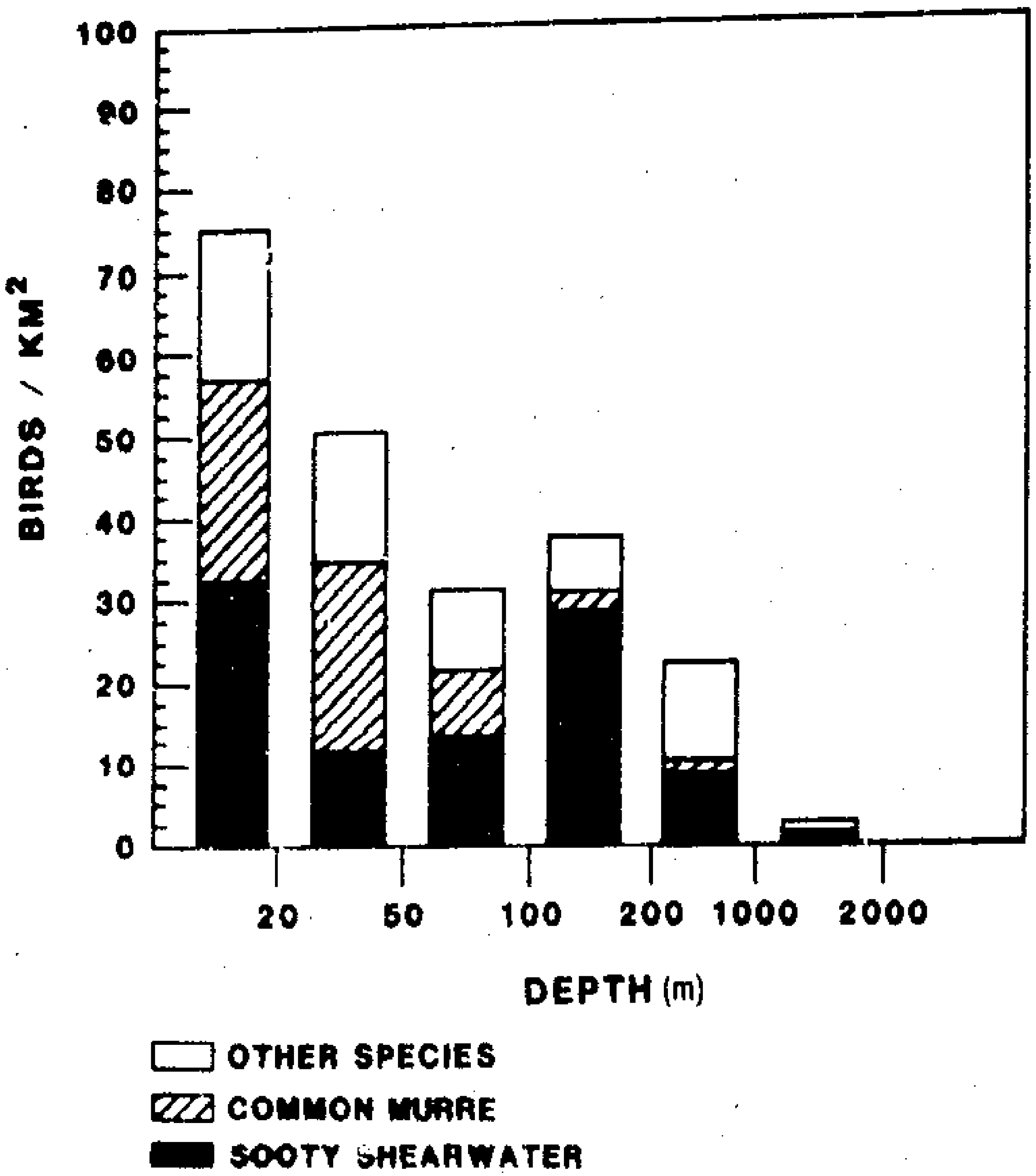
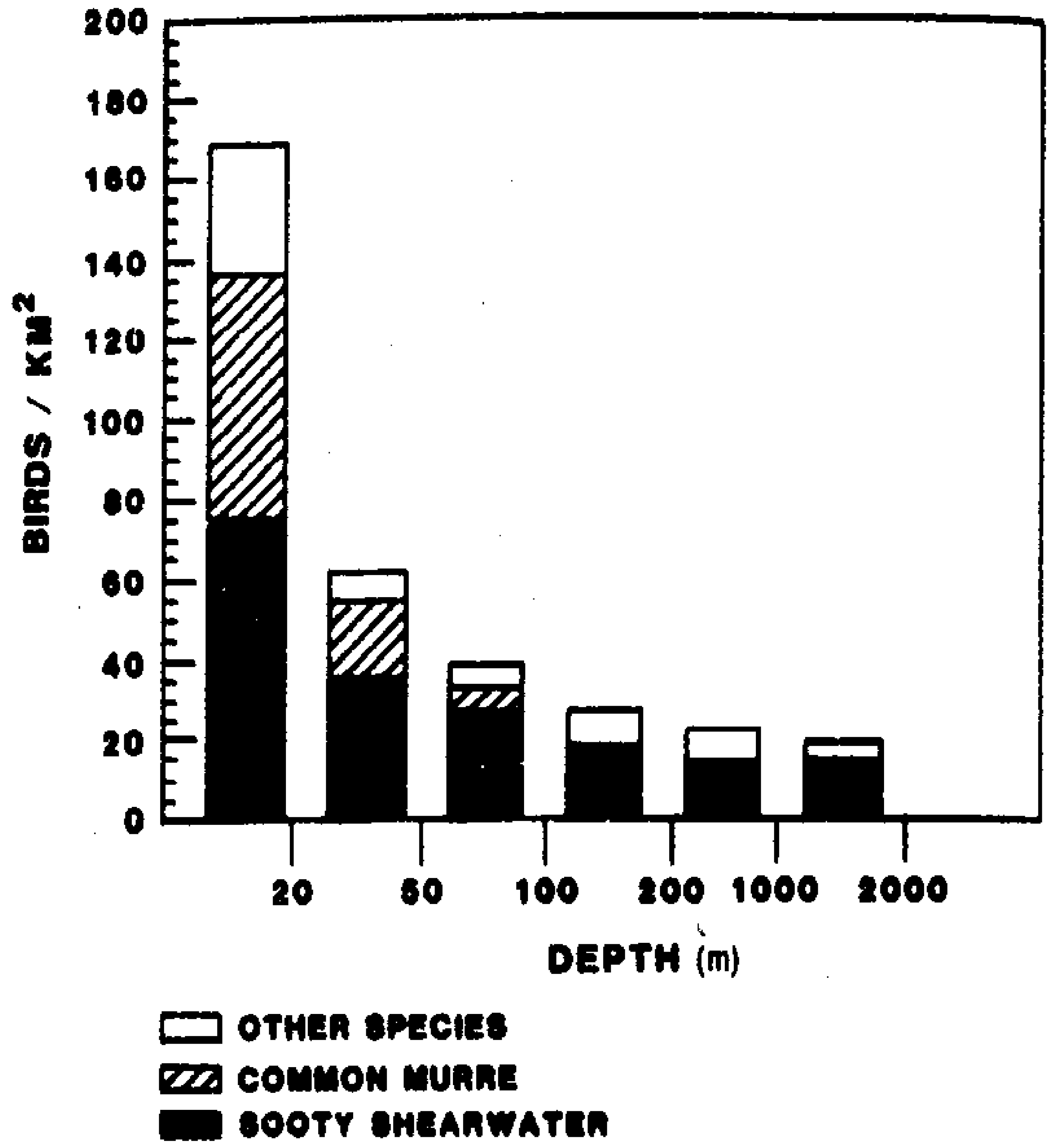


Figure 4
Density Indices of birds by depth off southern Washington in August, 1972–1988 (no samples >2000 m)



to depth are complicated by estuarine outflows, large inlets, offshore banks, and, in some areas, a narrower shelf.

Overall, there is a pattern of decreasing seabird abundance with increasing depth. For example, Vermeer et al. (1989) found significantly more birds over depths of <60 m than >100 m. There are general patterns of different seabird species occurring in water of different depths, though these patterns vary by season (e.g., Figs. 3 and 4). Distributions are undoubtedly related to prey and their availability; but in general, as Botsford et al. (1989) state, "the identification of the influence of oceanographic conditions on fish stocks is at a relatively primitive stage in the Pacific northwest as elsewhere."

Off Washington, Sooty Shearwaters concentrate farther offshore in May (Fig. 3), when food is relatively scarce (see Chu 1984), than in August, when northern anchovies are extremely abundant nearer shore (Fig. 4). Off southwestern Vancouver Island, Vermeer et al. (1989) found Sooty Shearwaters present at higher densities over the mid-shelf than either nearshore or more oceanic waters. Vermeer (unpubl. data) did not find anchovies in stomach analyses of birds collected off southwestern Vancouver Island during September and October. This was likely due to the fact that the occurrence of anchovies in British Columbia is sporadic (Hart 1973).

Buller's Shearwaters off Vancouver Island are most abundant beyond the shelf break (>200-m depth; Vermeer et al. 1987), whereas off southern Washington the largest concentrations occur between 100- and 200-m depth (Wahl, unpubl. data).

The distribution of phalaropes off southern Washington varied somewhat from that found by Briggs et al. (1984) off California. Red-necked Phalaropes were most abundant off Washington over mid-shelf fronts and were seldom observed with Red Phalaropes over the continental slope and oceanic waters (Fig. 5, and see Wahl et al. 1989).

3.9.5. Upwelling

Numbers of birds present during summer and fall appeared to vary annually relative to the strength of upwelling along the coast (Wahl, unpubl. data). Locally, phalaropes are most often abundant in regions where wind-driven upwelling takes place (ca. 10 km offshore, 20–50-m depth, see Fig. 5), though within that region they tend to concentrate at fronts. Other species usually concentrate offshore of this region, often at the edge of canyons and along the shelf edge where deep waters are upwelled toward the surface (Hickey 1989).

3.9.6. Effects of major oceanographic events

During the 1983 El Niño event some seabird abundances were far above the normal ranges, and others were far below. This, along with the northern extensions of several species, supported patterns reported elsewhere (Pearcy and Schoener 1987). Ainley (1976) and Guzman and Myres (1983) suggested that Pink-footed Shearwaters may move north in greater numbers during El Niño events. Numbers of Pink-footed Shearwaters off Washington were average or slightly higher in 1982–83 (Wahl, unpubl. data).

Patterns of distribution were also different during the 1982–83 El Niño than at other times. Density Indices close to shore were greater (Wahl, unpubl. data) and included more Brown Pelicans *Pelecanus occidentalis*, kittiwakes, and other common species (and never-before-recorded Elegant Terns *S. elegans*) than during other years. This pattern, featuring larger numbers of birds that breed south of Washington, suggested food shortages to the south.

3.9.7. Prey species

Although Density Indices of birds generally decreased with distance offshore, some variations in this pattern were evident and likely attributable to the location of prey species.

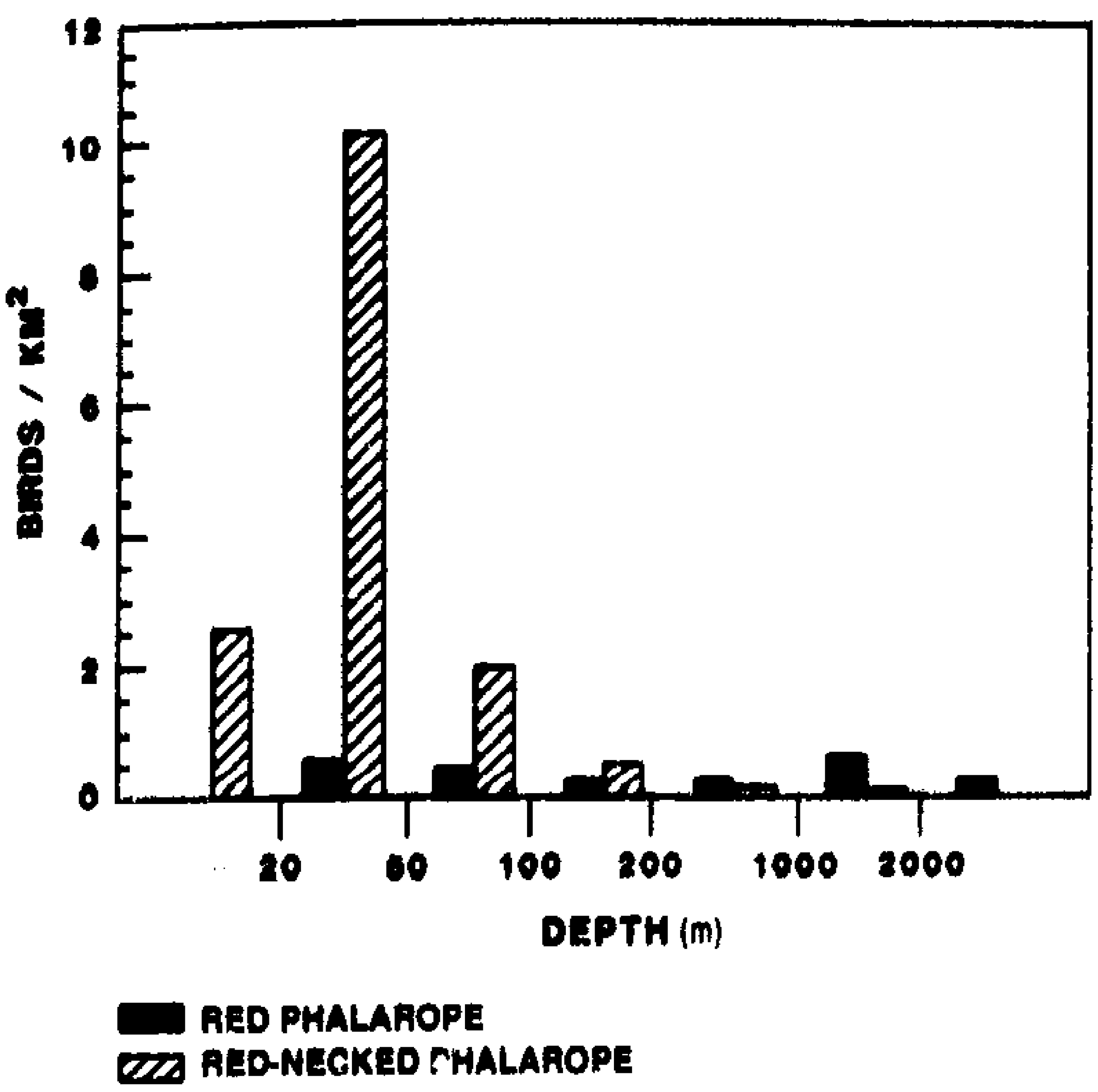


Figure 5
Density indices of phalaropes by depth off southern Washington in September–October, 1971–1987

Very high concentrations of birds near shore (especially Sooty Shearwaters and Common Murres) were evident in July–September (Wahl, unpubl. data). That period coincides with when anchovies are abundant and present in coastal estuaries. These nearshore concentrations varied with either time of day or tidal stage, with feeding flocks often forming in late afternoon. At these locations, shearwaters and murres joined large numbers of Brown Pelicans, cormorants, Heermann's Gulls *L. heermanni*, Black-legged Kittiwakes, Caspian Terns, Rhinoceros Auklets, and other nearshore species. The flocks were very mobile, and feeding was often quite limited in time at any one location. Thus, the distribution of many species of birds is likely affected by the location and availability of anchovies in late summer and early fall, and of Pacific herring *Clupea harengus* during the spring.

Additional prey-related observations include Fork-tailed Storm-Petrels feeding, reportedly on Dungeness crab *Cancer magister* larvae (D. Samuelson, pers. commun.), inside coastal harbours during the El Niño period in 1983, when they occurred far inland in protected marine waters (Wahl, unpubl. data).

Except for prey data obtained from locally breeding seabirds during the nesting season (e.g., Wilson and Manuwal 1986), there are few data for Washington on offshore prey taken by resident and visiting species at other seasons, though there are more for British Columbia (Vermeer and Ydenberg 1989; Vermeer et al. 1989). Descriptions of the relation of birds and prey species for a seabird colony, such as off northern California (Ainley et al. 1990), or birds, food webs, and environment (e.g., in Alaskan waters; Springer 1991) are, however, much more thorough than is currently possible for breeding and/or visiting seabirds off the coasts of British Columbia and Washington.

3.10. Associations with human activities and events

3.10.1. Fishing

Commercial fishing activity attracts large numbers of birds (Vermeer et al. 1989). However, the overall effects of this on seabird distribution and abundance through provision of otherwise unavailable food are unknown. Similarly, the extent to which existing commercial fishing competes with seabirds for food is unknown. On many offshore transits approximately 50% of Black-footed Albatrosses, Sooty Shearwaters, and California Gulls recorded were near fishing vessels (Wahl, unpubl. data, and see Wahl and Heinemann 1979 and Vermeer et al. 1989). The range of attraction of vessels over time, and whether birds observed "away" from vessels had been "at" them previously, are among questions unanswered to date. Enhanced populations of some species (e.g., California Gull) may have resulted from increased industrial fishing. In the 1960s, the Russian industrial fishing fleet of dozens of vessels, which fished continually for days, entered the offshore waters to capture hake *Merluccius productus*. The establishment of the 200-mile limit and subsequent restriction of foreign fishing effort was apparently replaced at least in part by increased Canadian and U.S. fishing effort (e.g., Vermeer et al. 1989). The reports of exceptionally high numbers of California Gulls offshore (e.g., Wahl 1975; Vermeer et al. 1987) may represent increases in numbers of this species.

The offshore region has had relatively few bird mortalities caused by nets. There is no driftnet (offshore gill-net) fishery at present. Gill nets are widely used; however, for salmon fishing in inland marine waters and in coastal estuaries, and, though mortality has not been quantified, these fisheries do kill birds (e.g., Carter and Sealy 1984). Murres and grebes appear to be the principal victims, though shearwaters have been killed in these inshore nets (Wahl, unpubl. data). A gillnet fishery in northern Washington reportedly killed about 2500 murres during the 1989 nesting season. The effects of this and other fisheries on populations of offshore species require study and concern.

3.10.2. Oil

To date, the birds of the offshore region have been subjected to relatively few major impacts of oil. In late 1988, however, a major spill (the "Nestucca" spill) just offshore of southern Washington oiled an unknown number of birds. About 13 000 were recovered from Washington and British Columbia coastal beaches. The great majority of oiled birds collected in Washington were Common Murres, with murres and Cassin's Auklets predominating in British Columbia (Burger 1989). Most of the other birds killed were inshore species — loons, grebes, scoters, and gulls — though a few additional offshore birds (Thick-billed Murres, Parakeet Auklets *Cyclorrhynchus psittacula*, Horned and Tufted puffins) were also found.

4. Conclusions and recommendations

Surveys need to be expanded to include more thorough geographic and seasonal coverage, especially from November through April (Wahl 1984; Vermeer and Rankin 1985; Morgan et al. 1991). The generality of observations of populations associating with physical/bathymetric features (shelf edge, canyons) needs to be tested to establish vulnerability levels throughout the region.

Diet, especially of nonbreeding populations, and changes in extent of prey availability due to variable oceanographic conditions should be studied (Wahl 1984; Vermeer et al. 1987). Analysis of the spatial effects of upwelling through the water column and the process of conversion of nutrients through the food web to bird prey would greatly assist the understanding of the situation. The distribution and abundance of zooplankton and of important fish prey such as anchovies, herring, smelt *(Hypomesus, Spirinchus)*, eulachon *Thaleichthys pacificus*, Pacific saury *Cololabis saira*, and Pacific sand lance *Ammodytes hexapterus* need further investigation.

The impacts of human activities (especially petroleum-related activities and commercial fishing) on breeding and nonbreeding populations require thorough study. Satellite photos of fishing vessels within the region in conjunction with surveys of bird species at vessels could assess the degrees of concentration and potential impacts. The extent and the potential impacts of inshore gillnetting on both inshore and offshore seabird populations should also be investigated.

Acknowledgements

Anonymous reviewers and K.T. Briggs made many helpful suggestions on an earlier version of this paper.

Literature cited

Ainley, D.G. 1976. The occurrence of seabirds in the coastal region of California. West. Birds 7:33–68.

Ainley, D.G.; Strong, C.S.; Penniman, T.M.; Boekelheide, R.J. 1990. The feeding ecology of Farallon seabirds. Pages 51–127 *in* Ainley, D.G.; Boekelheide, R.J. (eds.), Seabirds of the Farallon Islands. Stanford Univ. Press, Stanford, CA.

Bakun, A. 1973. Coastal upwelling indices, west coast of North America, 1946–71. NOAA Tech. Rep. NMFS SSRF-671. U.S. Dep. Commer., Seattle, WA.

Barnes, C.A.; Duxbury, A.C.; Morse, B.-A. 1972. Circulation and selected properties of the Columbia River effluent at sea. Pages 41–80 *in* Pruter, A.T.; Alverson, D.L. (eds.). The Columbia River estuary and adjacent ocean waters. Univ. of Washington Press, Seattle.

Botsford, L.W.; Armstrong, D.A.; Shenker, J.M. 1989. Oceanographic influences on the dynamics of commercially fished populations. Pages 511–566 *in* Landry, M.R.; Hickey, B.M. (eds.), Coastal oceanography of Washington and Oregon. Elsevier Oceanography Series 47. Elsevier, New York.

Briggs, K.T.; Dettman, K.F.; Lewis, D.B.; Tyler, W.B. 1984. Phalarope feeding in relation to autumn upwelling off California. Pages 51–62 *in* Nettleship, D.N.; Sanger, G.A.; Springer, P.F. (eds.), Marine birds: their feeding ecology and commercial fisheries relationships. Can. Wildl. Serv. Spec. Publ., Ottawa.

Briggs, K.T.; Tyler, W.B.; Lewis, D.B.; Carlson, D.R. 1987. Bird communities at sea off California: 1975 to 1983. Stud. Avian Biol. No. 11.

Brinkhurst, R.O. 1987. Distribution and abundance of macrobenthic infauna from the continental shelf off southwestern Vancouver Island, British Columbia. Can. Tech. Hydrogr. Ocean Sci. No. 85.

Burger, A.E. 1989. Effects of the "Nestucca" oil spill (January 1989) on seabirds along the southwest coast of Vancouver Island. Unpublished report. Can. Wildl. Serv., Vancouver, B.C.

Campbell, R.W.; Dawe, N.K.; McTaggart-Cowan, I.; Cooper, J.M.; Kaiser, G.W.; McNall, M.C.E. 1990. The birds of British Columbia. Vols. I and II. Royal British Columbia Museum and Canadian Wildlife Service.

Carpenter, R.; Peterson, M.L. 1989. Chemical cycling in Washington's coastal zone. Pages 367–510 *in* Landry, M.R.; Hickey, B.M. (eds.), Coastal oceanography of Washington and Oregon. Elsevier Oceanography Series 47. Elsevier, New York.

Carter, H.R.; Sealy, S.G. 1984. Marbled Murrelet mortality due to gill-net fishing in Barkley Sound, British Columbia. Pages 212–220 *in* Nettleship, D.N.; Sanger, G.A.; Springer, P.F. (eds.), Marine birds: their feeding ecology and commercial fisheries relationships. Can. Wildl. Serv. Spec. Publ., Ottawa.

Chu, E.W. 1984. Sooty Shearwaters off California: diet and energy gain. Pages 64–71 *in* Nettleship, D.N.; Sanger, G.A.; Springer, P.F. (eds.), Marine birds: their feeding ecology and commercial fisheries relationships. Can. Wildl. Serv. Spec. Publ., Ottawa.

DeSante, D.F.; Ainley, D.G. 1980. The avifauna of the South Farallon Islands, California. Stud. Avian Biol. No. 4.

Favorite, F.; Dodimead, A.J.; Nasu, K. 1976. Oceanography of the subarctic Pacific region 1960–71. Int. North Pac. Fish. Comm. Bull. 33.

Flahaut, M.R. 1947. Red-billed tropic-bird at Westport, Washington. Murrelet 28:6.

Gruchy, C.G.; Dykes, A.R.R.; Bowen, R.H. 1972. The Short-tailed Albatross recorded at Ocean Station Papa, North Pacific Ocean, with notes on other birds. Can. Field-Nat. 86:285–287.

Guzman, J.R.; Myres, M.T. 1983. The occurrence of shearwaters (*Puffinus* spp.) off the west coast of Canada. Can. J. Zool. 61:2064–2077.

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180.

Hickey, B.M. 1989. Patterns and processes of circulation over the Washington continental shelf and slope. Pages 41–116 *in* Landry, M.R.; Hickey, B.M. (eds.), Coastal oceanography of Washington and Oregon. Elsevier Oceanography Series 47. Elsevier, New York.

Hunt, G.L. Jr.; Schneider, D.C. 1987. Scale-dependent processes in the physical and biological environment of marine birds. Pages 7–41 *in* Croxall, J.P. (ed.), Seabirds: feeding ecology and role in marine ecosystems. Cambridge Univ. Press, Cambridge, U.K.

Jewett, S.A.; Taylor, W.P.; Shaw, W.T.; Aldrich, J.W. 1953. Birds of Washington State. Univ. of Washington Press, Seattle.

Landry, M.R.; Hickey, B.M. (eds.). 1989. Coastal oceanography of Washington and Oregon. Elsevier Oceanography Series 47. Elsevier, New York.

Landry, M.R.; Lorenzen, C.J. 1989. Abundance, distribution and grazing impact of zooplankton on the Washington shelf. Pages 175–210 *in* Landry, M.R.; Hickey, B.M. (eds.), Coastal oceanography of Washington and Oregon. Elsevier Oceanography Series 47. Elsevier, New York.

Landry, M.R.; Postel, J.R.; Peterson, W.K.; Newman, J. 1989. Broad-scale distributional patterns of hydrographic variables on the Washington/Oregon shelf. Pages 1–40 *in* Landry, M.R.; Hickey, B.M. (eds.), Coastal oceanography of Washington and Oregon. Elsevier Oceanography Series 47. Elsevier, New York.

Martin, P.W.; Myres, M.T. 1969. Observations on the distribution of some seabirds off the outer coasts of British Columbia and Washington State, 1946–1949. Syesis 2:241–256.

Morgan, K.H.; Vermeer, K.; McKelvey, K.W. 1991. Atlas of pelagic birds of western Canada. Can. Wildl. Serv. Occas. Pap. No. 72. Ottawa.

Pearcy, W.G.; Schoener, A. 1987. Changes in the marine biota coincident with the 1982–1983 El Niño in the northeastern subarctic Pacific Ocean. J. Geophys. Res. 92:14 417–14 428.

Perry, M.J.; Bolger, J.; English, D.C. 1989. Primary production in Washington coastal waters. Pages 117–139 *in* Landry, M.R.; Hickey, B.M. (eds.), Coastal oceanography of Washington and Oregon. Elsevier Oceanography Series 47. Elsevier, New York.

Pruter, A.T.; Alverson, D.L. (eds.). 1972. The Columbia River estuary and adjacent ocean waters. Univ. of Washington Press, Seattle.

Sanger, G.A. 1965. Observations of wildlife off the coast of Washington and Oregon in 1963, with notes on the Laysan Albatross *Diomedea immutabilis* in the area. Murrelet 46:1–6.

Sanger, G.A. 1970. The seasonal distribution of some seabirds off Washington and Oregon; with notes on their ecology and behavior. Condor 72:339–357.

Sanger, G.A. 1972. Checklist of bird observations from the eastern North Pacific ocean. Murrelet 53:16–21.

Savard, J.-P.L. 1979. Marine birds of Dixon Entrance, Hecate Strait and Chatham Sound, B.C., during fall 1977 and winter 1978. Can. Wildl. Serv., Delta, B.C.

Slipp, J.W. 1952. A record of the Tasmanian whitecapped albatross in American North Pacific waters. Auk 69:458–459.

Speich, S.M.; Wahl, T.R. 1989. Catalog of Washington seabird colonies. U.S. Fish Wildl. Serv. Biol. Rep. 88(6).

Springer, A.M. 1991. Seabird distribution as related to food webs and the environment: examples from the North Pacific Ocean. Pages 39–48 *in* Montevecchi, W.A.; Gaston, A.J. (eds.). Studies of high-latitude seabirds. 1. Behavioural, energetic, and oceanographic aspects of seabird feeding ecology. Can. Wildl. Serv. Occas. Pap. 68, Ottawa.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56.

Vermeer, K. 1989. Introduction to the nesting seabirds of the Strait of Georgia. Pages 84–87 *in* Vermeer, K.; Butler, R.W. (eds.). The ecology and status of marine and shoreline birds in the Strait of Georgia, British Columbia. Can. Wildl. Serv. Spec. Publ., Ottawa.

Vermeer, K.; Rankin, L. 1984. Pelagic seabird populations in Hecate Strait and Queen Charlotte Sound: comparison with the west coast of the Queen Charlotte Islands. Can. Tech. Rep. Hydrogr. Ocean Sci. 52. Sidney, B.C.

Vermeer, K.; Rankin, L. 1985. Pelagic seabird population in Dixon Entrance. Can. Tech. Rep. Hydrogr. Ocean Sci. 65. Sidney, B.C.

Vermeer, K.; Ydenberg, R.C. 1989. Feeding ecology of marine birds in the Strait of Georgia. Pages 62–73 *in* Vermeer, K.; Butler, R.W. (eds.). The ecology and status of marine and shoreline birds in the Strait of Georgia, British Columbia. Can. Wildl. Serv. Spec. Publ., Ottawa.

Vermeer, K.; Robertson, I.; Campbell, R.W.; Kaiser, G.; Lemon, M. 1983. Distribution and densities of marine birds on the Canadian west coast. Can. Wildl. Serv., and Chevron Standard Ltd., Spec. Publ., Calgary.

Vermeer, K.; Hay, R.; Rankin, L. 1987. Pelagic seabird populations off southwestern Vancouver Island. Can. Tech. Rep. Hydrogr. Ocean Sci. 87.

Vermeer, K.; Morgan, K.H.; Smith, G.E.J.; Hay, R. 1989. Fall distribution of pelagic birds over the shelf off SW Vancouver Island. Colon. Waterbirds 12:207–214.

Vermeer, K.; Morgan, K.H.; Smith, G.E.J. 1992. Habitat analysis and co-occurrences of pelagic birds off the west coast of Vancouver Island. Pages 78–85 *in* Vermeer, K.; Butler, R.W.; Morgan, K.H. (eds.). The ecology, status, and conservation of marine and shoreline birds of the west coast of Vancouver Island. Can. Wildl. Serv. Occas. Pap. No. 75.

Wahl, T.R. 1975. Seabirds in Washington's offshore zone. West. Birds 6:117–134.

Wahl, T.R. 1984. Distribution and abundance of seabirds over the continental shelf off Washington (including information on selected marine mammals). Washington Department of Ecology, Olympia.

Wahl, T.R. 1985. The distribution of Buller's Shearwater (*Puffinus bulleri*) in the North Pacific Ocean. Notornis 32:109–111.

Wahl, T.R.; Heinemann, D. 1979. Seabirds and fishing vessels: co-occurrence and attraction. Condor 81:390–396.

Wahl, T.R.; Speich, S.M.; Manuwal, D.A.; Hirsch, K.V.; Miller, C.S. 1981. Marine bird populations of the Strait of Juan de Fuca, Strait of Georgia and adjacent waters in 1978 and 1979. U.S. Dep. Commer. Interagency Energy/Environment R&D Prog. Rep. EPA-600/7-81-156.

Wahl, T.R.; Ainley, D.G.; Benedict, A.H.; DeGange, A.R. 1989. Associations between seabirds and water masses in the northern Pacific Ocean in summer. Mar. Biol. 103:1–11.

Wilson, U.W.; Manuwal, D.A. 1986. Breeding biology of the Rhinoceros Auklet in Washington. Condor 88:143–155.