Seabirds of the central North Pacific

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Abstract

The central North Pacific Ocean hosts a large and diverse assemblage of seabirds. Besides resident breeders, species breeding in eastern and western extremes of the Pacific and from the Antarctic to the Arctic occur there regularly. Oceanographically, the region is characterized by a broad Transition Zone between subtropical and subarctic waters. The borders of the Transition Zone are defined by a subarctic front at 41–45°N latitude and a subtropical front at 30–34°N latitude. The avifauna includes species that are i) generally restricted to either subarctic or subtropical waters but may penetrate transitional waters, ii) species that concentrate in the Transition Zone, and iii) species that occupy all water types about equally. These zoogeographic patterns parallel those observed for some plankton, squid, and fish species in the region. We observed large sea surface salinity and temperature gradients while criss-crossing the Transition Zone during a research cruise in October and November of 1989. Some seabird species and their potential prey were aggregated near the subarctic front. For many species, however, the front acted simply as a distributional boundary, and birds were dispersed or locally aggregated over large areas to the north or south of the front. Overall, seabird densities declined markedly while moving from subarctic (± 100s birds/km^2) to transitional (± 10s birds/km^2) and subtropical (± 1s birds/km^2) waters.

The status and distribution of many seabird species are not well known, particularly in the central part of the region. We provide new location records for some species that are difficult to identify or uncommon in the region—based on voucher specimens collected by observers of North Pacific driftnet fisheries. Throughout the central North Pacific, oil pollution and commercial fisheries pose the greatest threats to birds while they are at sea. Habitat destruction, disturbance at their colonies, and predation by introduced mammals also pose serious threats to some seabirds that nest in the region.

Résumé

Le centre du Pacifique Nord abrite de nombreux oiseaux marins, d'espèces différentes. En plus des nicheurs, des espèces s'accouplant dans les régions orientale et occidentale du Pacifique, de l'Antarctique à l'Arctique, séjournent régulièrement dans le centre du Pacifique Nord. Sur le plan océanographique, la région présente un grand écotone entre les eaux subtropicales et les eaux subarctiques. Un front subarctique à 41–45° de latitude nord et un front subtropical à 30–34° de latitude nord définissent les frontières de l'écotone. L'avifaune comprend i) des espèces habituellement confinées dans les eaux subarctiques ou subtropicales, mais qui peuvent faire de brefs séjours dans l'écotone; ii) des espèces qui se concentrent dans l'écotone; et iii) des espèces presque également distribuées dans les trois zones. Ces schémas zoogéographiques sont comparables à la distribution de certains types de plancton, et de certains encornets et poissons dans la région. Au cours d'une croisière de recherche, en octobre et novembre 1989, les auteurs ont sillonné l'écotone en croisements alternatifs, observant une forte salinité en surface et des gradients thermiques appréciables. Certaines espèces d'oiseaux marins et leurs proies potentielles étaient assemblées près du front subarctique. Pour bien des espèces, cependant, le front n'est qu'une limite de distribution, et les oiseaux sont alors dispersés ou réunis localement sur de grandes surfaces, au nord ou au sud du front. Dans l'ensemble, la densité des oiseaux marins fond considérablement quand on passe des eaux subarctiques (centaines d'oiseaux au km^2), à l'écotone (dizaines d'oiseaux au km^2) et aux eaux subtropicales (quelques oiseaux au km^2).

On connait peu l'état et la distribution géographique de beaucoup d'espèces d'oiseaux marins, surtout dans le centre du Pacifique Nord. Les auteurs fournissent de nouvelles données d'emplacement pour certaines espèces difficiles à reconnaître ou peu abondantes dans la région. Ces données sont fondées sur les spécimens témoins recueillis par les observateurs de la pêche aux filets dérivants dans le Pacifique Nord. Dans tout le centre du Pacifique Nord, la pollution par les hydrocarbures et la pêche commerciale sont les plus grandes menaces pour les oiseaux, au cours de leur séjour en mer. La destruction de l'habitat, la perturbation des colonies par les humains et la prédation par des mammifères introduits sont d'autres menaces graves pour certains oiseaux marins qui nichent dans cette région.

1. Introduction

Compared to other oceanic regions of the world, relatively few studies have focused on marine birds in the central North Pacific (Table 1)—which we define here as the high seas between Alaska and Hawaii, and from the longitudinal meridians of 145°W to 170°E (Fig. 1). As in other marine ecosystems, we know that marine bird distribution and abundance in this region are influenced primarily by the availability of breeding sites, production of plankton and fish, current and wind regimes, and interactions with other animals—including prey species, predators, marine mammals, and people. However, much of the available information on

Table 1
Studies on the pelagic distribution and abundance of marine birds in various regions of the North Pacific Ocean

Central North Pacific
Arnold 1948
Bourne 1967a, 1968
Gould 1983
Hamilton 1958
Kuroda 1988, 1991
Poole 1966
Robbins and Rice 1974
Sanger 1972a, 1974a, 1974b
Sanger and Ainley 1988
Tanaka 1986
Wahl 1985
Wahl et al. 1989
Woodward (undated)

Northwest Pacific
Degawa and Watabe 1983
Hasegawa 1984
Kuroda 1955, 1960
Nakamura and Tanaka 1977
Ogi 1980, 1984a
Ogi et al. 1980, 1981
Shuntov 1972
Tanaka and Inaba 1981
Tanaka et al. 1985
Wahl 1978

Alaska
Arnold 1948
DeGange and Sanger 1986
Gould et al. 1982
Lensink 1984

Hawaii
Crossin 1974
Harrison et al. 1984
Gould 1974
Gould et al. 1974
King 1970, 1974
Pyle and Eilerts 1986
Robbins and Rice 1974
Sanger 1974a, 1974b

Northeast Pacific
Ainley and Manolis 1979
Sanger 1972b, 1973
Wahl 1975

Figure 1
Principal oceanographic features of the central North Pacific Ocean

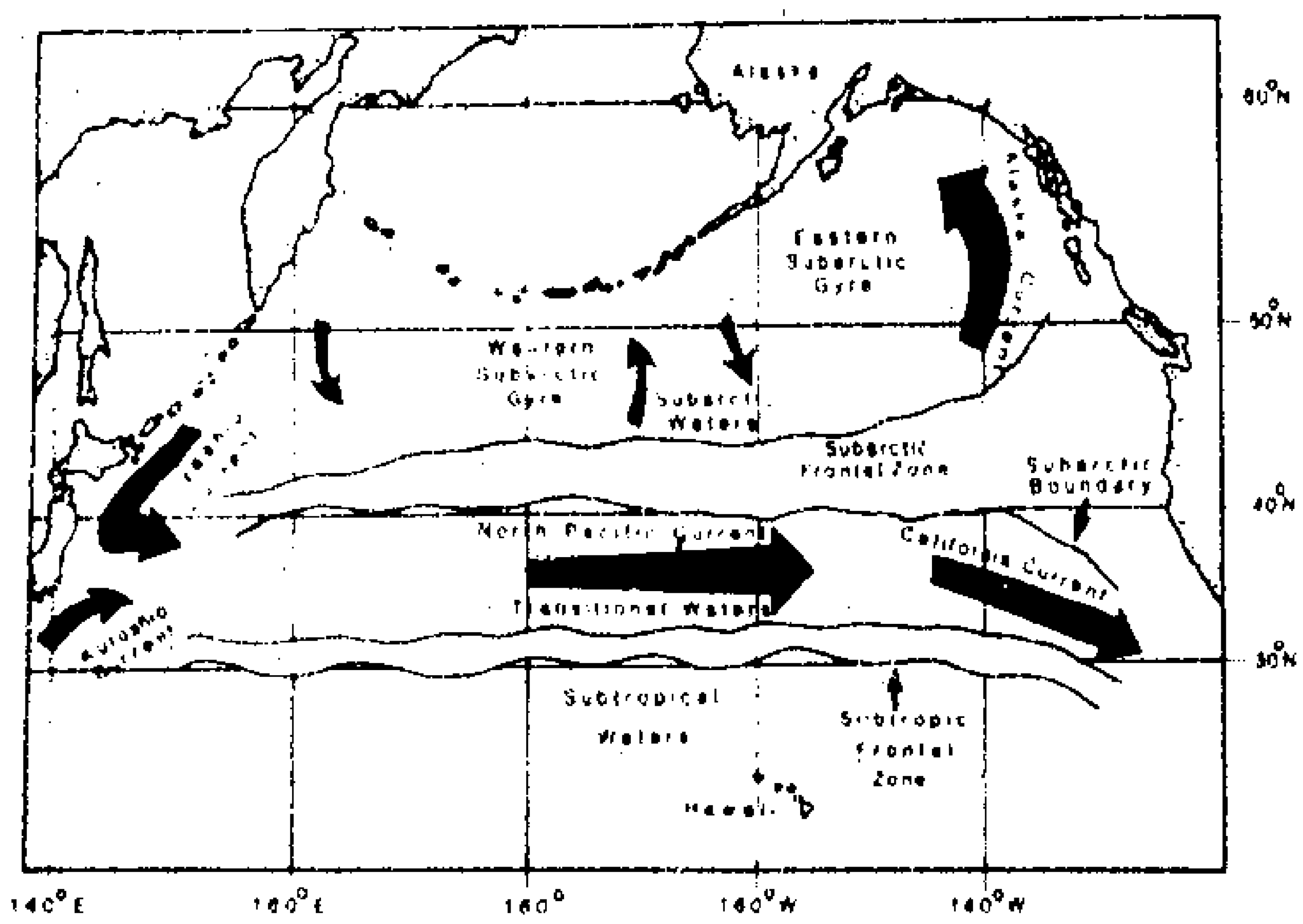


Table 2
Studies on seabirds and fishing operations in the central North Pacific

Ainley et al. 1981
DeGange and Day 1991
DeGange and Newby 1980
Fiscus and Mercer 1982
Gooder 1989
International North Pacific Fisheries Commission 1990, 1991a, 1991b
Jones and DeGange 1988
King 1984
Ogi 1984b
Tsunoda 1989

Table 3
Studies on marine organisms in the central North Pacific

Aron 1962
Beklemishev and Nakonechnaya 1972
Bieri 1959
Blackburn 1965
Bradshaw 1959
Burgner and Meyer 1983
Fager and McGowan 1963
Gong et al. 1985
Hamanaka and Mishima 1981
Kanayama 1981
Kotori 1981
LeBrasseur and Kennedy 1972
McGowan 1971
McGowan and Williams 1973
Park 1984
Sanger 1972c
Sato 1981
Semina and Tarkhova 1972
Taniguchi 1981

Table 4
Studies on the oceanography of the central North Pacific

Dodimead et al. 1963
Donaldson and Pearcy 1972
Favorite et al. 1976
Joyce 1987
Kirwan et al. 1978
Kitano 1972, 1981
Lynn 1986
Reed and Laird 1977
Reed and Schumacher 1985
Roden 1970, 1971, 1972, 1975, 1977a, 1977b, 1980, 1981
Roden and Robinson 1988
Seckel 1985
Sverdrup et al. 1942
Tully 1964
Uda 1938, 1963

bird distribution at sea in the central North Pacific is anecdotal, or pertains to abundant species, and many sight records of uncommon species have not been substantiated with specimen collections. Major information gaps exist both in geographical coverage (e.g., few data exist on seabird distribution in the subtropics) and in seasonal coverage (e.g., no winter data).

The purpose of this paper is to summarize available information on the distribution, abundance, and status of marine birds in the central North Pacific. For this, we rely largely on the studies of Gould (1983), Wahl et al. (1989), and Kuroda (1991). A significant amount of unpublished data on birds in this region is held by Robert Day (University of Alaska, Fairbanks)—some of which was available in confidental reports. We also referred to files of the U.S. Fish and Wildlife Service (Anchorage, Alaska), including some of our own unpublished data collected in recent years. Additional data on seabird distribution were obtained through the Scientific Observer Programs on North Pacific driftnet fisheries: Japanese squid fishery by Canada, Japan, and the United States (International North Pacific Fisheries Commission 1990, 1991a); Japanese large-mesh fishery by Japan and the United States (International North Pacific Fisheries Commission 1991b); Korean squid fishery by Korea and the United States (Anonymous 1991a); and Taiwan squid and large-mesh fisheries by Taiwan and the United States (Anonymous 1991b). Additional distributional data on marine birds have been acquired during the monitoring of these commercial fishing operations and from directed scientific studies conducted on research vessels (Table 2). Finally, we reviewed pertinent literature on the biology and oceanography of the region and adjacent areas (Tables 3 and 4).

Drawing upon these sources, we describe the distribution patterns of 85 species of seabirds in the central North Pacific with respect to the biological oceanography of the region. We suggest that there are three major avifaunal communities in the region, comprising nine different guilds of species that show differing affinities for three oceanographically distinct water masses. These water masses are easily defined by north-to-south salinity gradients across the central North Pacific, and are demarcated by two east-to-west frontal zones.

2. Area description and oceanography

On a large scale, the oceanography of the central North Pacific is well understood (Table 4). Oceanic waters from Alaska to Hawaii and between 145°W and 170°E longitudes range from subarctic to subtropical with a transitional area in the middle (Fig. 1). The Subarctic Boundary—defined by Favorite et al. (1976) as the area where the 34.00 ppt isohaline is vertical to the surface—represents a physically stable oceanographic and biological mid-point at around 41°N latitude. Off Japan, the warm, northward-flowing Kuroshio and cold, southward-flowing Oyashio currents meet and water is deflected eastwards to cross the entire North Pacific. Mixing of waters occurs at this confluence. Near the west coast of North America, part of the North Pacific Current is deflected northwards, forming the Alaska Current, and the remainder flows southwards, forming the California Current. The Alaska Current curves westward and flows west along the coast of Alaska and the Aleutian Islands, sending a branch south to form the Eastern Subarctic Gyre. Subarctic waters are characterized by a well-defined permanent halocline between 100 and 150 m. The California Current eventually curves westwards to form the North Equatorial Current.

Thus, the structure of the central North Pacific Ocean is relatively simple—with fairly uniform water properties from west to east, but with large property gradients from north to south. The transitional area (called the Subarctic–Subtropical Transition Zone by Roden and Robinson [1988]) occurs between 43°N and 32°N. In this Transition Zone, surface water temperature and salinity increase from north to south with rapid changes (fronts) over short distances at its northern and southern boundaries. The Subarctic Frontal Zone is the area between the point of surfacing of the isohaline that forms the bottom of the permanent halocline in the south (33.8 ppt) and the point of isohaline surfacing that forms the top of the permanent halocline in the north (33.0 ppt) (Roden and Robinson 1988). The Subtropical Frontal Zone is less well defined but occurs in the area of 30–34°N, and is marked by salinities of 34.4–34.5 ppt along its northern edge, of 34.8–34.9 ppt along its southern edge, and by water temperatures of about 18°C (Lynn 1986). Temperature and salinity fronts are not always coincident and temperature fronts are absent from the subtropical frontal zone in summer. Individual fronts meander and portions frequently break off to form eddies. At any given time, the frontal zones may have very complex structures.

3. Processes influencing patterns of seabird distribution

3.1. Oceanography and biological production

Many different oceanographic processes contribute to the distribution of seabirds via enhancement of food production and the concentration of food vertically and horizontally (Table 5). In coastal areas of Alaska and in the Aleutian Islands, upwelling and frontal systems arise from tidal and wind-induced currents. These upwellings and fronts increase production and concentrate prey and seabirds in predictable locations (Spindler 1976; Hunt et al., this volume; Piatt, unpubl. data). Seabird density indices near the coast typically range from 20 to 200 birds/km^2 (Gould et al. 1982). The continental shelf of Alaska is also very productive, and similar bird density indices may be found over and on the edge of the shelf where upwelling fronts concentrate prey (Gould et al. 1982; Gould 1983). Although there are few detailed studies of this area, processes influencing seabird distributions in coastal and shelf habitats are well described for other regions (Hunt and Schneider 1987; Brown 1988; Hunt et al., this volume).

Table 5
Physical processes that influence prey abundance and availability and seabird abundance in different oceanographic regions of the central North Pacific

Coastal and islands
Coastal upwelling (current and wind-induced)
Submarine upwelling over seamounts (currents, tides)
Island effect (wakes, eddies)
Passes between islands (upwelling, tide rips)
Headland effects (jets, eddies)
Salinity fronts (glacier and river outflow)
Continental shelf
Topographically induced fronts (current, tide, wind)
Water mass boundaries (fronts, eddies, cores)
Vertical stratification (property gradients, internal waves)
Shelf edge (upwelling, current boundaries)
Oceanic
Current and water mass boundaries (fronts, eddies, cores)
Vertical stratification (property gradients)
Surface mixing (storms, waves)
Langmuir cells (wind induced)

Beyond the continental shelf, deep oceanic waters are much less productive. Storms and turbulence at current boundaries mix waters vertically and horizontally and thereby increase production (Table 5). The depths and gradients of the haloclines, thermoclines, and pycnoclines that characterize subarctic waters may also be important components of the physical processes that influence the mixing of water, and thereby affect the organic content and productivity of North Pacific waters (Aron 1962; McGowan and Williams 1973). The scale of these processes is generally in the order of hundreds of kilometres (Hunt et al. 1987).

In subarctic oceanic waters, average seabird density indices range from 3 to >100 birds/km^2. These indices decline by an order of magnitude to 1–10 birds/km^2 in transitional waters and again to 0–1 birds/km^2 in subtropical waters (King 1970; Sanger 1972a; Gould et al. 1982; Gould 1983; Wahl et al. 1989). The gradient in seabird densities from Alaska to Hawaii parallels the gradient in abundance of zooplankton and pelagic fish (e.g., myctophids) over this range (Aron 1962) (Fig. 2).

3.2. Fine-scale distribution around the Subarctic Front

Because there have been few reports that relate seabirds to oceanography in this region on a fine scale, we present some representative data obtained on a cruise of the National Oceanic and Atmospheric Administration vessel *Miller Freeman* in October and November 1989 (Figs. 3–5). On one survey track running from 45°20′N to 40°N (ca. 600 km) at 158°W longitude, we found that the steepest gradient in sea surface salinity occurred at about 42°30′N latitude (Fig. 3). Salinity profiles obtained from Conductivity–Temperature–Depth (CTD) casts and sea surface measurements confirmed this as the centre of the Subarctic Front (Roden and Robinson 1988). The frontal zone encompassed waters about 50 km on either side of the centre of the front. Heat is transferred between water masses more rapidly than salt, and therefore sea surface and subsurface temperature profiles were less useful than salinity profiles for locating the frontal zone (Fig. 3).

Figure 2
Gradients in seabird density, macrozooplankton abundance, and myctophid abundance from coastal Alaska to subtropical waters of the central North Pacific. Seabird densities from Gould et al. (1982) and Gould (1983); plankton and fish densities from Aron (1962).

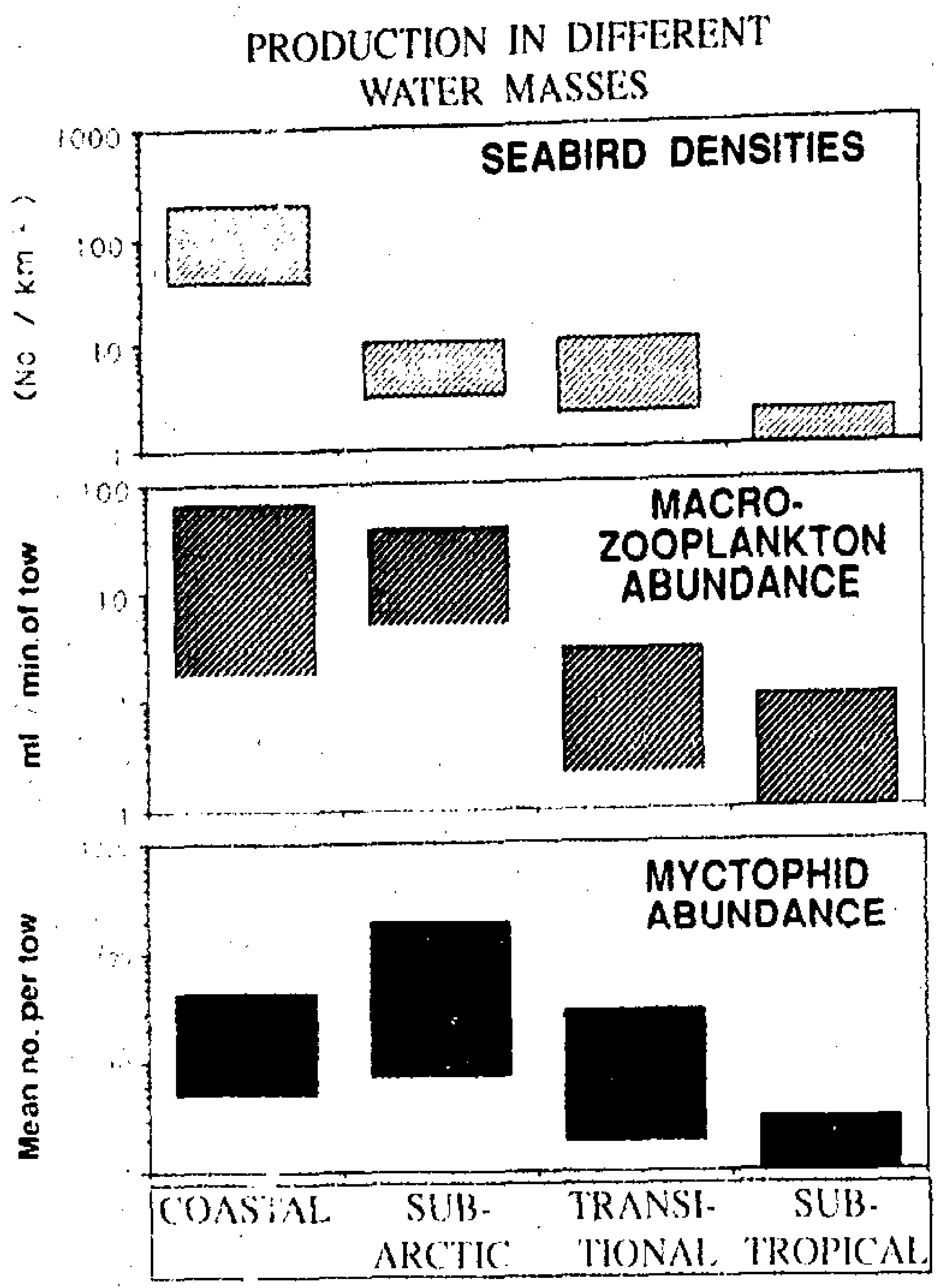
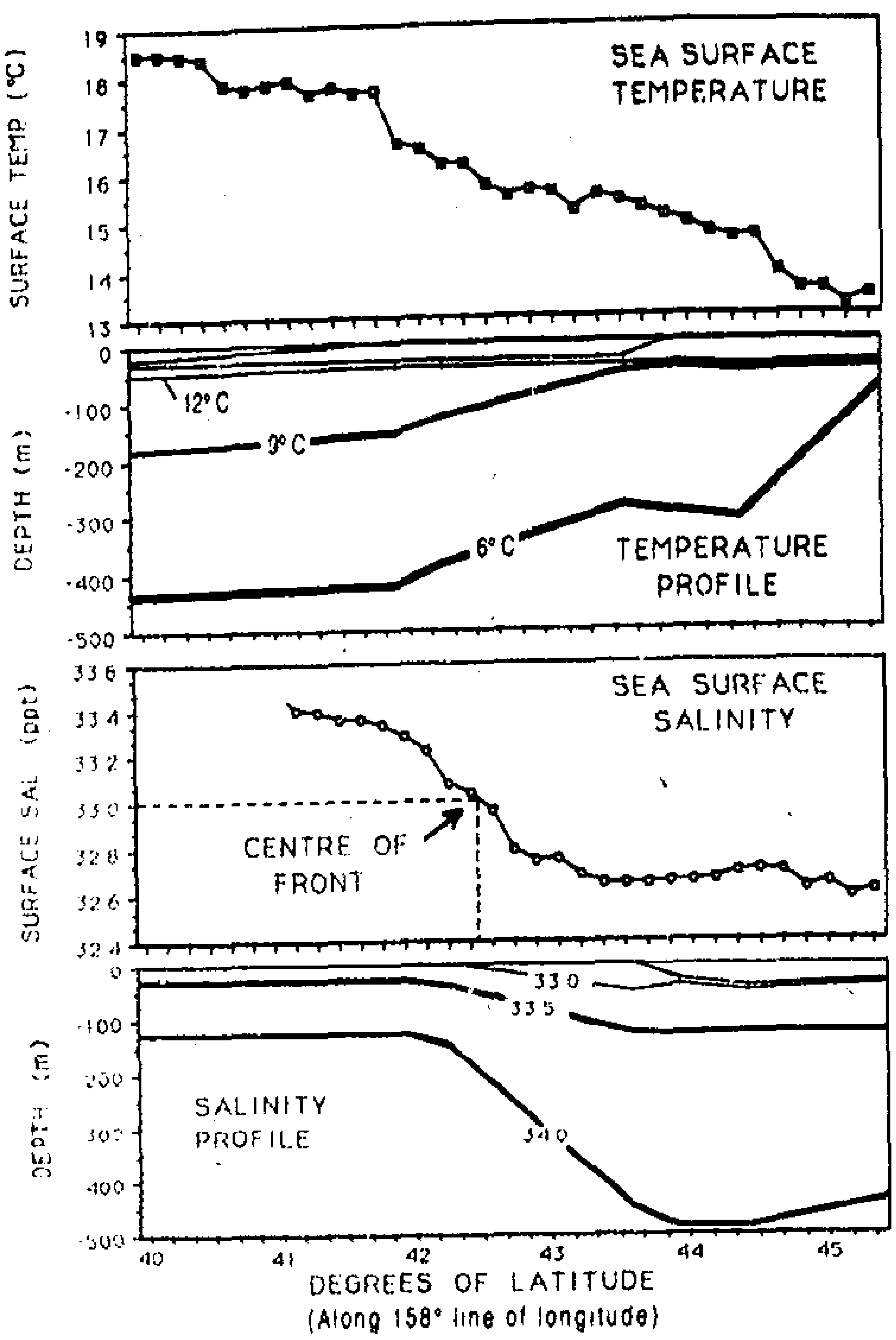


Figure 3
Sea surface temperature and salinity gradients and subsurface temperature and salinity profiles across the Subarctic Front in the central North Pacific, October 1989



Seabird species, or species groups, were distributed differently around the Subarctic Front. On the transect described in Figure 3, all the common seabird species except Mottled Petrel *Pterodroma inexpectata* foraged mostly in transitional waters south or near the borders of the frontal zone (Fig. 4). On a similar transect run at 168°W longitude (Fig. 5), most of the abundant species foraged north of the Subarctic Front. It appears that many species did not aggregate at the front itself, but rather the frontal zone served as a boundary in the oceanic distribution of those species. In contrast, hydroacoustic surveys and tows made for neuston revealed a high abundance of plankton in a broad zone (ca. 150 km) north and south of the front (Ebberts and Wing 1991; K. Krieger, pers. commun.), and some of the nekton-feeding seabird species (e.g., storm-petrels, phalaropes) were also most abundant in the frontal zone (Fig. 4).

3.3. Adaptations and foraging behaviour

The behavioural adaptations and adjustments of these birds to search for, locate, and capture prey also determine their distribution and local abundance. Most sightings of seabirds at sea, especially in oceanic areas beyond the continental shelf, involve solitary individuals that are presumably searching for prey (Gould 1974). These birds use cues to oceanographic conditions that indicate high probabilities of food, e.g., surface slicks (Brown and Gaskin 1987; Hunt et al., this volume). They may also use tactile cues such as water temperature or salinity. Within foraging areas, sight (Sealy 1973; Gould 1974; Hoffman et al. 1981), smell, and sound (Hutchinson et al. 1984) are important senses in locating prey. Once a bird locates food, it begins to feed. Other searching birds join the feeding bird, and a feeding flock forms. The longer food is available, the greater the number of birds associated with it (Gould 1974). Birds are also attracted to feeding mammals (Hoffman et al. 1981). Examples of feeding behaviour and interspecific feeding associations are provided in Table 6 from data collected during our cruise in October 1989. Although not uncommon in subarctic waters, observations of actual feeding behaviour or of feeding flocks are relatively rare in transitional and subtropical waters—reflecting the low productivity and patchy distribution of prey in these areas. For these reasons, the avifauna of transitional waters is well represented by truly pelagic seabirds with large foraging ranges (e.g., the albatrosses, *Pterodroma* petrels, shearwaters, and storm-petrels).

A bird's ability to secure prey once located also influences where each species occurs. Although all other feeding techniques are represented, pursuit diving is the most common technique used by marine birds in subarctic waters where dense-schooling plankton and fish form the basis of seabird food webs. Surface feeding, except for surface plunging, predominates in transitional waters. This is true to an even greater extent than indicated by Wahl et al. (1989) because

Figure 4
Distribution of seabirds around the Subarctic Front at longitude 158°W in October 1989 (see Fig. 3). Question marks (?) indicate periods when seabird surveys were not conducted.

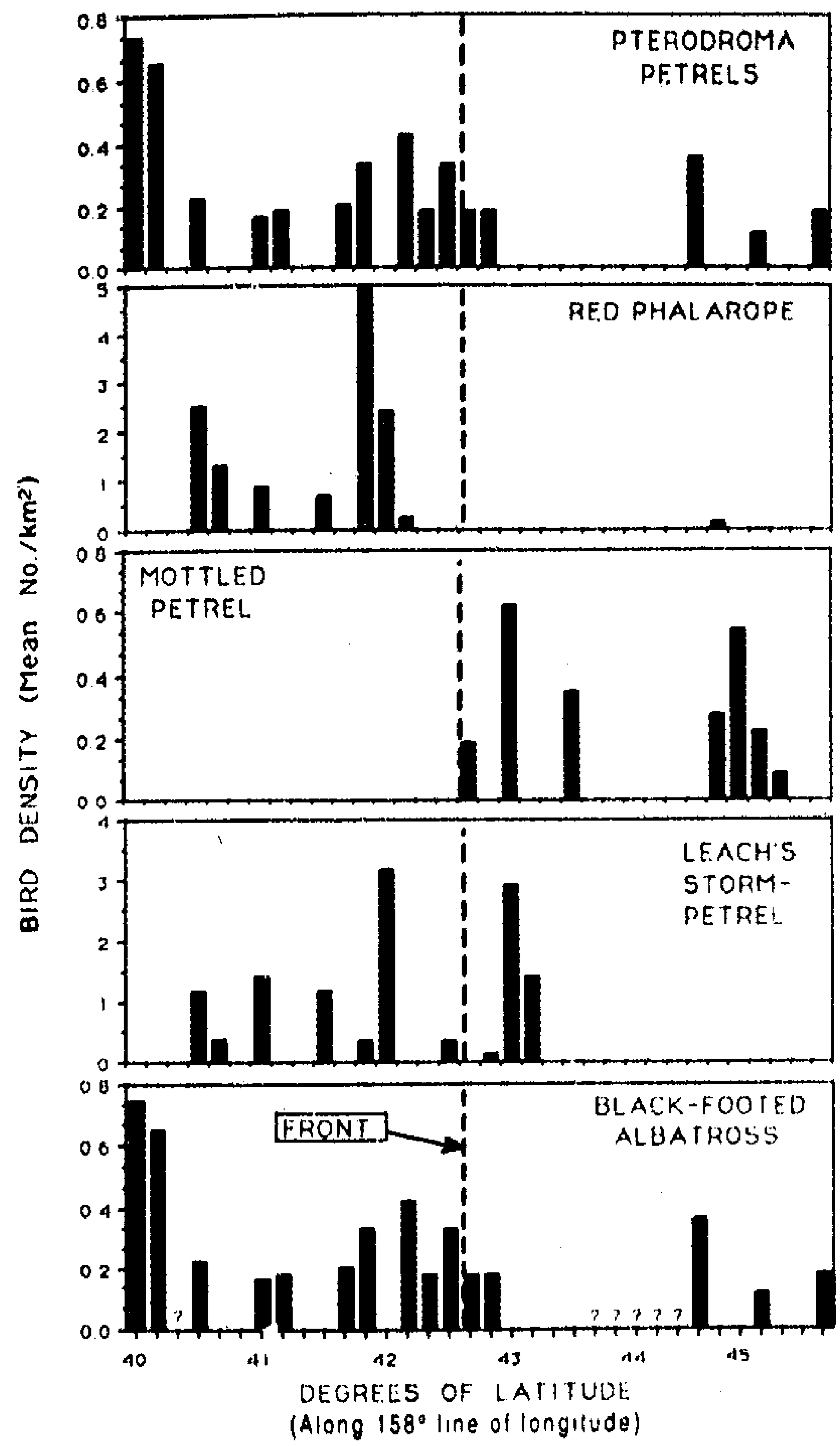
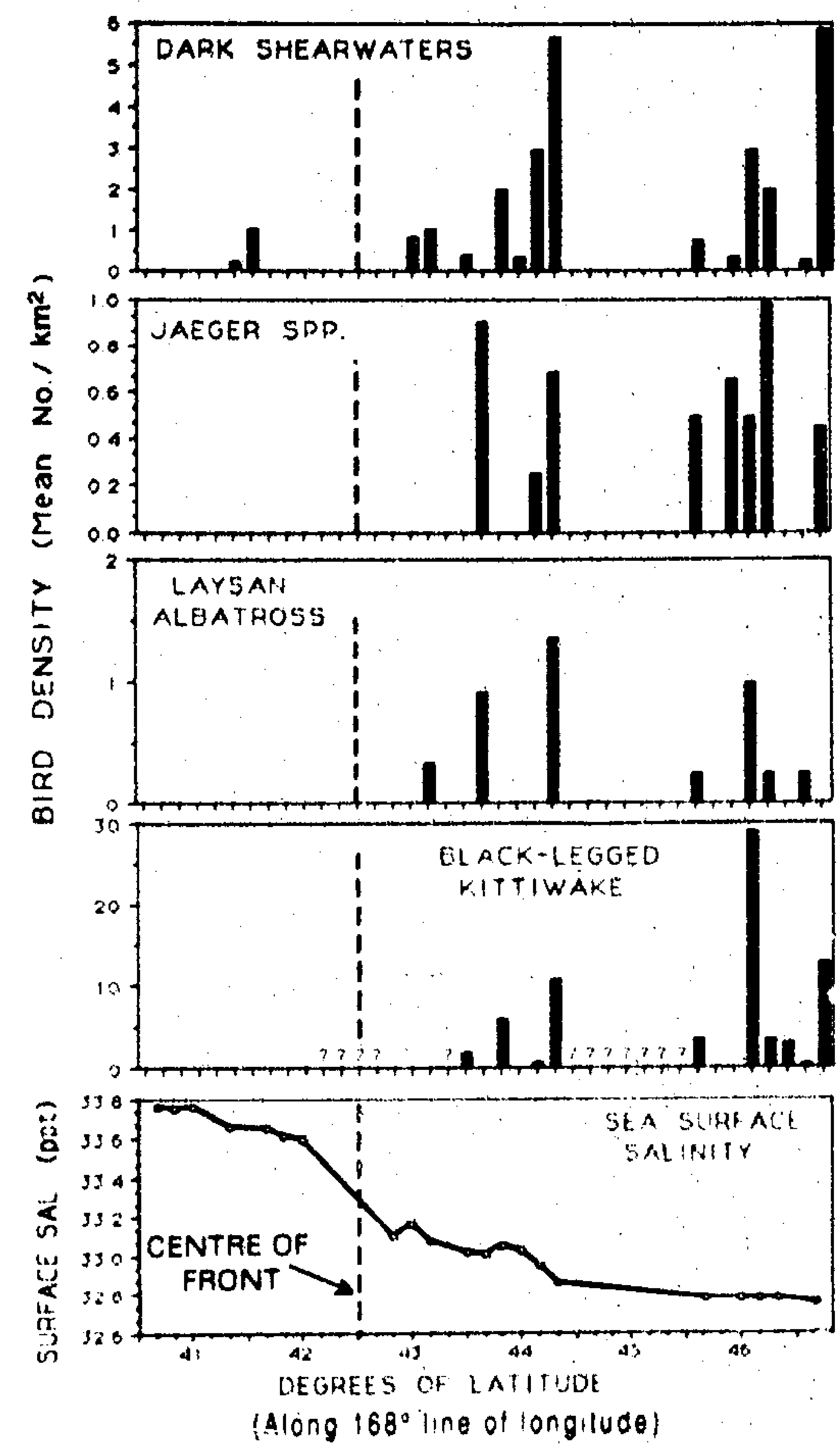


Figure 5
Sea surface salinity profile and seabird distributions around the Subarctic Front at longitude 168°W in November 1989. Question marks (?) indicate periods when seabird surveys were not conducted.



pursuit divers like Sooty *Puffinus griseus* and Short-tailed *P. tenuirostris* shearwaters frequently shift to surface feeding outside the Subarctic. Most shearwaters in the central North Pacific become entangled in driftnets between the surface and 3–4 m below the floatline—suggesting that most of their feeding is at or near the surface (DeGange et al. 1985; Gould, pers. obs.). In subtropical waters, pursuit diving is rare.

4. Overall patterns of seabird distribution in the central North Pacific

We summarize the distribution "patterns" of marine birds in the central North Pacific with some reservations—because these patterns are highly dynamic and still poorly described for many species. Distributions shift daily, seasonally, and annually in response to the factors discussed above, as well as in relation to constraints imposed by breeding and migration. Marine birds may wander far from their normal haunts, and this complicates analyses of distribution patterns because such movements are superimposed on "normal" patterns (Bourne 1967b). Furthermore, many species are difficult to identify at sea (e.g., *Pterodroma* petrels), and we are skeptical about many reported records of certain species. Recent studies of the incidental catch of marine birds in high-seas squid and large-mesh driftnets set in the central North Pacific (Anonymous 1991a, 1991b; International North Pacific Fisheries Commission 1990, 1991a, 1991b) provide specimen records to corroborate distributional data for several species. Most of these specimens are in the collection of the Burke Museum, University of Washington, Seattle, Washington. Sooty and Short-tailed shearwaters were the most common species taken in driftnets. Other species commonly taken throughout the area included Laysan *Diomedea immutabilis* and Black-footed *D. nigripes* albatrosses, Flesh-footed *Puffinus carneipes* and Buller's *P. bulleri* shearwaters, and Leach's *Oceanodroma furcata* and Fork-tailed *O. furcata* storm-petrels. Distributional records of some uncommon or difficult to identify species taken in this study are provided in Table 7.

Table 6
Feeding behaviour of marine birds and associations with marine mammals observed between Alaska and Hawaii in October 1989. Terminology follows Ashmole and Ashmole (1967).

Species (No.)	Latitude	Longitude	Behaviour
Laysan Albatross (300) Black-footed Albatross (1) Sooty Shearwater (150) Short-tailed Shearwater (20) South Polar Skua (1)	46°07′N	161°02′W	Flying tight circles over ca. 550 Pacific white-sided dolphins and 25 right whale dolphins
Tristram's Storm-Petrel (1)	45°07′N	158°49′W	Feeding on surface, small fish in bill
Short-tailed Shearwater (19) Laysan Albatross (6) Black-legged Kittiwake (47)	44°23′N	168°00′W	Feeding on surface around school of Pacific white-sided dolphins
Leach's Storm-Petrel (7)	42°41′N	161°00′W	Feeding on surface and contact dipping
Tristram's Storm-Petrel (1)	42°11′N	158°03′W	Feeding on surface, small fish in bill
Northern Fulmar (1)	40°53′N	161°00′W	Feeding on surface
Black-footed Albatross (8) Laysan Albatross (1) Stejneger's Petrel (16) Leach's Storm-Petrel (12) Northern Fulmar (1)	40°51′N	161°00′W	Feeding at surface on dead squid (1 m long)
Stejneger's Petrel (4) Leach's Storm-Petrel (2) Northern Fulmar (1)	40°43′N	161°00′W	Feeding on surface
Wedge-tailed Shearwater (18) Unidentified *Pterodroma* (1)	23°54′N	160°00′W	Feeding on surface
Red-footed Booby (1)	23°44′N	159°54′W	Air dipping

The distribution pattern of seabirds in the central North Pacific, excluding vagrants, can be described as consisting of three primary avifaunal communities, each comprising several species guilds, and structured from north to south by prominent water mass boundaries. One community occurs in subarctic waters, a second occurs in subtropical waters, and a third is found in the transitional area of mixed water between the other two. Gould (1983), Wahl et al. (1989), and Kuroda (1991) discussed these water masses and provided details on the occurrence of seabirds within them. Using their information as a base, modified by data from our studies, unpublished reports, and records in the literature, we recognize five guilds of species found in subarctic waters (Fig. 6), five guilds of species in transitional waters (Fig. 7), and four guilds of species in subtropical waters (Fig. 8). These guilds consist of (often closely related) species groups with shared dispersal patterns and/or foraging styles. For example, the South Coastal Alaska guild (Fig. 6) includes species that rarely venture far from the coast (e.g., cormorants), whereas the Trans-Pacific guild includes species that are widely dispersed throughout the central North Pacific (e.g., albatrosses). Both guilds contribute to the Subarctic Avifaunal Community (as indicated by the black bars in Fig. 6).

We have chosen to illustrate distribution patterns (Figs. 6–8) by schematically describing only north-to-south associations with water masses and current boundaries. Like Kuroda (1991), however, we have identified some east-to-west gradients in seabird distributions as well. These east–west

Table 7
Distribution records of species taken east of 170°E by scientific observers on board high-seas driftnet fishery vessels (saved specimens are archived at the Burke Museum, University of Washington, Seattle, Washington)

Species	No.	Month	Latitude	Longitude	Water temp., °C	Specimen saved?
Dark-rumped Petrel	1	August	45°N	148°W	13.3	yes
Juan Fernandez Petrel	3	August	45°N	158°W	—	no
Juan Fernandez Petrel	1	August	45°N	159°W	—	no
Juan Fernandez Petrel	1	August	45°N	160°W	—	no
Solander's Petrel	1	August	44°N	149°W	15.3	yes
Solander's Petrel	1	March	30°N	172°E	17.0	yes
Stejneger's Petrel	1	July	42°N	161°W	—	no
Stejneger's Petrel	1	June	36°N	175°E	—	yes
Pink-footed Shearwater	1	July	42°N	166°W	17.0	yes
Pink-footed Shearwater	1	August	45°N	152°W	12.7	yes
Pink-footed Shearwater	1	August	45°N	153°W	12.8	yes
Newell's Shearwater	1	June	39°N	178°W	—	no
Wilson's Storm-Petrel	6	August	44°N	156°W	—	no
Tristram's Storm-Petrel	1	August	43°N	169°W	15.1	yes
Pomarine Jaeger	1	July	42°N	166°W	21.6	yes
Long-tailed Jaeger	1	August	44°N	176°E	15.1	yes
Red Phalarope	1	July	41°N	170°E	13.7	yes
Black-legged Kittiwake	1	March	31°N	172°W	—	yes
Thick-billed Murre	1	June	42°N	160°W	15.2	no
Parakeet Auklet	1	June	36°N	175°E	—	yes
Parakeet Auklet	1	March	31°N	173°E	18.5	yes
Parakeet Auklet	1	February	28°N	177°E	19.8	yes
Parakeet Auklet	1	June	36°N	175°E	—	yes

patterns, however, are primarily related to coastal versus deep-water habitat use by a few species, are poorly documented for many species, and generally fall outside the geographic scope of this paper.

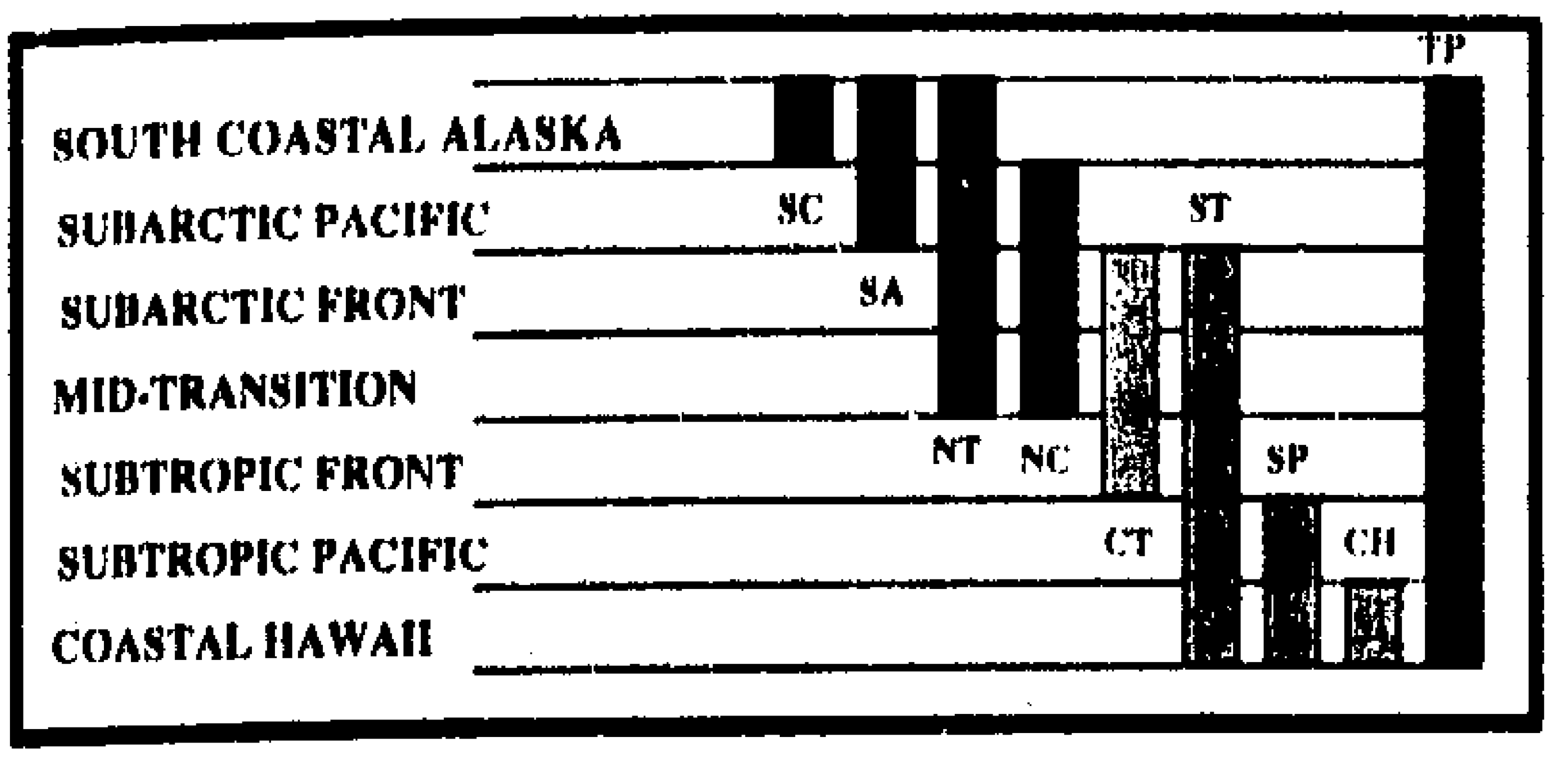
4.1. Subarctic avifauna

In the subarctic North Pacific, seasonal and geographical variability in species distribution and abundance are primarily associated with the quality and location of breeding and feeding areas. With the exception of Short-tailed *Diomedea albatrus*, Black-footed, and Laysan albatrosses, Murphy's Petrel *Pterodroma ultima*, and Solander's Petrel *P. solandri*, all species within the subarctic avifauna breed in cold (arctic/subarctic/antarctic/subantarctic) climates. Lensink (1984) lists 11 subarctic species exceeding one million individuals each: Northern Fulmar *Fulmarus glacialis*, Fork-tailed Storm-Petrel, Leach's Storm-Petrel, Black-legged Kittiwake *Rissa tridactyla*, Common Murre *Uria aalge*, Thick-billed Murre *U. lomvia*, Crested Auklet *Aethia cristatella*, Least Auklet *A. pusilla*, Tufted Puffin *Fratercula cirrhata*, and Horned Puffin *F. corniculata*. Millions of Sooty and Short-tailed shearwaters arrive in subarctic waters in April and stay through October. The species compositions of the marine bird guilds in subarctic waters are as follows (Fig. 6):

South Coastal Alaska (SC): The 10 species of marine birds in this guild, except for a few vagrants, remain within coastal waters throughout the year. Pelagic Cormorant *Phalacrocorax pelagicus*, Pigeon Guillemot *Cepphus columba*, and Marbled Murrelet *Brachyramphus marmoratus* are the most common and widespread members of this guild.

Subarctic Pacific (SA): A second guild with 16 species also inhabits coastal waters. Individuals disperse throughout the Subarctic, especially during their nonbreeding periods.

Figure 6
Subarctic Avifaunal Community: species composition of seabird guilds found in subarctic waters (solid bars) during summer in the central North Pacific Ocean. See figures 7 and 8 for definitions of CT, ST, SP, and CH.



<u>South Coastal Alaska (SC)</u>

Double-crested Cormorant
Pelagic Cormorant
Red-faced Cormorant
Mew Gull
Bonaparte's Gull
Pigeon Guillemot
Whiskered Auklet
Crested Auklet
Kittlitz's Murrelet
Marbled Murrelet

<u>North-Central Transition (NC)</u>

Buller's Shearwater
Mottled Petrel
Murphy's Petrel
Solander's Petrel
Cook's Petrel
South Polar Skua

<u>Subarctic Pacific (SA)</u>

Northern Phalarope
Glaucous Gull
Glaucous-winged Gull
Herring Gull
Black-legged Kittiwake
Red-legged Kittiwake
Sabine's Gull
Aleutian Tern
Arctic Tern
Common Murre
Crested Auklet
Whiskered Auklet
Least Auklet
Rhinoceros Auklet
Cassin's Auklet
Ancient Murrelet

<u>Northern Transition (NT)</u>

Northern Fulmar
Sooty Shearwater
Short-tailed Shearwater
Fork-tailed Storm-Petrel
Red Phalarope
Parasitic Jaeger
Long-tailed Jaeger
Thick-billed Murre
Parakeet Auklet
Horned Puffin
Tufted Puffin

<u>Trans-Pacific (TP)</u>

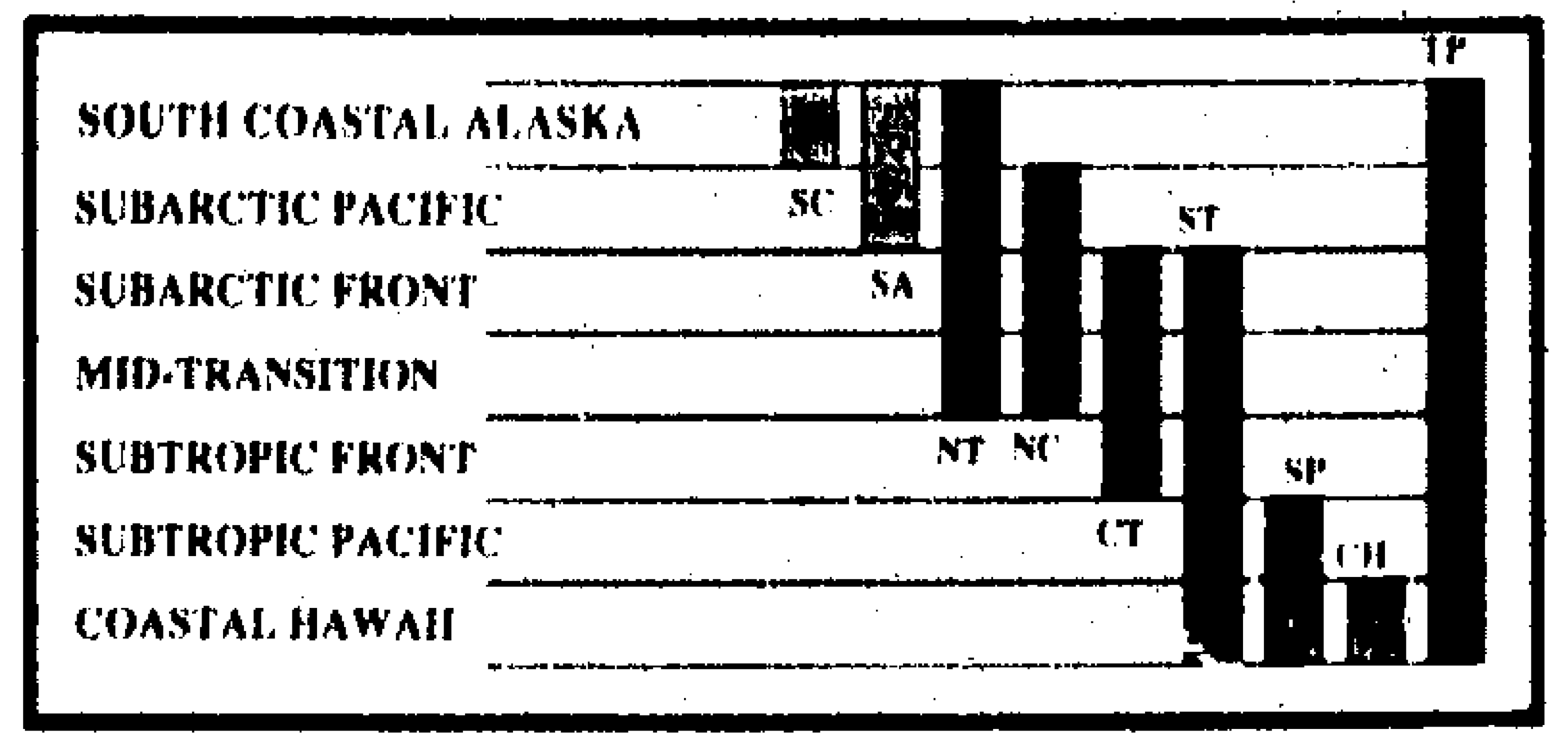
Short-tailed Albatross
Black-footed Albatross
Laysan Albatross
Leach's Storm-Petrel
Pomarine Jaeger

Black-legged Kittiwake, Common Murres, and Glaucous-winged Gull *Larus glaucescens* are the most abundant and widespread members of this guild.

Northern Transition (NT): This guild of 11 species occurs in both subarctic and transitional waters. Sooty and Short-tailed shearwaters are the most abundant and widespread species within this guild, with the former numerically dominant in the south (ca. 40–50°N) and the latter numerically dominant in the north. Sooty Shearwaters dominate the driftnet bycatch records and were caught throughout the study area (37–45°N by 140°E–145°W). Highest capture rates, however, were at the northern edge of this area. Short-tailed Shearwaters were also taken throughout the area but in lower numbers (ca. 95 Sooty to five Short-tailed shearwaters). Immature birds made up 79% of all Sooty Shearwaters and 88% of all Short-tailed Shearwaters taken from driftnets (Gould and Wood 1991). The Tufted Puffin is also a dominant member of this guild. It breeds in abundance throughout the subarctic basin, and apparently disperses in winter throughout subarctic and transitional waters. The age composition of shearwaters, Tufted Puffins, and Horned Puffins retrieved from fishing nets supports the suggestion of Gould et al. (1982) that the central North Pacific may represent a vital nursery area for nonbreeding and juvenile seabirds.

North-Central Transition (NC): Six species occur only in the deep basin waters of the subarctic and colder waters of the transitional area. Buller's Shearwater is the most abundant and widespread species within this guild. The placement of Cook's Petrel *Pterodroma cooki* in this group, rather than in the Central Transition guild, is tentative. Murphy's Petrels are most likely to be found in the far southeastern parts of the area, whereas Solander's Petrel is more common in western parts.

Figure 7
Transitional Avifaunal Community: species composition of seabird guilds found in transition waters (solid bars) during summer in the central North Pacific Ocean. See figures 6 and 8 for definitions of SC, SA, SP, and CH.



<u>Northern Transition (NT)</u>

Northern Fulmar
Sooty Shearwater
Short-tailed Shearwater
Fork-tailed Storm-Petrel
Red Phalarope
Parasitic Jaeger
Long-tailed Jaeger
Thick-billed Murre
Parakeet Auklet
Horned Puffin
Tufted Puffin

<u>North-Central Transition (NC)</u>

Buller's Shearwater
Mottled Petrel
Murphy's Petrel
Solander's Petrel
Cook's Petrel
South Polar Skua

<u>Central Transition (CT)</u>

Pink-footed Shearwater
Flesh-footed Shearwater
Stejneger's Petrel
Pycroft's Petrel

<u>Southern Transition (ST)</u>

Bulwer's Petrel
Dark-rumped Petrel
Juan Fernandez Petrel
Kermadec Petrel
Bonin Petrel
Wilson's Storm-Petrel
Tristram's Storm-Petrel
Band-rumped Storm-Petrel

<u>Trans-Pacific (TP)</u>

Short-tailed Albatross
Black-footed Albatross
Laysan Albatross
Leach's Storm-Petrel
Pomarine Jaeger

Trans-Pacific (TP): Five species appear to occur widely throughout the central North Pacific between Alaska and Hawaii. All are common and widespread except for the Short-tailed Albatross, which is a rare and endangered species. Black-footed and Laysan albatrosses show a tendency in subarctic waters to forage in eastern and western areas, respectively.

4.2. Transitional avifauna

Stejneger's Petrel *Pterodroma longirostris* and Red Phalarope *Phalaropus fulicarius* are typical members of this 33-species community. The group includes two visitors from the Arctic, eight from the Subarctic, eight from the Tropics and Subtropics, 13 from the Subantarctic, and two from the Antarctic. The species compositions of marine bird guilds in this area are as follows (Fig. 7):

Northern Transition (NT): This guild is shared with the Subarctic Avifaunal Community (see above).

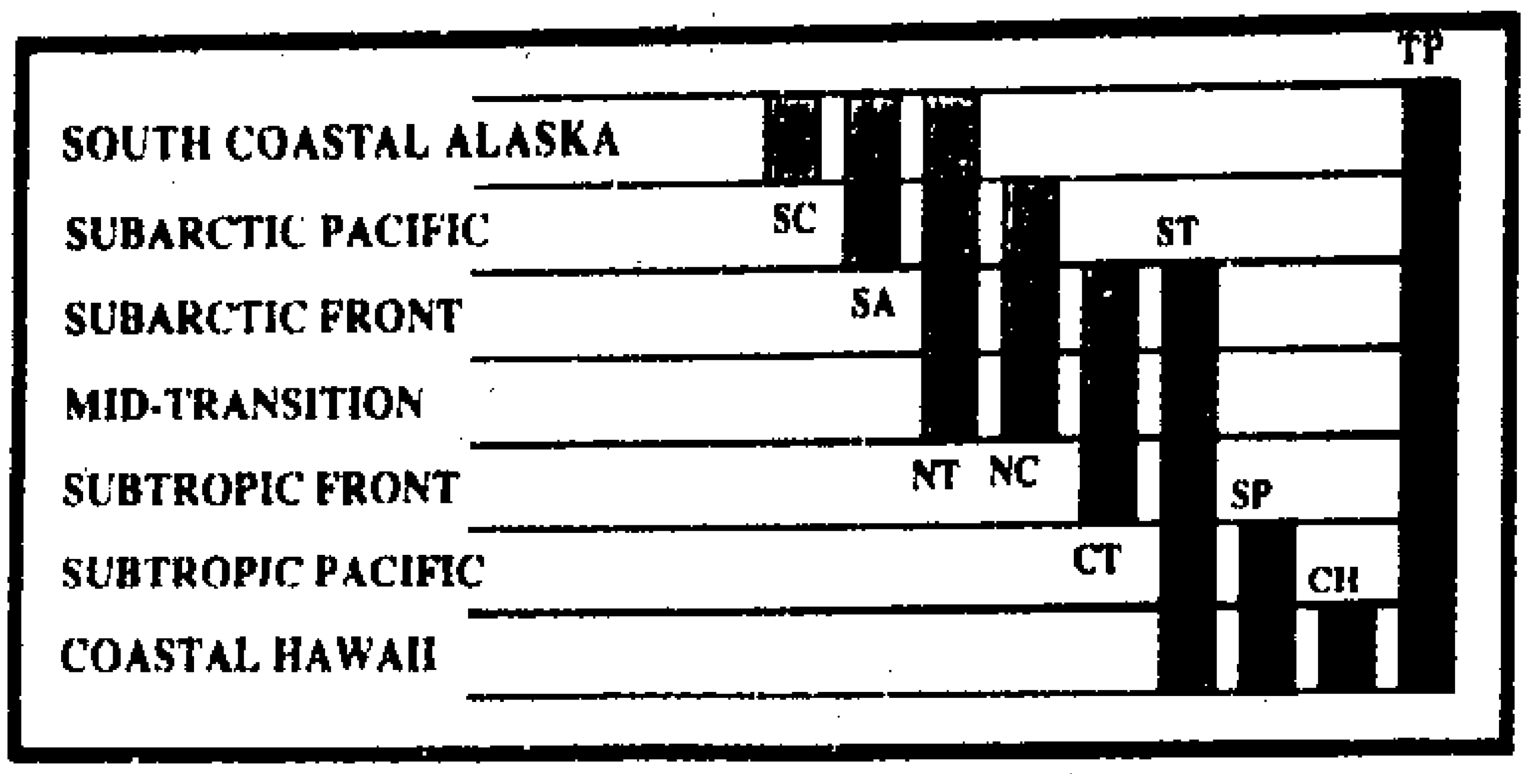
North-Central Transition (NC): This guild is shared with the Subarctic Avifaunal Community (see above).

Central Transition (CT): Flesh-footed Shearwater and Stejneger's Petrel appear to be more or less restricted to this area, but their status is still unclear. We tentatively place the Pink-footed Shearwater *Puffinus creatopus* and Pycroft's Petrel *Pterodroma pycrofti* here until we obtain better documentation. Stejneger's Petrel is the most abundant member of this guild, and has perhaps been underreported owing to the difficulty in identifying this species.

Southern Transition (ST): With the possible exception of Juan Fernandez Petrel *Pterodroma externa*, these species breed in subtropical areas. Bonin Petrel *P. hypoleuca* appears to be the most abundant and widespread species in this guild.

Trans-Pacific (TP): This guild is shared with the Subarctic and Subtropical avifaunal communities (see above).

Figure 8
Subtropical Avifaunal Community: species composition of seabird guilds found in subtropical waters (solid bars) during summer in the central North Pacific Ocean. See Figures 6 and 7 for definitions of SC, SA, NT, NC, and CT.



Southern Transition (ST)

Bulwer's Petrel
Dark-rumped Petrel
Juan Fernandez Petrel
Kermadec Petrel
Bonin Petrel
Wilson's Storm-Petrel
Tristram's Storm-Petrel
Band-rumped Storm-Petrel

Subtropic Pacific (SP)

Wedge-tailed Shearwater
Christmas Shearwater
Newell's Shearwater
Herald Petrel
Black-winged Petrel
Masked Booby
Red-footed Booby
Great Frigatebird
Red-tailed Tropicbird
White-tailed Tropicbird
Sooty Tern
White Tern

Coastal Hawaii (CH)

Brown Booby
Brown Noddy
Black Noddy
Blue-gray Noddy
Gray-backed Tern

Trans-Pacific (TP)

Short-tailed Albatross
Black-footed Albatross
Laysan Albatross
Leach's Storm-Petrel
Pomarine Jaeger

4.3. Subtropical avifauna

Twenty-four of the 30 species that constitute the subtropical avifauna breed in warm-water areas, whereas one is from the Arctic, one is from the Subarctic, three are from the Subantarctic, and one is from the Antarctic. Four species exceeding one million individuals each include Sooty Tern *Sterna fuscata*, Laysan Albatross, Wedge-tailed Shearwater *Puffinus pacificus*, and Bonin Petrel (Fefer et al. 1984). Red-footed Booby *Sula sula* typify all subtropical waters of the central North Pacific. Black Noddy *Anous minutus* and Brown Noddy *Anous stolidus* terns are numerically dominant in the narrow coastal belt around the Hawaiian and Leeward islands, whereas Wedge-tailed Shearwater, Sooty Tern, Juan Fernandez Petrel, and Black-winged Petrel *P. nigripennis* are the most abundant species farther offshore. The species compositions of the marine bird guilds in this area are as follows (Fig. 8):

Southern Transition (ST): This guild is shared with the Transitional Pacific avifaunal community (see above).

Subtropic Pacific (SP): With the possible exception of Black-winged Petrel, all of these species breed in subtropical areas of the central Pacific. Sooty Tern and Wedge-tailed Shearwater are the most abundant species within this guild.

Coastal Hawaii (CH): These five species remain close to their breeding islands, but Gray-backed Terns *Sterna lunata* may occasionally forage far from land.

Trans-Pacific (TP): This guild is shared with both the Subarctic and Transitional avifaunal communities (see above).

5. Threats to marine bird populations

5.1. Subarctic avifauna

At present, most populations of seabirds in Alaska appear to be relatively secure. Potential threats to Alaskan seabird populations are discussed by Lensink (1984). They include oil pollution (Piatt et al. 1990), competition with commercial fisheries (Springer et al. 1986), incidental mortality in gill nets (DeGange et al. 1985), introduced domestic animals and mammalian predators (Jones and Byrd 1979), natural predators, and human exploitation (U.S. Fish and Wildlife Service 1990). Environmental perturbations such as El Niño or long-term changes in the marine environment may also have a direct or indirect negative impact on seabird populations (Hatch 1987).

There is concern about the continuing decline in numbers of the Red-legged Kittiwake *Rissa brevirostris*, Black-legged Kittiwake, Common Murre, and Thick-billed Murre (U.S. Fish and Wildlife Service 1990)—although populations are still relatively large (100 000s to millions). It appears that these declines are related to poor breeding success and presumably poor feeding conditions—the cause of which is not understood but may be related to oceanographic conditions. Marbled Murrelets are listed as threatened in British Columbia, and are proposed to be listed as threatened in Washington, Oregon, and California owing to severely reduced populations and the continuing loss of breeding habitat (old-growth forests). In Alaska, populations are relatively large (low 100 000s) but declining, and continue to suffer from oil pollution, drowning in gill nets, and loss of breeding habitat. The closely related Kittlitz's Murrelet *B. brevirostris* is much rarer (10 000s), but nothing is known of population trends or threats.

5.2. Transition avifauna

Pollution from shore-based and especially from ship-based operations continues to be a problem in this area. However, the greatest threat during the past 13 years has been that of large-scale squid driftnet fishing. Besides killing large numbers of seabirds that become accidentally entangled in the nets (International North Pacific Fisheries Commission 1990, 1991a, 1991b, 1991c, 1991d), driftnets also seriously affect the regional food web by killing large numbers of other animals including the target species, the neon flying squid *Ommastrephes bartrami*. Squid of all sizes, including the large ones targeted by the squid driftnet fisheries, are an important food source for albatrosses, *Pterodroma* petrels, and other species (Harrison et al. 1983; Warham 1990). On the other hand, offal discarded in this fishery may also supplement the normal diet of seabirds. Japan, Taiwan, and the Republic of Korea recently announced their intent to abide by the United Nations moratorium on large-scale driftnet fishing in the North Pacific by the end of 1992.

The most threatened species in this community is the Short-tailed Albatross—which once numbered in the hundreds of thousands. At present, less than 200 individuals are found on three small islands off the coast of Japan (Hasegawa 1984), and the population appears to be increasing slowly. Present threats include loss and degradation of breeding habitat, and entanglement in driftnets. About one-third of the transition avifauna comprises *Pterodroma* petrels, which are nowhere abundant and threatened at many of their breeding colonies in the southwest and southeast Pacific by habitat destruction and particularly introduced predators (Warham 1990). Pycroft's Petrel is the rarest of this group, and only a few hundred individuals are known to breed at a few islands off New Zealand.

5.3. Subtropical avifauna

Garnett (1984), Harrison et al. (1984), Robertson and Bell (1984), and Warham (1990) review threats to seabird populations in the Hawaiian Archipelago, New Zealand, and other areas of the central and south Pacific. By far the greatest threat to seabirds throughout the region is from introduced predators, which have eliminated populations of seabirds on some islands and continue to reduce numbers on other islands. Direct exploitation by indigenous peoples, incidental take in fishing gear, and habitat destruction or disturbance are more or less important threats to seabirds in some locations. Of particular concern in Hawaii are the Dark-rumped Petrel *Pterodroma phaeopygia*, which numbers in the low hundreds, and Newell's Shearwater *Puffinus puffinus newelli*, which numbers in the low thousands. The status of many other species that use transitional waters, but breed elsewhere (particularly storm-petrels and *Pterodroma* petrels), is poorly known owing to a lack of historical data and difficulties in censusing (Warham 1990).

6. Conclusions and recommendations

Kuroda (1991) recognized five avifaunal communities in the central North Pacific (Boreal–Temperate; Temperate-Subtropical; Coastal; Subtropical Endemic; and Subtropical–Northward Dispersal) based primarily on their affinities to different surface water temperatures. Wahl et al. (1989) concluded that there were four major avifaunas (Bering Sea and adjacent regions; Subarctic Current System/Transition Domain and adjacent regions; Upwelling Domain; and North Pacific Central Waters) based primarily on their affinities to surface water temperature and salinity patterns. Both Gould (1983) and Wahl et al. (1989) stressed that the Subarctic Boundary was the major oceanographic feature that separates avifaunas in the central North Pacific. In their classifications they relied on the oceanographic interpretations of Favorite et al. (1976) and water masses defined by sea surface properties.

Whereas the communities described by previous investigators are in many respects similar to our own, we offer a description of the avifauna that is based on somewhat different biogeographical considerations. We recognize the utility of surface water properties for defining habitats, but emphasize the importance of frontal systems and current boundaries in segregating three distinct seabird communities within the area. Furthermore, we recognize nine basic seabird guilds—each consisting of species with similar dispersal patterns and/or foraging styles. Thus, we provide a relatively simple picture of seabird communities in the central North Pacific that integrates both oceanography and seabird behaviour.

To improve our understanding of the distribution of seabirds in the central North Pacific, we need to: i) verify distribution patterns of hard-to-identify species by collecting voucher specimens, ii) obtain more data on seabirds around the subtropical frontal system, iii) directly correlate seabird distribution with "real-time" oceanography and measures of food abundance (e.g., using hydroacoustics and fish sampling), iv) obtain more data from winter, and v) identify food-web relationships for at least the dominant species in the area.

With regard to marine bird conservation, there is a pressing need to: i) eliminate introduced predators from important breeding colonies, ii) restore, preserve, and protect important breeding habitats, iii) assess the extent and impact of commercial fisheries in the area, and iv) census and monitor key colonies of declining and/or rare species.

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