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SEASONAL ABUNDANCE AND MARINE HABITATS OF *Procellaria* FULMARINE AND GADFLY PETRELS OFF CENTRAL NEW SOUTH WALES

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ABSTRACT

Between April 1985 and March 1987, standardised shipboard censuses were conducted during 23 monthly transects from shore to well beyond the continental shelf. The average transect distance was 66 km and maximum depth 4200 m. Twelve (probably 13) species and 2311 birds were recorded. Regular petrels (listed in descending percentage abundance) had zonal and seasonal distributions as follows: *Pterodroma macroptera* (50%), pelagic, spring and summer; *P. solandri* (24%), pelagic, autumn, winter and spring; *Daption capense* (16%), neritic, winter and spring; *Macronectes* spp. (5%), marginally neritic, winter and spring; small *Pterodroma* spp. ("Cookilaria") (4%), pelagic, summer and autumn; *P. lessonii* (1%), pelagic, autumn, winter and spring. Petrels rarely observed were *Fulmarus glacialoides* (1), *Pterodroma neglecta* (3), *Procellaria parkinsoni* (4) and *Pseudobulweria rostrata* (1). Temperature preferences, morphological characters, behaviour and breeding status are discussed. The 200 + "Cookilaria" observed during two cruises in April 1985 may have been associated with a slope-water intrusion generated by the East Australian Current.

INTRODUCTION

Many studies have been made on the distribution of seabirds in Australasian waters. Most have focused on seasonal abundance and have included "true" petrels from the fulmarine, *Pterodroma* and *Procellaria* groups. Pelagic studies include those by Vooren (1972) and Bartle (1974) off New Zealand, Johnstone & Kerry (1976) in the Southern Ocean, Holmes (1977) and Milledge (1977) off New South Wales and Storr (1964) and Abbott (1979) off West Australia. Marchant (1976) conducted a land-based study from Burrewarra Point, New South Wales. In South Australia, Cox (1976) has presented a detailed review of the Procellariiformes using data from shore-based and oceanic observations as well as beach patrols. Of these authors, only Johnstone & Kerry (1976) and Cox (1976) included an area beyond the continental shelf (200 m isobath).

Only Marchant (1976), Johnstone & Kerry (1976) and Abbott (1979) used a sampling method. The relationship between abundance and distance from shore, i.e. offshore zonation, has been analysed by only Storr (1964), Cox (1976) and Abbott (1979).

This paper presents results of a quantified study of seasonal abundance and offshore zonation of "true" petrels off the coast of Wollongong, NSW. Between April 1985 and March 1987, standardised shipboard censuses were made during 23 return cruises from shore to well beyond the edge of the continental shelf.

STUDY AREA AND METHODS

The study area lies in the subtropical zone. It contains a mixture of warm water carried south from the Coral Sea by the East Australian Current (EAC) and nutrient-rich cool water forced north from the subtropical convergence (Nilsson & Creswell 1981, Rochford 1984). Sea surface temperatures (SST) are highest (c. 23 °C) in March and lowest (c. 17.5 °C) in August (Edwards 1979). The continental shelf extends some 34 km eastwards to a depth of 200 m, beyond which the continental slope falls abruptly (depth 2000 m at 64 km eastwards).

This study was conducted on board the MV *Sandra K*, a 14 m converted trawler chartered monthly to observe seabirds. In autumn and winter departure was from Wollongong Harbour (34° 25′S, 150°54′E) at 0615 EST returning at 1545 EST. In spring and summer, departure and return were both about an hour earlier. The vessel's course and speed were set roughly eastwards at 7-8 knots. The maximum distance from shore was 89 km, depth 4200 m (Figure 1, Table 1). The vessel's return was direct to Wollongong Harbour from the turning point, except on cruises 2, 19 and 21, when it was via The Five Islands. Censusing ceased when these islands were reached. During all cruises fish remains and animal fats were chopped on board and cast astern to attract the birds.

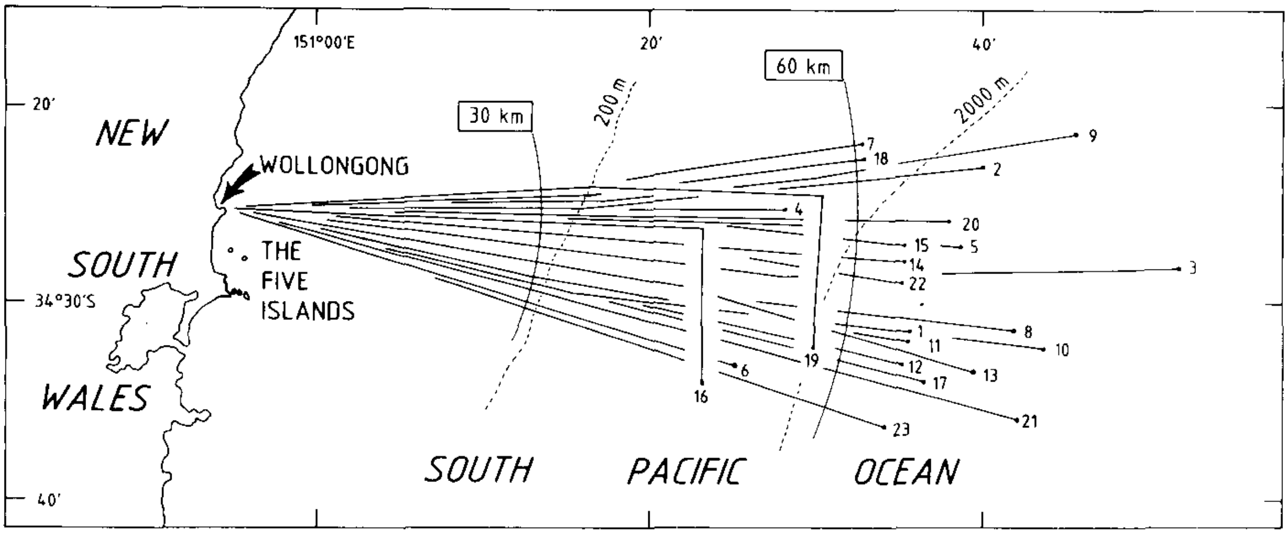

FIGURE 1 —Map showing outgoing course of 23 numbered cruises mentioned in Table 1. Courses shown are true after allowing for the effects of magnetic variation, wind and current

TABLE 1 —Cruise data with corresponding wind speed and direction, water temperature and total number of species and individuals observed

Cruise number	Date	Max distance offshore (km)	Nominal 20 minute census periods: No.	Nominal 20 minute census periods: Mean duration ± Std error (minutes)	Beaufort wind scale at 0900, 1200 and 1500 EST	Wind direction at 1200 EST	Rolling 3-week av. SST and departure from 10 year monthly mean (°C)#	Number of petrel species*	Number of petrel individuals†
1	20 Apr 85	65	26	21.9 ± 0.7	3-4-5	S	22.3 (+0.1)	6	159
2	26 May 85	70	33	17.9 ± 1.6	3-3-2	SSE	20.6 (+0.2)	5	47
3	29 Jun 85	89	30	20.2 ± 1.8	3-4-3	SSW	19.1 (+0.5)	4	74
4	27 Jul 85	52	30	17.8 ± 1.6	4-4-3	SSW	16 (-2.0)	6	88
5	24 Aug 85	69	32	17.1 ± 1.2	4-5-4	WSW	18.3 (+0.7)	4	84
6	21 Sep 85	50	24	20.3 ± 1.4	5-6-5	SSW	18.6 (+0.8)	7	221
7	27 Oct 85	59	27	19.4 ± 1.2	5-6-5	SE	18.4 (-0.1)	5	159
8	3 Nov 85	74	26	21.3 ± 1.2	3-4-3	S	18.8 (-1.1)	4	67
9	23 Nov 85	80	26	21.4 ± 1.7	4-4-4	SSE	20.9 (+1.0)	4	172
10	14 Dec 85	78	30	21.3 ± 1.5	4-4-4	S	22.4 (+1.2)	2	113
11	25 Jan 86	65	29	19.9 ± 0.8	3-4-4	SSW	22.9 (+0.4)	4	30
12	15 Feb 86	65	29	19.3 ± 0.9	2-3-4	SE	22.9 (+0.2)	3	85
13	22 Mar 86	72	29	21.0 ± 1.1	4-4-5	NE	22.8 (0)	5	13
14	26 Apr 86	63	26	21.4 ± 1.3	5-6-5	W	22.3 (+0.1)	3	85
15	24 May 86	63	27	20.4 ± 1.1	5-5-5	W	20.9 (+0.5)	2	18
16	28 Jun 86	46	27	21.4 ± 0.8	4-4-4	SW	17.4 (-1.2)	6	68
17	26 Jul 86	67	27	21.2 ± 0.6	4-3-2	ESE	16.3 (-1.7)	5	105
18	24 Aug 86	59	29	19.6 ± 0.6	4-3-4	N	17.1 (-0.5)	4	189
19	25 Oct 86	56	26	20.3 ± 0.5	7-6-7	W	17.9 (-0.6)	2	158
20	23 Nov 86	67	29	20.1 ± 0.2	2-5-5	S	18.4 (-1.5)	3	107
21	13 Dec 86	76	28	20.4 ± 0.5	6-6-5	W	20.9 (-0.3)	1	47
22	25 Jan 87	63	29	20.1 ± 0.4	4-4-3	NE	22.5 (0)	1	99
23	21 Mar 87	65	29	20.5 ± 0.5	3-4-4	S	20.9 (-1.9)	3	123
								TOTAL	2311

Sea surface temperature and 10 year monthly means 1967-1976 estimated at 34° 30'S, 151° 30'E.

* Probable species included.

† Assumes that no individual followed for longer than 20 minutes, refer text. Includes individuals of unusual species.

The vessel's track and position were determined from engine speed, compass bearing and radar. Depth was read directly from an echo-sounder or extrapolated from Admiralty Chart AUS 808. Wind speed was assessed by Beaufort criteria and checked during 3 cruises with a hand-held anemometer. Wind speed and direction estimated at sea agreed with corresponding measurements taken by the Maritime Services Board at Port Kembla (near The Five Islands). SST at 34°30'S, 151°30'E was considered to be most representative of the study area. Temperatures at that point were obtained from weekly charts provided by the Australian Oceanographic Data Centre (AODC 1985, 1986, 1987) and converted to rolling 3-week averages (Table 1). Converted SST values were checked for accuracy on three cruises using a chromel-alumel thermocouple. Mean monthly SST was evaluated from CSIRO Technical Report No. 88 (Edwards 1979).

During each cruise I kept a continous sea log while watching from the stern (eye height 2.6 m above water). Regularly at about 8 minute intervals and whenever a change in bird numbers was noticed, I made 360° scans. All birds within a radius of c. 250 m were counted with 8 x 40 binoculars. When unusual petrels were seen, the vessel was temporarily stopped and colour transparencies or field notes were taken. Entries in the sea log were subsequently regrouped into successive 20-minute periods, which provided for each taxon (1) the highest number of individuals seen together while boat-following or sitting on the water and (2) the cumulative number of discrete individuals seen passing by. Birds that followed, sat on the water and passed by within a 20-minute period were added. Count durations used by researchers range from 10 minutes to 1 hour but a 10 minute count is recommended if the boat is not discharging offal (Tasker *et al.* 1984). I selected 20-minute censuses to reduce the number of birds recounted when offal was tossed to stabilise the bias introduced by this activity.

The analysis of seasonal abundance is based on the average number of birds per 20-minute census in each month. Abundance data for cruises on 27 September 1986 and 28 February 1987 were kindly supplied by D.H. Fischer. Zonal distribution of a given taxon is based only on census results for the months in which that taxon was observed. Average abundances in the 60–90 km zone should be used cautiously when making comparisons with other zonal abundances because the number of 20-minute censuses beyond 60 km was highly variable (range 0–30 per cruise). For all species, seasonal and zonal sample variances (to 60 km) were heterogeneous, even after square root transformation (Zar 1984), thus precluding the use of ANOVA to test for differences between monthly or zonal abundances.

The marine habits recognised were: inshore zone, within 8 km of the mainland; offshore zone, within the continental shelf (but not inshore); and pelagic zone, at depths > 200 m. The neritic zone is at depths <200 m and includes inshore and offshore zones. Foraging terms follow Harper *et al.* (1985).

TABLE 2 — Distribution of regularly occurring petrels in eacn marine zone

Species	Inshore				Offshore				Pelagic				Total for all zones	
	n	c	$\frac{n}{c}$	P(%)	n	c	$\frac{n}{c}$	P(%)	n	c	$\frac{n}{c}$	P(%)	n	c
Giant Petrels	13	30	0.43	31	65	100	0.65	46	42	130	0.32	23	120	260
Cape Pigeon	5	30	0.17	6	161	107	1.5	49	198	141	1.4	45	364	278
Grey-faced Petrel	4	70	0.06	1.5	126	224	0.56	13.5	1021	292	3.5	85	1151	586
White-headed Petrel	0	33	0	0	5	113	0.04	25	18	136	0.13	75	23	282
Providence Petrel	0	53	0	0	68	181	0.37	16	490	240	2.0	84	558	474
Small *Pterodroma* ("Cookilaria")	0	29	0	0	2	89	0.02	3	84	123	0.68	97	86	241
												TOTAL	2302	

n = No of individuals.
c = No. of 20-minute census periods.
P = percentage of individuals per census period in each zone.

RESULTS

For regularly occurring species (*sensu* van Tets & Fullagar 1984, Blakers *et al.* 1984) c. 50% of all birds were Grey-faced Petrels (*Pterodroma macroptera*), 24% were Providence Petrels (*P. solandri*), 16% were Cape Pigeons (*Daption capense*), 5% were giant petrels (*Macronectes* spp.), 4% were small *Pterodroma* spp. ("Cookilaria") and 1% were White-headed Petrels (*P. lessonii*) (Table 2). Giant Petrels, Cape Pigeons and Grey-faced Petrels were distributed in all marine habitats, whereas White-headed Petrels, Providence Petrels and "Cookilaria" were seen in only offshore and pelagic zones (Table 2, Figures 2b and 3b). The frequency with which individuals of each species were counted is shown in Table 3. Four unusual species were observed (Table 4).

Sea temperatures were cold (c. 16–19 °C) between June and October, and warm (c. 21–23 °C) between January and April. Giant petrels, Cape Pigeons and White-headed Petrels were cold water species (Table 5). Almost all "Cookilaria" (99%) were seen over warm water. Grey-faced and Providence Petrels were seen throughout the full range of temperatures, although 65% of the latter species were present during cold water months (Table 5).

The number of species and individuals seen on each cruise was highly variable (Table 1). Although there was no significant difference in the total number of petrels counted in each 12-month period, data for each species analysed separately showed significant variations in abundance (Table 6).

TABLE 3 — Frequency distribution of number of individuals of regularly occurring petrels observed during 20-minute census periods

Species	Number of individuals							
	1	2-3	4-6	7-10	11-15	16-20	21-30	31-60
Giant Petrels	35	18	6	2				
Cape Pigeon	56	57	16	3	4	1		
Grey-faced Petrel	36	65	68	30	9	5	2	2
White-headed Petrel	19	2						
Providence Petrel	66	78	38	5	3	1	1	
Small *Pterodroma* ("Cookilaria")	14	2	1		2	2		

TABLE 4 —Observation details of unusual petrels off Wollongong between April 1985 and March 1987

Species	No. of individuals	Time (EST)	Date	Distance from shore (km)	Depth (m)	Beaufort wind speed and direction	Surface water temp. (°C)	No. of 35 mm colour slides	Field notes
Southern Fulmar	1	1004-1412	21Sep 1985	12-50	90-1500	Force 6 S	19	3	Yes
Kermadec Petrel	1	1211	20 Apr 1985	56	2100	Force 4 S	23	*	Yes
	1	0805	25 Jan 1986	39	460	Force 2 SW	21.9		
	1	1010	21 Mar 1987	55	2200	Force 4 S	21.1	4	Yes
Black Petrel	1	0838	3 Nov 1985	52	1600	Force 3 SW	17.9	2	Yes
	1	1001, 1018	23 Nov 1985	75-80	2500-2700	Force 4 S	20	2#	Yes
	1	0919, 0930	15 Feb 1986	58-59	2300-2400	Force 2 SE	22		Yes
	1	1000-1233	23 Nov 1986	34-64	220-2400	Force 5 S	17.2-17.5	18	Yes
Tahiti Petrel	1	1221	15 Feb 1986	39	380	Force 2 E	22		Yes

• Colour plate of a 35mm slide is shown in Lindsey (1986b) p.193.
Colour plate of a 35mm slide is shown in Lindsey (1986b) p.257.

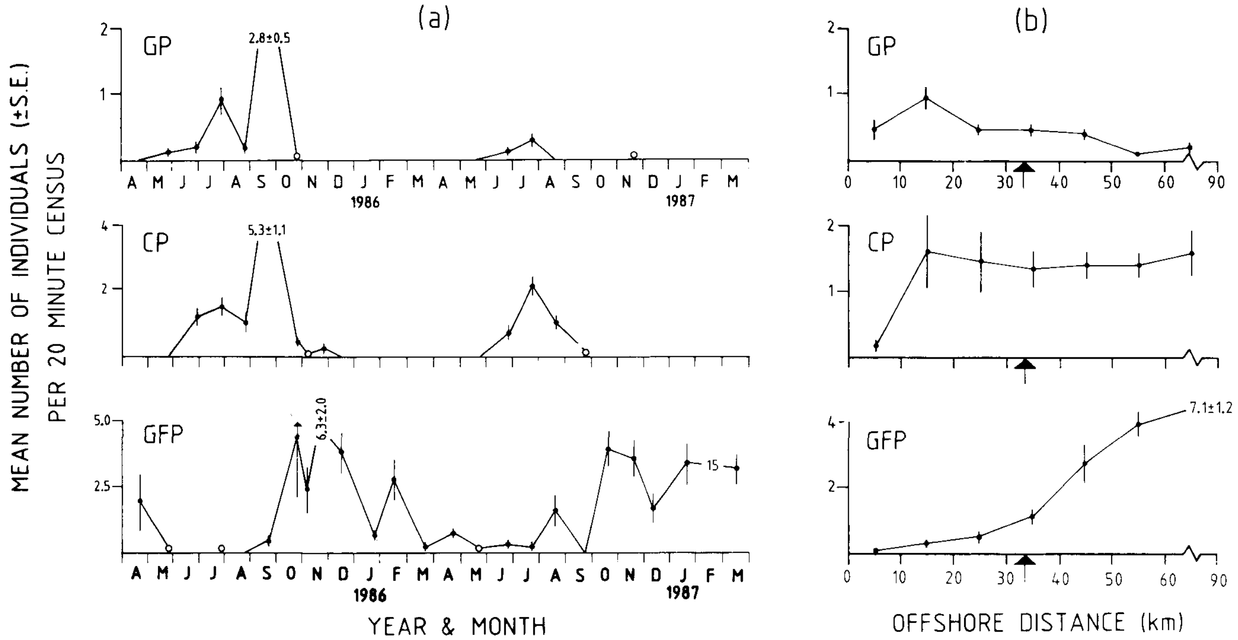

FIGURE 2 — (a) Relative abundance & (b) offshore distribution of regularly occurring petrels off Wollongong between April 1985 & March 1987. Open circles represent a total of one or two individuals. Data for cruises on 27 September 1986 & 28 February 1987 are total number of individuals observed.

Arrows indicate approximate position of 200 m isobath.

GP = Giant Petrel, CP = Cape Pigeon, GFP = Grey-faced Petrel

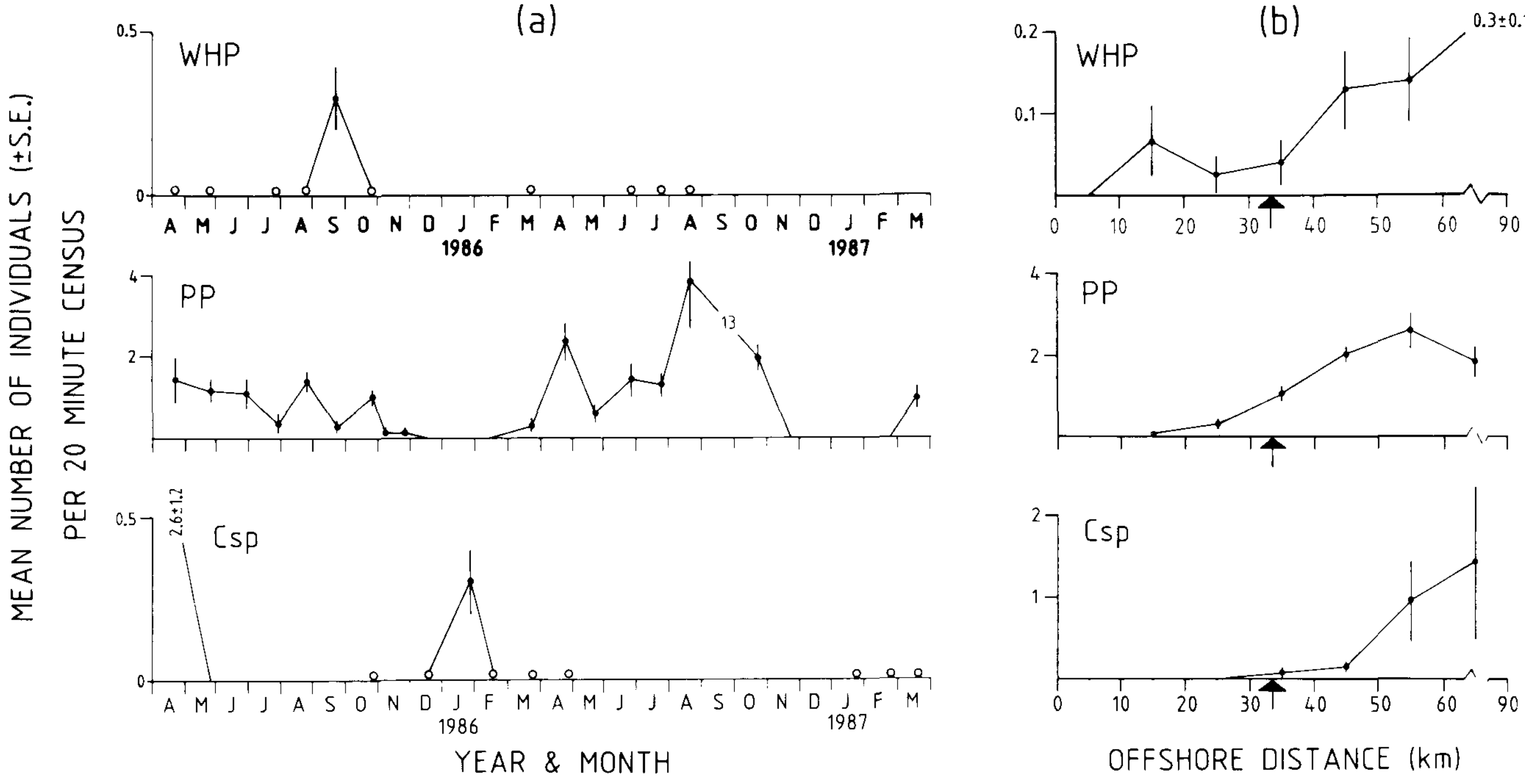

FIGURE 3 — (a) Relative abundance & (b) offshore distribution of regularly occurring petrels off Wollongong between April 1985 & March 1987. Open circles represent a total of one or two individuals. Data for cruises on 27 September 1986 & 28 February 1987 are total number of individuals observed.
Arrows indicate approximate position of 200 m isobath.
WHP = White-headed Petrel, PP = Providence Petrel, Csp = "Cookilaria" species

TABLE 5 — Percentage distribution of petrels according to sea surface temperatures in the study area between April 1985 and March 1987

	Warmest (Jan.-Apr.)	Intermediate (May, Nov. & Dec.)	Coldest (June-Oct.)
AODC weekly (°C)*	22.7-21		18.8-16.3
Rolling 3-wk. av. (°C)#	22.9-20.9		19.1-16
10-yr. monthly mean (°C)†	22.8-22.2		18.6-17.6
Giant Petrels		3	97
Cape Pigeon		2	98
Grey-faced Petrel	33	42	25
White-headed Petrel	13	9	78
Providence Petrel	24	11	65
Small *Pterodroma* "Cookilaria"	99		1

* AODC value on census weeks at 34° 30'S., 151° 30'E.
# AODC value on census weeks at 34° 30'S., 151° 30'E.
† Mean monthly value at 34° 30'S., 151° 30'E. from 1967 to 1976 (Edwards 1979).

TABLE 6 — Comparison between the number of individuals of each taxon observed in each 12-month period

Species	Apr. 1985 to May 1986 (c = 371)*	Apr. 1986 to May 1986 (c = 277)*	χ^2	Level of Significance
Giant Petrel	109	11	42	P < 0.001
Cape Petrel	260	104	30	P < 0.001
Grey-faced Petrel	624	527	4.2	P < 0.05
White-headed Petrel	18	5	4.3	P < 0.05
Providence Petrel	213	345	81	P < 0.001
Small *Pterdroma* "Cookilaria"	82	4	50	P < 0.001
Total Petrels	1306	996	0.2	ns

* c = No. of 20-minute census periods.

For giant petrels, Cape Pigeons and "Çookilaria", the number of birds censused in the first 12 months was very significantly higher (P<0.001) than in the second 12 months. For Providence Petrels a reverse comparative abundance existed with the same level of significance (Table 6). In comparing the difference between mean number of birds per census in each 12 months, square root transformed-data for only the Grey-faced Petrel was homogeneous (F = 1.2, df = 370,276). For that species, a z-test for differences between means resulted in significance at P<0.05 (z = 2.05). Month-by-month analysis of total abundance and total biomass showed a similar degree of variability (Figure 4). Abundance and biomass were highest during the cold water months.

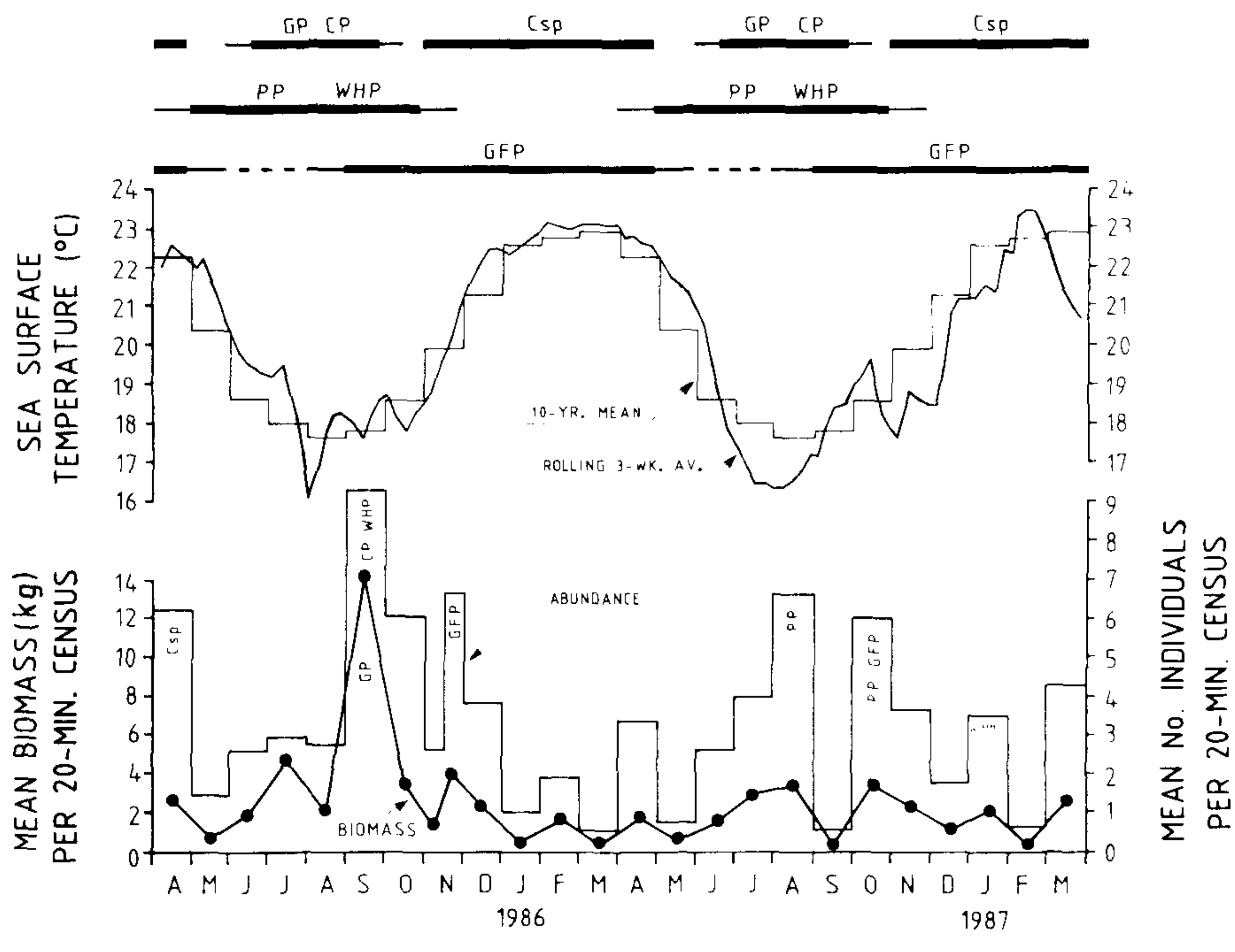

FIGURE 4 —Variation in petrel abundance (all species combined), total biomass and sea surface temperature at 34°30'S, 151°30'E. Species present and species with main contributions to abundance and biomass peaks are shown with abbreviations in figures 2 and 3. Ten year mean monthly SST from Edwards (1979); rolling 3-week average SST during the study was calculated from weekly isotherm charts (AODC 1985, 1986, 1987)

SPECIES ACCOUNTS

NORTHERN & SOUTHERN GIANT PETRELS – *Macronectes halli*, *Macronectes giganteus*.

Overall, 120 giant petrels were recorded, 90 of which were identified to species level. *M. giganteus* outnumbered *M. halli* by 4 to 1 (72:18). Results are presented collectively as both species had similar seasonal occurrences and habitat preferences. Absent from Dec to Apr (Figure 2a), monthly abundance remained generally low between May and Oct, except for Sep 1985, when 67 were recorded (35 *M. giganteus*, 15 *M. halli*, 17 unidentified). No such influx was noted in 1986. Some of this tally was probably of recounted birds because both species followed persistently. Johnstone (1974) found that giant petrels occasionally followed ships "for several hours". In the Southern Ocean, he concluded that *M. halli* tended to follow the *Nella Dan* more than *M. giganteus*. However, I did not notice any difference in the boat-following behaviour of either species behind the *Sandra K.* Immatures of both species were identified by the absence of a pale facial area near the base of the bill (Johnston 1974). Using this criterion I assessed that more than 90% of all individuals were probably less than 4 years old (Serventy *et al.* 1971). Both species breed in the Southern Ocean; *M. halli* from Aug to Mar and *M. giganteus* from Sep to Apr (Watson 1975). Immatures disperse widely during their first few years at sea (Weimerskirch *et al.* 1985). All Southern Giant Petrels were dark morphs. Indeed, only once have I seen a white phase *M. giganteus* off Sydney and Wollongong over the last 10 years (a slightly speckled bird off Cape Solander, 34°01 S, 151°14 E, in September 1983). These results are generally consistent with findings of Milledge (1977) and Jones (1973) slightly north of the study area, except that more white phase *Macronectes* (c.1%) were recorded at the Malabar sewer outfall between 1959 and 1972.

Giant petrels were spread across all marine zones but showed a preference for neritic waters (Figure 2b, Table 2). I counted 78 birds inside the shelf break but only 42 beyond it. Peak offshore distribution in the 10–20 km zone (Figure 2b) was attributed to boat-following by 6–8 individuals in that region during the Sep 1985 influx. Weimerskirch *et al.*(1985) also reported giant petrels in both neritic and pelagic habitats. Jenkins *et al.* (1977) found *Macronectes* abundant "right across the Tasman and in Australian coastal waters" between Jun and Sep in the 15 year period 1959–1974. Giant petrels in the study area were usually encountered alone or in small groups (Table 3).

SOUTHERN FULMAR *Fulmarus glacialoides*

On 21 Sep 1985, a Southern Fulmar followed the boat for more than 4 hours. At 1023 h, it was seen with a Light-mantled Sooty Albatross (*Phoebetria palpebrata*) and c.70 other petrels. Both unusual tubinares may have been forced into the study area by prolonged adverse weather in the western Tasman Sea. During the preceding 13 days, complex low-pressure systems were directing a strong southerly airflow on to the south coast of New South Wales. On 21 Sep 1985, one such low was centred about 950 km SE of Wollongong. Jervis Bay and Montague Island weather stations had registered gale force winds of > 35 km on 20 Sep 1985. Persistently strong southerlies accompanying these lows may have forced the Southern Fulmar north of its normal foraging region. Johnstone & Kerry (1976) and Lindsey (1986b) considered that the species rarely ranges north of c.40°S.

This sighting adds yet another fulmar to at least 20 NSW records since 1954 (Lindsey 1986b, Morris *et al.* 1981). Van Tets & Fullagar (1984) regarded the species as a rare vagrant but possibly a regular visitor in Australian seas.

CAPE PIGEON *Daption capense*

Absent between Dec and May, Cape Pigeons were seasonally most numerous in winter when data for both years were combined. Yet the highest monthly total was 128 in Sep 1985 (Figure 2a). Many birds followed the vessel, taking both kinds of offal. During outgoing voyages, following birds were obviously lured eastwards but return voyages probably attracted them back towards the coast. Despite their boat-following fidelity, only 5 birds were recorded inshore. Furthermore, my data revealed a fairly even distribution between offshore and pelagic habitats (Figure 2b and Table 2). Although I saw Cape Pigeons mostly in small flocks (Table 3), much larger numbers have been reported near the study area. For example, Milledge (1977) and Rogers (1975) reported flocks of c. 300 off Sydney in Sep 1973 and Aug 1974 respectively.

Cape Pigeons breed in summer on the Antarctic Continent and many sub-antarctic islands (Watson 1975). Outside the breeding season they disperse widely, ranging north to about 25° S (Fullagar 1976, Harrison 1983). The rise in numbers in winter-spring and subsequent decline from Dec to May coincide with their movements away and from back to the breeding colonies. All Cape Pigeons were very manoeuvrable in air and on water. They often surface-seized offal just before the arrival of aggressive albatrosses. When apparently hungry they scavenged within 7 m of the boat.

GREY-FACED PETREL *Pterodroma macroptera*

Clearly the most abundant *Pterodroma* in the study area, *P. macroptera* outnumbered *P. solandri* by 2 to 1 (Table 2). Like *P. solandri*, it was seen predominantly in the pelagic zone (Figure 2b). Indeed despite almost equal coverage in pelagic and neritic waters, 89% (1021 birds) were seen over water > 200 m deep (Table 2). These data tend to confirm Imber's (1973) suggestion that "over 95% of the food is taken beyond the continental shelf".

Although opinions vary on seasonal occurrence off NSW (Lindsey 1986b, Morris *et al.* 1981), Grey-faced Petrels were markedly most numerous through spring and summer (Figure 2a). In total, only 5% of birds (n = 61, both years combined) were seen between May and Aug. However, some *P. macroptera* were seen on all cruises except in June and Aug 1985.

At least 90% of birds were conspicuously grey-faced, indicating a majority of either *P.m. gouldi* from New Zealand or immature *P.m. macroptera* from the southern Indian or Atlantic Oceans (Harper & Kinsky 1978, Harrison 1983). Grey-faced Petrels have extended breeding cycles with *P.m. macroptera* laying in May (Warham 1956) and *P.m. gouldi* in July (Imber 1976). Juveniles fledge in Oct (*P.m. macroptera*) or Dec (*P.m gouldi*). Imber (1973) suggested that the foraging range of *P.m. gouldi* breeders was 600 km. As the study area is c.2000 km from New Zealand colonies of *P.m. gouldi* and much further from colonies of *P.m. macroptera,* it is likely to be outside the foraging range of breeders of both subspecies. Thus the majority of Grey-faced Petrels seen in spring and summer were probably *P.m. gouldi* failed breeders, non-breeders

(1–7 years old) (Imber 1985), or very young *P.m. macroptera*. This hypothesis is supported by observations of wing moult. During cruises in Nov 1985, Oct 1986 and Nov 1986, > 80% of birds (cumulative) had trailing edges of the wings clearly "notched" behind the carpal joint, indicating absence of the first few primaries and secondaries. Successful breeders undertake wing moult at sea between Jan and Apr (Watson 1975, Imber 1985). Morris *et al.* (1981) and Lindsey (1986b) considered that the race *P.m. gouldi* dominates the NSW population; although Barton (1978) has reported birds thought to be the nominate race off southern NSW – eastern Victoria.

Sustained boat-following was not observed but I often noticed surface scavenging when the *Sandra K* was temporarily drifting. Birds from various directions would alight on the surface, quickly grasp the offal with wings held half-open, and take off again. On such occasions, some *P. macroptera* formed temporary flocks on the water behind the boat. I counted > 15 birds flocked together around the boat during 7 cruises (Table 3). The highest number of birds cumulatively recorded during any 20-min census period was 60 on 27 Oct 1985 (depth 500 m). Imber (1973) and Fullagar (1976) considered that *P.m. macroptera* were solitary non-followers. When feeding on offal they took mainly fat 10–20 m away. Being less buoyant, most pieces of fish sank or were taken by other seabirds before reaching *P. macroptera*. In the Southern Ocean, Harper (1987) found that *P.m. gouldi* "fed only at night from the surface of the sea, its main prey being squid and crustaceans."

WHITE-HEADED PETREL *Pterodroma lessonii*

White-headed Petrels were seen in small numbers from autumn to spring through winter. They were absent from Nov to Feb. Between Mar and Oct, I saw one or two birds on 9 of the 15 cruises, except in Sep 1985, when I counted 8 birds. Of 23 birds overall, 17 were present in 1985 and 6 in 1986. These data indicate a sporadic occurrence off Wollongong. The species is a summer breeder on the Antipodes, Auckland and Macquarie Islands. The present seasonal data correlate with a northward movement from the breeding islands into the Tasman Sea and South Pacific Ocean (to about 30°S) after breeding (Serventy *et al.* 1971, Warham 1985). Most birds made one or two passes at viewing distances of > 50 m, showing no interest in the vessel.

P. lessonii was found to be highly pelagic (Figure 2b, Table 3). Indeed, only 4 birds were seen coastwards of the 200 m isobath. Jenkins (1982) also noted flocks of 170 + and 250 + feeding and rafting in the pelagic zone, east of the study area at 34°S, 154°E in Aug 1980 and at 35°S, 155°E in July 1981 respectively.

PROVIDENCE PETREL *Pterodroma solandri*

This was the second most abundant petrel; present from Mar to Nov and absent in summer (Figure 3b). The seasonal occurrence coincides with the breeding season at Lord Howe Island (31°30'S, 159°E), where an estimated 96 000 pairs lay their eggs in May and the young fledge from early Nov (Fullager 1985). The 20-min censuses generally resulted in tallies of fewer than 6 birds (Table 3), but in Aug 1986, I listed 20 and 25 in successive counts at a rate of one or two every few minutes. Of the total, 88% (490 birds) were over the continental slope (Table 2). Indeed, none were within 10 km of the mainland and only 4 in the 10–20 km zone (Figure 3b). Holmes (1977) and Cheshire & Jenkins (1981) respectively found a similar seasonal occurrence and zonation off northern NSW and east of the study area to 161°E. Barton (1977, 1978) made no mention of the species off southern NSW from Oct 1976 to Dec 1976 (3 months) or Jan 1977 to Dec 1977 (12 months). Milledge (1977) did not record the species during his 12-month study.

In 15 cruises, both *P. solandri* and *P. macroptera* were present. They were similar in size, plumage and flight behaviour. But unlike *P. macroptera*, *P. solandri* rarely scavenged for scraps and did not come close to the boat. Observation distances were usually 60–100 m. I noted seasonal renewal of the upper wing-coverts and back in Mar and Apr each year. Whereas *P. solandri* usually appeared in mature uniformly dark plumage dorsally, in Mar and Apr its secondary coverts and back were tinted silver-grey, contrasting with much darker primary coverts and wing tips. One bird seen in Aug 1986 had an off-white breast and belly, a pattern which Serventy *et al.* (1971) and Bowles (1988) considered results from abrasion of the pigmented dark tips of the body feathers exposing their white bases. I found that *P. solandri* in mature plumage was difficult to separate from *P. macroptera* in dorsal aspect but easy to identify if the distinctive black crescents inside the white triangular flashes of the underwing could be seen. These are formed by black tips to the white greater coverts (Simpson & Day 1984).

KERMADEC PETREL *Pterodroma neglecta*

Three birds were recorded: a dark morph in Jan 1986 and intermediate morphs in Apr 1985 and Mar 1987 (Table 4). In good light at < 60 m I saw diagnostic white shafts of the primaries of the upperwing (Lindsey 1986b) and the prominent white basal area of the primaries in the underwing on all three birds. Both intermediate morphs had a dark head, throat and under tail-coverts and a white breast and belly. Their underwings showed irregular white patches, except for a white subterminal band on the primary coverts, giving the appearance of a dark stripe across the white primary bases. This feature appears to have been omitted from most identification literature on *P. neglecta.* All birds were viewed in soaring flight for about 7 minutes.

The three previous Australian records (Lindsey 1986b, Morris *et al.* 1981) are of beach-washed specimens from NSW. Fullagar (1976) and Fullager *et al.* (1974) reported that the nearest known colony has fewer than 100 breeding pairs at Balls Pyramid (32° S, 160 °E), where the breeding season is probably between January and July. Previous records and these sightings coincide temporarily with the breeding season.

BLACK PETREL *Procellaria parkinsoni*

All birds were seen singly in spring or summer well beyond the 200 m depth contour (av. depth 1680 m). In the eastern Pacific Ocean, Pitman & Unitt (1981) made 68 sightings of this species, also as single birds. But whereas their sightings were of birds which "did not flock with other marine birds", all *Procellaria parkinsoni* in the study area were seen with Wedge-tailed Shearwaters (*Puffinus pacificus*) and either Flesh-footed Shearwaters (*Puffinus carneipes*) or Grey-faced Petrels. This allowed accurate comparisons of size, flight, plumage and bill structure. *P. parkinsoni* appeared slightly larger in wing span and body size than *Puffinus carneipes.* With ideal viewing, primary shafts were visible in the underwing (Harrison 1983). Dorsally, dark feet were mostly seen protruding about a centimetre beyond a short rounded tail. This flight characteristic, which is useful for distinguishing *P. parkinsoni* from *Puffinus carneipes*, is rarely mentioned in reference literature. All birds had a deep stubby bill which was yellowish horn with a dark (almost black) nail and upper ridge of the culmen. The nares also appeared yellowish horn. On two birds, only the very tip of the maxillary unguis was black; its basal area was greenish horn, suggesting the presence of subadults less than 5 years old (Imber 1987). Since first listed as beach-washed near Sydney in 1875 (Condon 1975), *P. parkinsoni* was not recorded in Australia until 1983 and 1984 (Lindsey 1985, 1986a, 1986b).

This species is known to breed only on Great and Little Barrier Islands, New Zealand, between Oct and July (Imber 1987). The total population is estimated at c.4000 birds, of which c.2000 are non-breeders. Although breeding birds have a foraging range of about 500 km (Imber 1987), these sightings suggest that some non-breeders range westwards to the continental slope off central NSW during the early breeding season.

TAHITI PETREL *Pseudobulweria rostrata*

The lone Tahiti Petrel was seen clearly at c.80 m as it made just one pass. It did not associate with some 90 other tubinares foraging in the wake. Its gliding flight was leisurely and sinusoidal, towering to a height of c.25 m. Its underwing showed a distinctive white axial stripe extending from the axillaries to the base of the primaries. Harrison (1983) stated that this stripe often appears at sea due to reflected light.

The nearest known breeding colony is on New Caledonia (Naurois 1978), c.1900 km NE of Wollongong. Numerous sightings have been reported in northern NSW near the edge of the continental shelf since 1975 (Holmes 1981, Lindsey 1984, 1986a). Van Tets & Fullagar (1984) and Blakers *et al.* (1984) classified the species as a rare vagrant. This appears to be the most southern Australian record. All known sightings have been between Nov and Apr, when sea surface temperatures are highest.

"COOKILARIA" Small *Pterodroma* species

Using characteristics described by Bourne (1983), I identified 86 petrels from the "Cookilaria" group. Probably none of these was recounted because they did not follow the vessel. About 90% were seen in similar oceanographic environments: 68 on 20 Apr 1985 (56–65 km ESE of Wollongong, depth 2000–2800 m, SST 23 °C) and 9 on 25 Jan 1986 (49–65 km ESE, depth 1400–2800 m, SST 22.7 °C). Close views (< 70 m) in good light were rare. In fact, all 68 in Apr 1985 were obsrved at > 150 m, banking and wheeling over a particular section of the ocean which appeared to hold their attention.

Imber & Jenkins (1981), Jenkins & Cheshire (1982), Blakers *et al.* (1984), Harrison (1983) and van Tets & Fullagar (1984) considered that the "Cookilaria" in the study area are Black-winged (*Pterodroma nigripennis*), Cook's (*P. cookii*), Gould's (*P. leucoptera leucoptera*)., New Caledonian (*P. leucoptera caledonica*) and possibly Collared (*P. leucoptera brevipes*) petrels.

On this basis and using identification criteria given in Slater (1986), Harrison (1983), and Lindsey (1986b), I identified 13 (of the 86 "Cookilaria") as *P. leucoptera* (Gould's or New Caledonian), 65 as probably *P. leucoptera* (Gould's or New Caledonian), 3 as *P. nigripennis* and 1 as probably *P. cookii*. Four were not identified. The probability of Collared Petrel was low because none of the "Cookilaria" appeared to have dusky underparts or partial breast collars. All birds but one were present between Dec and Apr when sea surface temperatures were highest (22–23 °C, Table 1). The highly pelagic nature of this species group was reflected by a complete absence of birds within 35 km of the mainland (Table 2, Figure 3b).

Other observers have also encountered "Cookilaria" off the NSW coast e.g. 2000 + (including numerous *P. leucoptera*) near the Gascoyne Seamount (36° S, 156° E) in Jan 1980 (Barton 1980), 49 (mixed) east of the study area (to 160° E) in Jan 1977 (Harrison 1978), and 22 *P. leucoptera* during a pelagic cruise between Port Stephens and Bateman's Bay in Dec 1984 (Lindsey 1986a). D.H. Fischer(*in litt.*), saw about 150 and 60 *P. leucoptera* in the study area beyond the shelf-break during *Sandra K* cruises on 21 Apr 1985 and 26 Jan 1986 respectively. My data (Table 3) and the above sightings suggest that these small gadfly petrels sometimes form loose interspecific flocks. They are probably more abundant and less solitary then previously reported (see Imber & Jenkins 1981, Morris *et al.* 1981, Blakers *et al.* 1984, Lindsey 1986b). Moreover, it is most unlikely that all *P. leucoptera* reported above belong to the small colony of c.500 pairs of Gould's Petrel on Cabbage Tree Island (Lane 1979). Observations to date therefore support the view that most *P. leucoptera* in the Tasman Sea in the breeding season are New Caledonian Petrels (Imber & Jenkins 1981).

DISCUSSION

Relative abundance, habitat preferences and seasonal pattern

The census method has unavoidable biases (Tasker *et al.* 1984). Species which followed the boat have probably been overestimated in abundance (Griffiths 1982). However, at least 12 (probably 13) petrel species were present between April 1985 and March 1987. After allowing for biases I assessed that *P. macroptera* was the most abundant species, occurring mainly in spring and summer. *P. solandri* was second most abundant, recorded in winter and spring. The fulmarine petrels, *Macronectes halli, M. giganteus* and *D. capense* were fairly common in winter and early spring. "Cookilaria" petrels were seen during summer and autumn, with highest numbers in April 1985 and January 1986. The least abundant but regularly observed petrel was *P. lessonii*. It was present mainly in ones and twos in the deep-sea zone during all seasons except summer. The remaining four species *Fulmarus glacialoides, Pterodroma neglecta, Pseudobulweria rostrata* and *Procellaria parkinsoni* were uncommon. These data supplement previous work. Milledge (1976), for example, made no mention of either *Fulmarus glacialoides* or *Pterodroma leucoptera* in NSW. Blakers *et al.* (1984) reported only three records of *P. solandri* within 50 km of mainland Australia between 1977 and 1981. They listed only one previous record of *Procellaria parkinsoni*. Holmes (1977) found that *P. solandri* was fairly common and *P. macroptera* was scarce in northern New South Wales (about 30° S), whereas Barton (1976, 1977, 1978) reported a reversed relative abundance off Eden (about 37° S).

All *Pterodroma* species and *Procellaria parkinsoni* showed a strong affinity for slope waters. These petrels completely shunned the inshore zone. By comparison, fulmarine petrels were much less dependent on a single marine biotope. *D. capense* was recorded in comparable numbers in both offshore and pelagic zones. *Macronectes* spp. showed the broadest zonal tolerance by scavenging in all marine habitats. Although pterodromine petrels foraged predominantly over the slope, c.11% (n = 205) were censused in the offshore zone, suggesting that zonal boundaries are defined by trophic segregation (and prey availability) rather than by distance from shore.

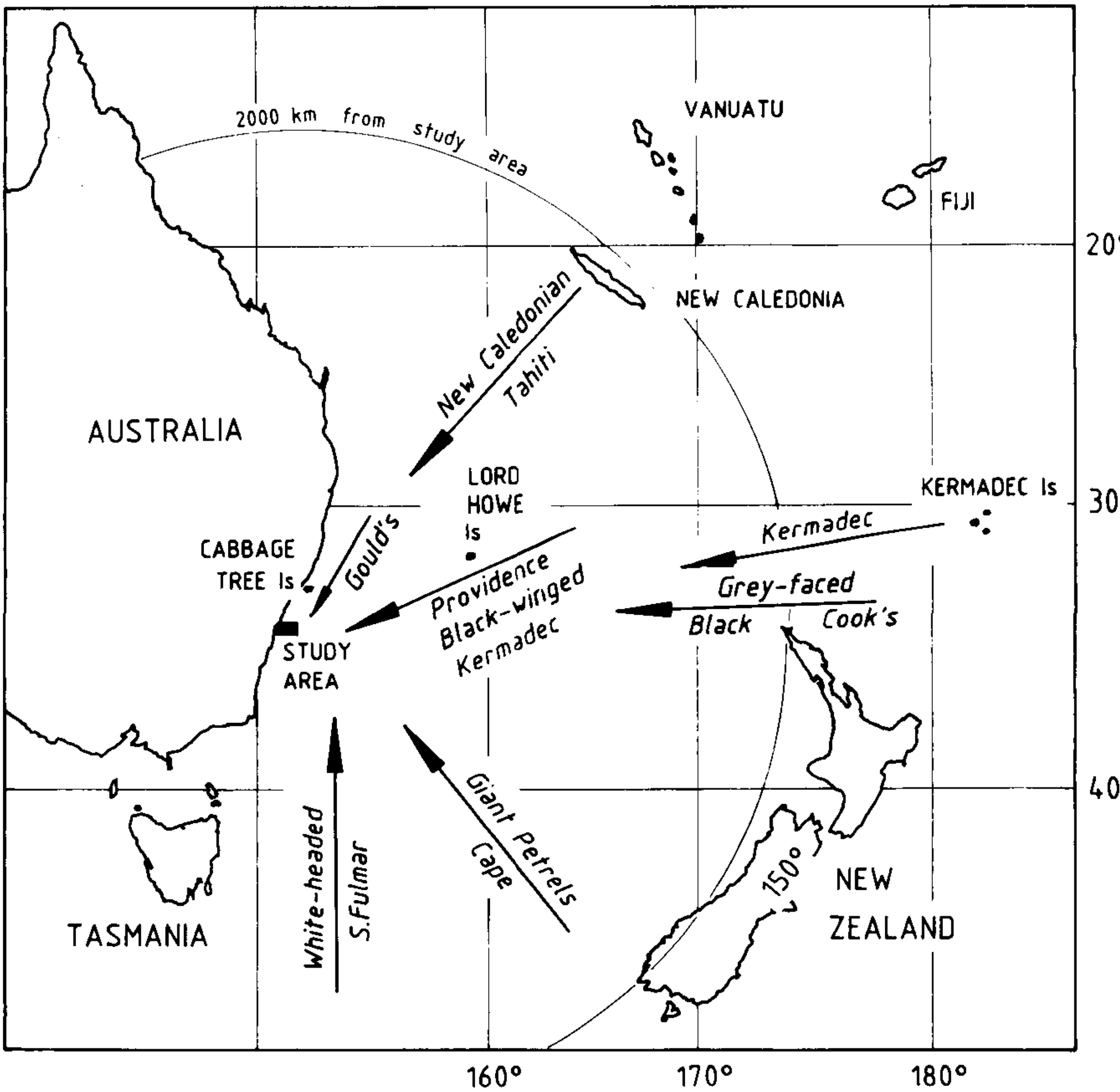

FIGURE 5 — Mercator projection of south-west Pacific Ocean showing breeding islands

Breeding status and origin

The petrels in the study area had origins to the north, east and south (Figure 5). At least 9 species consisted of non-breeders. Giant petrels were mostly immatures (> 90%) which moved northwards in winter and spring. The other fulmarine petrels and *P. lessonii* were also present in winter and spring, arriving after breeding in the Southern Ocean in summer. All the other petrels recorded breed in the south-west Pacific and were observed during their breeding seasons. *P. solandri* and *P. nigripennis* breed on Lord Howe Island, *P. neglecta* on Ball's Pyramid, and *P. leucoptera leucoptera* only on Cabbage Tree Island. These colonies are within 850 km of the study area. *P. macroptera, P. cookii, P. leucoptera caledonica, Pseudobulweria rostrata* and *Procellaria parkinsoni* breed on New Zealand islands, the Kermadec Islands or New Caledonia, all of which are > 2000 km from Wollongong (Figure 5). Procellariids are thought to range widely from the breeding colonies e.g. *Pterodroma macroptera* 3200 km (Imber 1973) and Short-tailed Shearwater (*Puffinus tenuirostris*) 1600 km (Serventy 1967). Imber (1973), however, suggested that the foraging range of *P. macroptera* while feeding young was limited to about 600 km. Recent studies by Montague *et al.* (1986) have shown that breeding *Puffinus tenuirostris* feed closer to the colony than previously thought (perhaps c.200 km).

The study area was therefore probably outside the foraging range of breeding adults from more distant colonies (> 1000 km). Thus *P. macroptera, P. cookii, P. leucoptera caledonica, Pseudobulweria rostrata* and *Procellaria parkinsoni* were probably non-breeding birds. Morphological characters of some *P. macroptera* and *Procellaria parkinsoni*, together with the pattern of abundance of *P. macroptera*, reinforce this suggestion. Segregation between foraging areas of breeding and non-breeding populations of the same species may be another mechanism by which seabirds reduce intraspecific competition for food. *P. solandri*, *P. neglecta* and *P. leucoptera leucoptera* from the closer breeding colonies (< 850 km) may have been either breeding or non-breeding birds.

Influence of weather

The distribution and abundance of seabirds are known to be affected by meteorological conditions (e.g. Manikowski 1971). In slight winds (Beaufort 0–2), they are less mobile and tend to rest on the water rather than fly (Tasker *et al.* 1984, Cox 1976, Harper 1987). Foraging is probably most efficient in moderate winds (Beaufort 3–6), whereas in strong winds (Beaufort > 7) prey is difficult to see (Abbott 1979) and obtain (Birkhead 1976). Gale-force winds associated with low-pressure systems occasionally force seabirds beyond their normal foraging zones (Cox 1976, Jenkins & Greenwood 1984). Data for the current study were obtained when winds were slight to moderate (force 3–6) and weather conditions were normal for 10 days before each cruise (except September 1985). I therefore concluded that wind did not statistically bias the normal distribution of "true" petrels within a few hundred kilometres of Wollongong. Only the Southern Fulmar, seen in September 1985, was considered to be outside its normal foraging zone.

Temperature preferences

Seabird affinities for water masses defined by surface temperatures have been described by various authors (Dunlop *et al.* 1988 and references). In the study area, giant petrels and Cape Pigeons were clearly cold water species and "Cookilaria" were obviously linked with the warmest water. *Pterodroma* *macroptera*, *P. lessonii* and *P. solandri* were associated with all temperature regimes (16-23°C). These data do not conflict with Pocklington's (1979) finding in the Indian Ocean that *P. lessonii* was encountered only over "low temperature " water (c. 10-22°C) whereas *P. macroptera* was present within the temperature range c. 10-25°C. Temperature data used in the present study are approximate because (a) they apply to the point 34°30'S, 151°30'E and (b) they are not synoptic. AODC weekly isotherm charts best show the changing nature of the eddy field rather than real time data (Tranter *et al.* 1986). Water temperatures measured directly at sea would provide a more accurate prediction of the temperature preferences of *P. macroptera, P. lessonii* and *P. solandri.*

Petrel distribution and oceanography

Oceanographic features such as offshore eddies and currents, thermal fronts, slope-water intrusions and warm water events (*El Ninos*) are known to influence the normal distribution of seabirds. In the South Atlantic Bight and off south-east Tasmania, Haney (1986) and Blaber (1986) respectively noted that various seabirds, including procellariids, exhibited affinities for ephemeral mesoscale (50–150 km) water masses formed by ocean currents, eddies or temperature fronts. Brown (1988) reported storm petrels (Hydrobatidae) concentrated over tidally induced upwellings and convergences off Nova Scotia. Was any oceanographic feature operating during the current study which could have affected the normal distribution of "true" petrels? First, the abundance of most species was significantly variable, between successive 12-month periods (Table 6) and between corresponding months (Figures 2 and 3). Secondly, temperature differences were significantly above and significantly below the 10-year mean in the first and second 12-month periods respectively (Table 7). A similar trend was evident in temperature deviations on cruise dates:

First 12 months: above $n = 9$, $\Sigma t = 5.7$ °C; below $n = 3$, $\Sigma t = 3.2$ °C.
Second 12 months: above $n = 2$, $\Sigma t = 0.6$ °C; below $n = 7$, $\Sigma t = 7.7$ °C.

TABLE 7 — Comparison between sea surface temperature deviations in each 12-month period. Weekly and mean SST is defined in Table 1

	SST above 10-yr. mean	SST below 10-yr. mean	χ^2	Level of Significance
No. of weeks between Apr. 1985 and Mar. 1986	34	12	9.6	P < 0.01
No. of weeks between Apr.1986 and Mar. 1987	21	29	1.0	ns
Cumulative weekly magnitude between Apr. 1985 and Mar. 1986	22°C	6.7°C	7.1	P < 0.01
Cumulative weekly magnitude between Apr. 1986 and Mar. 1987	15.5°C	32.7°C	5.4	P < 0.05

* Based on rolling 3-wk. av. and 10-yr. monthly mean values (refer Table 1).

Yet cold water species, *Macronectes* spp, *D. capense* and *P. lessonii*, were most abundant in the first 12 months (Table 6), when temperatures were above the monthly mean. Indeed, the largest influx of these species was in September 1985, when SST was 1.7 °C above mean (Table 1). Only Providence Petrels were most abundant when temperatures were below the 10-year mean (August 1986).

It could be argued that the September 1985 influx of regular petrels was due to abnormal weather, as was the coincidental sighting of the lone Southern Fulmar. Alternatively, the influx could have been due to some oceanographic feature not reflected in the temperature applicable to the spatial point 34°30′S, 151°30′E. I conclude that marked year-by-year and month-by-month variations in species abundance in the study area cannot be validly explained by analysing sea surface temperatures from AODC charts. Again, real time data is required to resolve these sources of variation because patchiness at coarse scales (1–100 km) can mask seabird distribution between water masses of different temperatures (Hunt & Schneider 1987).

AODC charts, however, provide reliable data for determining the nature of oceanographic anomalies at much larger scales (1000–2000 km). Because temperature deviations < 2 °C occurred randomly above and below 10-year monthly means (Table 1), they suggest a linkage with regional (10 000 km^2) irregularities rather than long-term global effects (Hsieh & Hammon 1985). Moreover, only a weak to moderate *El Nino* was influencing the marine environment in the Pacific Ocean in late 1986 (Bergman 1987) and it was therefore unlikely to have any significant effect on the distribution of petrels in the Tasman Sea.

Concerning regional oceanographic anomalies, Nilsson & Cresswell (1981) and Tranter *et al.* (1983) have shown that temperature fronts, eddies and meanders formed by the EAC are regular off NSW, particularly south of 32°S. Surface temperature fronts almost certainly existed off Wollongong between April 1985 and March 1987, but I was unable to determine whether the *Sandra K* had intersected any such front from an analysis of SST isotherms. Further, I am aware of an extraordinary short-term increase in the abundance of only one petrel species (group): 68 and 158 "Cookilarias" observed on 20 and 21 April 1985 respectively. I therefore concluded that some local oceanographic anomaly may have influenced the abundance of these "Cookilarias". A likely contributing factor was an upwelling or slope-water intrusion associated with the Tasman Front (15 °C isotherm at a depth of 250 m) which passed through the study area about the end of April 1985. Analysis of the weekly isotherm charts of the offshore eddy field (AODC 1985) indicated that, on 8 April 1985, the Tasman Front was about 130 km ENE of the shelf-break off Wollongong, advancing slowly southwards. A warm (28 °C) filament of surface water extended down the coast over the continental slope to about latitude 34°S. An extensive cold water mass lay between the Tasman Front and a warm-core eddy c.240 km SE of Cape Howe. Two weeks later, on 22 April (Figure 6), the warm surface filament was 26 °C, the Tasman Front had moved to within about 80 km of the study area, and the southernmost warm-core eddy was east of Cape Howe. On 6 May, the Tasman Front was inside the study area, very close to where the "Cookilaria" flocks were seen on 20 and 21 April 1985. Similar meanders

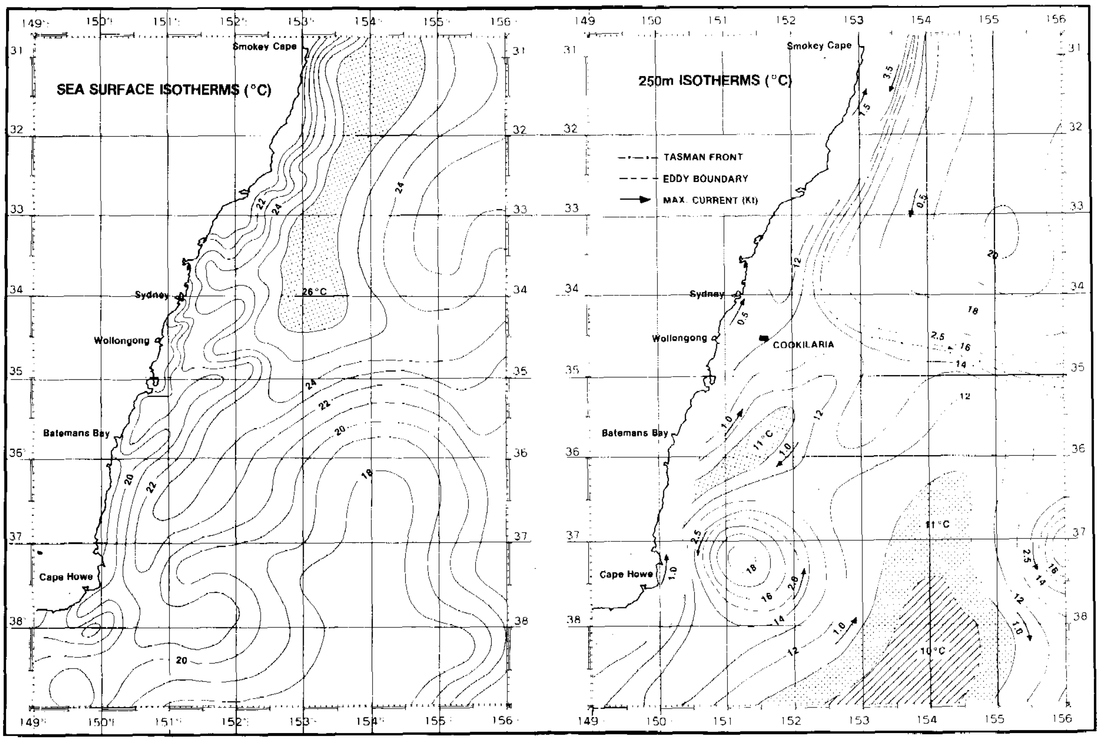

FIGURE 6 — Oceanographic conditions in the western Tasman Sea during the week 15-22 April 1985. Eddy boundaries & Tasman Front are defined by T_{250} = 15°C. Hot & cold water masses shown shaded. Solid rectangle indicates position of "Cookilaria" on 20 & 21 April 1985

(Source: Australian Oceanographic Data Centre) and eddies off NSW between July 1982 and June 1984 were recently analysed by Tranter *et al.* (1986) and found to produce at least seven slope-water intrusions at an offshore station east of Cronulla (34°05′S, 151°15′E, depth 100 m).

Water masses associated with slope intrusions are often enriched with nutrients which influence the composition of zooplankton, cephalopods and mesopelagic fish. This fauna belongs to a marine food web with seabirds at the apex. Meanders (or eddies) off NSW do not always produce upwellings (Tranter *et al.* 1986), but the April 1985 meander had features which are typical of those which do; it was within 90 km of the shelf-break, its velocity was relatively high (2.5 kt) and it had generated a slower (0.5 kt) inshore counter current (Tranter *et al.* 1986). Moreover, large flocks of "Cookilaria" were almost certainly absent from the study area in preceding months because a total of only 11 birds (mainly *Pterodroma leucoptera*) was seen during four earlier cruises to well beyond the shelf in late January, February and March 1985 (D.H. Fischer, *in litt.*). It is therefore presumed that the oceanographic conditions which prevailed off Wollongong in April 1985 caused enrichment of the slope-water column and a corresponding increase in the abundance of "Cookilaria". Jenkins (1971) and Barton (1980) have each reported large flocks of "Cookilaria" petrels flying over surface temperature fronts (SST 22-24°C) or bathymetric discontinuities within 750 km of the study area.

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