Adult Buller's Albatross *Diomedea bulleri* at sea off Wollongong on 28 June 1986. White spots on the upperwing suggest covert moult.

Plate 30

Photo: K.A. Wood

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Seasonal Abundance and Spatial Distribution of Albatrosses off Central New South Wales

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Summary

Between April 1985 and March 1987, albatrosses were censused during 25 one-day transects over the continental shelf and slope off Wollongong, New South Wales. The relative abundance of common species was as follows: Black-browed *Diomedea melanophrys* 54%, Yellow-nosed *D. chlororhynchos* 34%, Wandering *D. exulans* 6% and Shy *D. cauta* 6%. Numbers of these albatrosses were seasonally highest in winter or spring and spatially highest over pelagic water. Black-browed, Yellow-nosed and Shy had highest rates of encounter over the upper slope (depth 200-1500 m) whereas Wandering was encountered most frequently over the lower slope (depth 1500-4200 m). Observation details of four irregular species are reported. The abundance of Black-browed and Yellow-nosed Albatrosses was negatively correlated with sea surface and ambient air temperatures. A preliminary assessment of the latitudinal abundance of common species off New South Wales is presented.

Introduction

Accounts of the abundance of albatrosses off New South Wales reflect a lack of observations over the continental slope (depth 200-4000 m) and a need for more rigorous census procedures. Marchant (1977) conducted an eleven-month study from the shore at Burrewarra Point, latitude 35°50'S. Milledge (1977) off Sydney (34°S), and Holmes (1977) off Coffs Harbour (30°18'S) conducted surveys of 12 and 28 months duration respectively from fishing vessels over the continental shelf (depth $<$200 m). Barton (1979a) censused albatrosses for 19 months while fishing off Eden (36° to 38°S), occasionally to a depth of 800 m (in litt.). These authors used various semi-quantitative census techniques which have since been superseded.

This paper presents the results of an albatross census off Wollongong (34°25'S, 150°54'E). In the 24-month period from April 1985 to March 1987, 25 one-day return cruises were made from shore to well beyond the continental shelf. The average cruise duration, distance from shore and depth were 9.5 hours, 66 km and 2500 m respectively. The maximum depth was 4200 m. During each cruise an international standard census method was adopted (refer Tasker et al. 1984).

Study area and methods

The study area, methods and terms have been described in detail elsewhere (Wood 1989, 1990). Briefly, censuses were conducted from a 14 m converted trawler which was chartered regularly to view seabirds. Fish remains and pieces of animal fat were chopped on board and cast astern to attract the birds.

Watches were continuous from the stern deck (eye height 2.6 m above water). Albatrosses within a radius of c. 300 m were counted during 360° scans at about eight-minute intervals. Identification was aided with 8 x 40 binoculars. When unusual albatrosses were sighted the *Sandra K* was temporarily stopped to allow accurate identification. Colour transparencies and field notes were taken if possible because the validity of extralimital records is important (Bourne 1967). Data obtained at sea were regrouped and analysed as the highest number of individuals of each species seen together during successive 20-minute periods.

Statistical analyses are based on 20-minute census data. Zonal abundance is based only on results of cruises in which the particular species was observed. During the two-year period I was absent from cruises in September 1986 and February 1987 but the total number of individuals observed during these two cruises was kindly supplied by D.H. Fischer (in litt.).

Seasons are defined in Blakers et al. (1984) and shown in Table 3. Marine habitats or zones are classified as inshore, offshore, neritic and pelagic. Inshore refers to the area within 8 km of the mainland, offshore is eastwards to the shelf break (but not inshore). Neritic includes inshore and offshore. Pelagic is arbitrarily subdivided into upper slope (depth 200-1500 m) and lower slope (depth 1500-4200 m). Because the number of 20-minute censuses over the lower slope on cruise dates varied from zero (July and September 1985, July 1986) to 10 (June 1985), the overall zonal abundance calculated for this region should be treated with caution.

Results

Overall, 4710 individuals were recorded (Table 1), 4696 by the author and 14 by D.H. Fischer in September 1986. No albatrosses were seen in February 1987. Black-browed and Yellow-nosed Albatrosses *Diomedea melanophrys* and *Diomedea chlororhynchos* comprised 88% of all individuals. Wandering and Shy Albatrosses *Diomedea exulans* and *Diomedea cauta* were present in almost equal proportions (c. 6% each). Individuals of four unusual species accounted for less than 1% of the total (Tables 1 and 2). In the remaining statistical analyses, 20-minute census data obtained during the 23 cruises attended by the author are used exclusively. Figure 1 and Table 3 show monthly and seasonal abundances respectively. The common species were clearly most abundant in winter and spring with less than 1% of individuals present in summer. Figure 2 and Table 4 indicate the marine zones in which the common albatrosses were censused. The four common species occurred across all depth zones but were dominantly pelagic, Wandering and Shy slightly more so than Black-browed and Yellow-nosed. The rates of encounter of Black-browed, Yellow-nosed and Shy peaked over the upper slope (Table 4) whereas the rate of encounter of Wandering Albatrosses peaked over the lower slope. Differences in abundances between the various depth zones were also evident (χ^2 tests, Table 4), more significantly for Wandering, Black-browed and Yellow-nosed than for Shy.

Monthly variations in zonal abundance from April to November are shown in Figure 3. Only Black-browed and Yellow-nosed were more pelagic in the later months of each year than in the earlier months. Indeed, if monthly data for both years are combined, the increase in pelagic abundance of these two species was positively correlated with progressing month of year (Spearman Rank Correlation, one-tailed test: Black-browed r_s=0.64, n=8, p=0.05; Yellow-nosed r_s= 0.71, n=7, p=0.05). The composition of multispecific flocks and recording frequencies of various numbers of individuals censused in 20-minute periods appear in Figures 4 and 5 respectively.

Table 1. Relative abundance of common albatross species observed off Wollongong between April 1985 and March 1987 (25 cruises).

Species	*Wandering*	*Black-browed*	*Yellow-nosed*	*Shy*	*Unusual[a] albatrosses*	*Total*
No. of individuals censused	295	2550	1589	266	10	4710
Per cent	6.3	54.1	33.7	5.7	0.2	

[a]Includes Royal, Buller's, Grey-headed and Light-mantled Sooty Albatrosses (refer Table 2).

Table 2. Details of 10 irregular albatrosses observed off Wollongong between April 1985 and March 1987.

Species	*No. of Individuals*	*Time (E.S.T)*	*Date*	*Distance from shore (km)*	*Depth (m)*	*Beaufort wind speed and direction*		*Surface water temp. (°C)*	*No. of 35mm colour slides*	*Field Notes*
Northern Royal Albatross *D. epomophora sandfordi*	1	1130-1145	26 July 1986	67	3000	Force 3	SW	17	8	yes
Buller's Albatross		0906-0914	3 Nov. 1985	48	1800	Force 2	S	19	nil	no
D. bulleri	1	and								
		1226-1424	3 Nov. 1985	37-12		Force 3	SE	18-17	11	yes
	1	0741-0949	23 Nov. 1985	41-78	400-2600	Force 4	S	20-25	9	no
	max. 3	0705-1330	28 Nov. 1986	22-45	150-1300	Force 2-3	SW	16.5-17	32[a]	yes
Grey-headed Albatross *D. chrysostoma*	2	1005	26 May 1985	55	1200	Force 3	SW	21	40[a]	no
Light-mantled Sooty Albatross	1	1023-1027	21 Sept. 1985	46	1140	Force 6	S	19.5	nil	no
Phoebetria palpebrata	1	1130-1136	27 Oct. 1985	48	700	Force 5	SE	19	6	no

[a]Colour transparencies are held by National Photographic Index of Australian Wildlife (*D. bulleri* No. 1061, *D. chrysostoma* Nos. 1136, 1137 and 1138).

Table 3. Distribution of common albatross species off Wollongong in each season between April 1985 and March 1987 (23 cruises).

	Summer (DJF)				*Autumn (MAM)*				*Winter (JJA)*				*Spring (SON)*			
	n	*c*	$\frac{n}{c}$	*P(%)*	*n*	*c*	$\frac{n}{c}$	*P(%)*	*n*	*c*	$\frac{n}{c}$	*P(%)*	*n*	*c*	$\frac{n}{c}$	*P(%)*
Wandering (n=290)	2	145	0.01	<1	40	170	0.24	13	98	175	0.56	32	150	158	0.95	54
Black-browed (n=2543)	13	145	0.09	<1	362	170	2.13	14	1277	175	7.3	48	891	158	5.64	37
Yellow-nosed (n=1587)	0	145	0	0	226	170	1.33	14	1179	175	6.74	73	182	158	1.15	13
Shy (n=266)	1	145	0.01	<1	10	170	0.06	4	238	175	1.36	88	17	158	0.1	7

n=No. of individuals. c=No. of 20 minute census periods. P=Percentage of individuals per census period in each season.

Table 4. Distribution of common albatross species in marine zones off Wollongong between April 1985 and March 1987 (23 cruises). Symbols as for Table 3. Parenthesis indicates highest abundance for each species.

		Neritic		*Pelagic*	
	Depth (m)	*Inshore 0-50*	*Offshore 50-200*	*Upper Slope 200-1500*	*Lower Slope 1500-4200*
Wandering	n	18	82	108	82
(n=290)	c	54	183	145	94
	n/c	0.33	0.45	0.74	(0.87)
			χ^2 between zones=30.4, df=3, $p<0.001$		
Black-browed	n	197	972	887	487
(n=2543)	c	58	188	153	103
	n/c	3.4	5.2	(5.8)	4.7
			χ^2 between zones=51, df=3, $p<0.001$		
Yellow-nosed	n	102	625	585	275
(n=1587)	c	40	137	113	73
	n/c	2.6	4.6	(5.2)	3.8
			χ^2 between zones=54, df=3, $p<0.001$		
Shy	n	18	97	99	52
(n=266)	c	35	117	96	56
	n/c	0.51	0.83	(1.03)	0.93
			χ^2 between zones=8.6, df=3, $p<0.05$		

Table 5. Results of product moment correlation analysis of the abundance of Black-browed and Yellow-nosed Albatrosses vs sea-surface and average ambient air temperature (zero counts excluded).

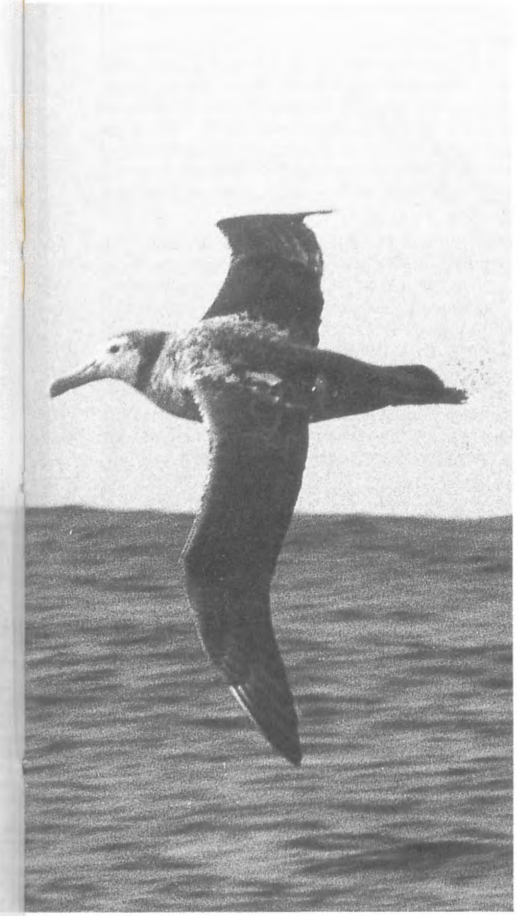
Albatross species	*Environment*	*Test Statistics*			
		r	*df*	*t*	*p*
Black-browed	Sea surface	−0.51	14	2.2	0.05
Yellow-nosed	Sea surface	−0.69	9	2.8	0.05
Black-browed	Ambient air	−0.56	14	2.5	0.05
Yellow-nosed	Ambient air	−0.74	9	3.3	0.01

Table 6. Longitudinal abundance of albatross spp. in the central Tasman Sea, presented as the average maximum number of birds in 10-minute observation periods per traverse.

Grid longitude (°E)	*150*	*151*	*152*	*153*	*154*	*155*	*156*	*157*	*158*	*159*	*160*	*161*	*162*
No. of times grid was transversed	*1*	*3*	*3*	*3*	*3*	*3*	*2*	*1*	*4*	*4*	*3*	*3*	*4*
Wandering (n=292)	8	3.7	4	3	2	0.7	0.5	7	7.8	6.8	7	3	1.8
Black-browed (n=109)	7	3	2	1	0.3	0	0.5	5	2.8	2.3	1	0	0.3
Yellow-nosed (n=8)	0	0	1	0	0	0	0	0	0	0	0.3	0	0
Shy (n=3)	0	0	0	0	0	0	0	0	0.3	0.3	0	0	0
Grey-headed (n=1)	0	0.3	0	0	0	0	0	0	0	0	0	0	0

Grid longitude (°E)	*163*	*164*	*165*	*166*	*167*	*168*	*169*	*170*	*171*	*172*
No. of times grid was transversed	*2*	*2*	*5*	*4*	*4*	*2*	*4*	*2*	*3*	*4*
Wandering (n=292)	2.5	6.5	7	6.8	3.8	6	4.8	3	1.7	1
Black-browed (n=109)	0.5	1.5	0.8	2	1.3	2	1.5	1.5	4.3	1.5
Yellow-nosed (n=8)	0	0.5	0	0	0	0.5	0.3	0	0	0.3
Shy (n=3)	0	0	0	0	0	0	0	0	0	0.3
Grey-headed (n=1)	0	0	0	0	0	0	0	0	0	0

Data obtained by N.G. Cheshire during seven Tasman crossings: Brisbane to North Cape (N.Z.) May 1979, North Cape to Sydney May 1979 and July 1980, Sydney to North Cape July 1980 and Sept 1989, North Cape to Melbourne July 1979 and North Cape to Hobart Sept 1978. One-degree grids defined according to Blakers et al. (1984).



Immature Wandering Albatross *Diomedea exulans*, Port MacDonnell, S.A., 20 September 1981.
Plate 31 Photo: P. Klapste

Wandering Albatross *Diomedea exulans*

Wandering Albatrosses were censused in small numbers (fewer than six) from April to November. More than 50% were present in spring and less than 1% in summer. All plumage stages (Harrison 1983) were observed. Overall, a majority of birds was counted beyond the shelf-break (Table 4). This finding concurs with the results of other studies in the Tasman Sea (Shuntov 1974), around the Crozet Islands (Weimerskirch et al. 1986) and off Argentina (Jehl 1974). Birds seen feeding in the pelagic zone scavenged mostly on offal discarded from the *Sandra K* and commercial trawlers whereas birds feeding over the shelf consumed a much higher proportion of dead or moribund cuttlefish *Sepia apama* (Cover Plate 28). This cephalopod becomes superabundant in the inshore zone each winter off Bellambi, c. 6 km north of Wollongong, allowing many Wanderers to be banded after gorging its flesh (references in Sudbury et al. 1985). On 15 August 1954, Gibson (1955) counted more than 300 albatrosses (mostly *D. exulans*) from a beach near Bellambi.

Northern Royal Albatross
Diomedea epomophora sanfordi

On 26 July 1986, one individual was seen intermittently for c. 15 minutes. It made three passes within 40 m. The bill was fleshy pink with light horn nails and a distinct black line along the cutting edge of the mandibles. The upperwings were black. Their proximal leading edges appeared brilliant white when the bird was gliding head-on in direct sunlight. Serventy et al. (1971) noted that some *D.e. sanfordi* show this feature in 'humeral flexure'. A thin black margin on the underwing from the tip to the carpal joint where it widens is diagnostic of this subspecies (Harrison 1983, Harper & Kinsky 1978, Marchant & Higgins, 1990). I did not see this character distinctly at sea but it was obvious in some of the colour transparencies. The tail showed very small black tips on the inner rectrices in dorsal view and much larger black tips on the outer rectrices when viewed ventrally. The dorsum appeared to be pure white without vermiculation. This tail-dorsum plumage combination is characteristic of a late-state adult with worn vermiculations on the back (J.C. Stahl in litt.). A very cold southerly air stream over south-eastern Australia during the two previous days may be significant. Since its first sighting at Bellambi, New South Wales in 1960 (Gibson & Sefton 1962), this species is being seen with increasing frequency off south-eastern Australia (Lindsey 1986, van Tets & Fullagar 1984). Most sightings are over pelagic waters (Blakers et al. 1984, Barton 1979a).

Black-browed Albatross *Diomedea melanophrys*

Black-browed Albatrosses were numerically dominant, accounting for 54% of all individuals. Numbers increased from 14% in autumn to a peak of 48% in winter then tailed off to 37% in spring (Table 3). This seasonal abundance pattern concurs with that determined by Milledge (1977). Birds which remained in the study area in spring were probably non-breeders as most breeders return to the colonies in September or October (Serventy et al. 1971, Marchant & Higgins 1990). Although substantial numbers were counted in all marine habitats, a preference was shown for the upper slope (Table 4 and Figure 3). Barton (1979a) found that the species preferred waters >50 fathoms deep off southern New South Wales. Most 20-minute censuses were of one to five individuals with groups of thirty birds recorded only twice (Figure 5).

I did not separate birds by age or race but adults and young of two subspecies were present. The proportion of birds from Campbell Island (race *D.m. impavida*) was clearly highest in April and May each year with numbers noticeably declining in winter and spring. Conversely, the proportion of young *D.m. melanophrys* appeared to remain more constant. I assessed that approximately 10% of all Black-browed Albatrosses were *D.m. impavida* (adults or sub-adults), 50-60% were immature/sub-adult *D.m. melanophrys* and the remainder were adult *D.m. melanophrys*. On 20 May 1979, Barton (1979b) sighted a much higher proportion of *D.m. impavida* in the scavenging albatross population off Eden. He observed some 1030 *Diomedea* individuals near five commercial trawlers (depth 200-225 fathoms), of which 50% were *D.m. melanophrys* and 40% were *D.m. impavida*. Off south-east Tasmania, Blaber (1986) reported that almost all of 240 Black-browed observed were *D.m. impavida*. These data suggest that the proportion of *D.m. impavida* in the *D. melanophrys* population increases with increasing latitude off south-eastern Australia.

Buller's Albatross *Diomedea bulleri*

3 November 1985. Colour transparencies taken of the first Buller's Albatross allowed detailed examination of the bill. It was rich smoke-grey with black nails and a thick black junction of the culminicorn and latericorn close to the head. There was a bright yellow tip to the maxillary unguis and a tinge of yellow at the base of the ramicorn. Such a bill suggests a first-year immature (Serventy et al. 1971, Harrison 1983), possibly sub-species *D.b. bulleri* from Snares Is. (Marchant & Higgins 1990). The neck was laterally smoke-grey with a lighter shaded nape. The cap was white. This mollymawk was in view initially for about eight minutes then reappeared at 1226 h. It avidly followed and foraged until 1424 h.

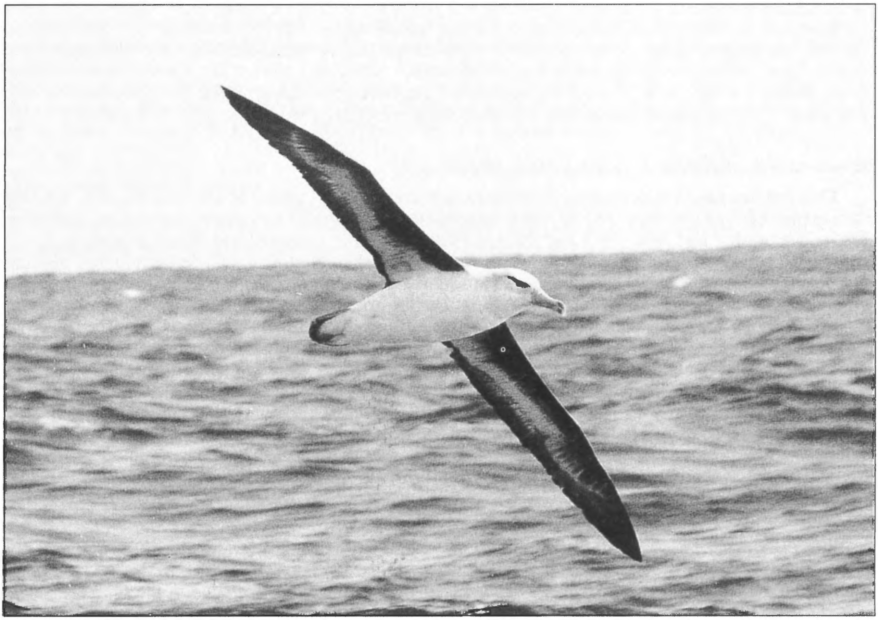
23 November 1985. A bird identical to that described above accompanied the vessel regularly between 0741 h and 0945 h. It too foraged with other albatrosses (25+) and *Puffinus* shearwaters (500+).

28 June 1986. Between 0705 h and 1330 h, one bird was seen regularly and two were observed occasionally. At 1015 h, three individuals were seen together. These three birds were adults. Their bills were laterally black with broad yellow stripes along the culmen and lower edges of the mandible. Their foreheads were white but the colour of their cheeks, chins and napes varied from faint smoke-grey to charcoal-grey.

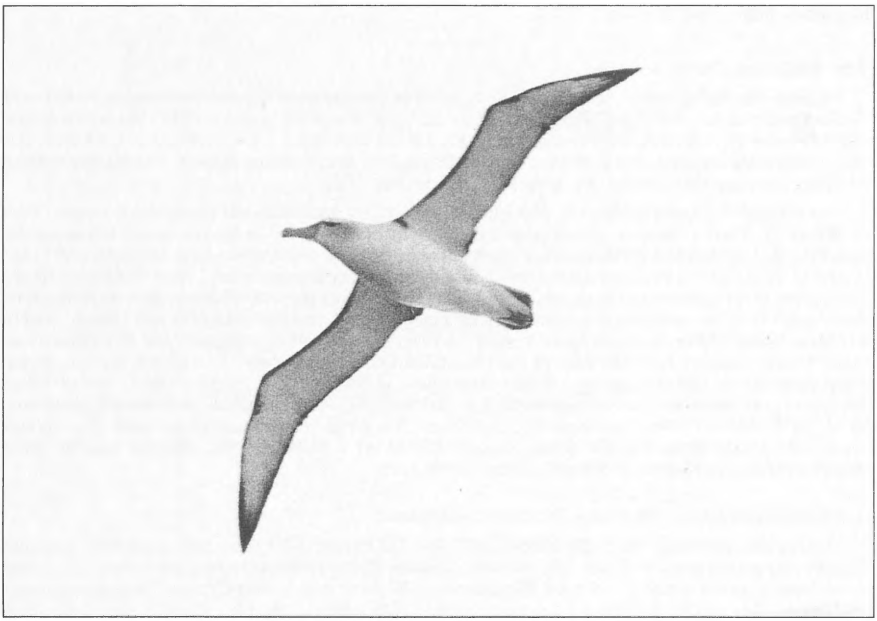
I found difficulty in subspecific identification of these adults even after close inspection of the colour transparencies taken at sea (Table 2). Robertson (1985) states that adult Southern Buller's *D.b. bulleri* have a white forehead with cheek, chin, nape and back light grey. In Northern Buller's *D.b. platei* the forehead is 'light silver-grey; back, cheek, chin and nape (are) darker silver-grey'. Marchant & Higgins (1990) give similar descriptions for adults of each subspecies but mention further that tones of grey on the head and neck vary in appearance with light intensity and feather wear. One of the Southern Buller's shown in *Reader's Digest Complete Book of New Zealand Birds* (1984, p.64) appears to have a silver-grey forehead whereas one of the Northern Buller's shown in Nelson (1980, p.39) seems to have a white forehead. One adult observed off Wollongong with a white forehead and a smoke-grey cheek, chin and nape [similar to that shown by Lindsey (1986), p.79] was almost certainly a Southern Buller's Albatross but the others, such as that shown in Plate 30, were of questionable subspecific identity. In south-eastern Australia, Barton (1979a) and Blaber (1986) have reported flocks of seven and 20+ birds respectively. Rogers (1975, 1977) and Rogers & Lindsey (1978) have reported occasional sightings.

Grey-headed Albatross *Diomedea chrysostoma*

On 26 May 1985, two first-year Grey-headed Albatrosses were enticed to within 15 m of the boat by tossing offal. In plumage they were identical. The head, neck and mantle, including the cap, were a rich leaden grey. The bill was dull black with jet-black nails and a yellow-tinged culminicorn. This description is similar to that given by Marchant & Higgins (1990) for birds about two years old. Two Black-browed Albatrosses were also present, one of which was an immature. It too had a bill with



Black-browed Albatross *Diomedea melanophrys*, Port MacDonnell, S.A., 20 September 1981.
Plate 32 Photo: P. Klapste



Shy Albatross *Diomedea cauta*, Port MacDonnell, S.A., 20 September 1981.
Plate 33 Photo: P. Klapste

black ungues but its lateral plates were horn-brown giving the bill a contrasting 'black-tipped appearance' (Serventy et al. 1971). Both Grey-headed Albatrosses dived (c. 1 m) to scavenge for offal whereas the two Black-browed individuals pecked it from the surface. Weimerskirch et al. (1985) considered that *D. chrysostoma* disperses into pelagic waters after breeding and that immatures 'often forage in areas different from adults'. Previously, about ten birds have been sighted at sea off the coast of N.S.W. and about five have been found beach-washed (Blakers et al. 1984, A.K. Morris in litt.).

Yellow-nosed Albatross *Diomedea chlororhynchos*

This species was ranked second most abundant, comprising c. 34% of all birds counted. During many cruises it was outnumbered by Black-browed by more than 1.3 to 1 (max. 2.3 to 1 in September 1985). Yet in May and June 1985 and August 1986, it actually outnumbered Black-browed by 1.1, 2 and 2.1 to 1 respectively. Yellow-nosed Albatrosses arrived in autumn (14%) with numbers peaking sharply in winter (73%) and falling again in spring (13%). By comparison, Black-browed were more evenly distributed in winter and spring (Table 3). During autumn and winter combined, Black-browed were 17% more abundant than Yellow-nosed. The bulk of the Yellow-nosed population appeared to leave the study area in early spring, whereas a greater proportion of Black-browed remained until November. This seasonal abundance pattern is also reflected in the composition of albatross flocks (Figure 4). In spring, summer and autumn combined Yellow-nosed comprised only 21% of individuals compared with 43 to 46% in winter. Milledge (1977) recorded a similar relative abundance in nearby offshore waters throughout 1973 but considered his counts 'apparently abnormal'. My data suggest that Milledge's (1977) counts off Sydney were normal and that this species is more common off central New South Wales than previously reported (Gibson 1967, 1977, Morris et al. 1981, Blakers et al. 1984). One large mixed flock of 500+ Yellow-nosed and Black-browed Albatrosses was sighted c. 19 km off Newcastle in June 1982 (Lindsey 1984).

The present data suggest that this mollymawk is numerous in all marine zones off Wollongong. It too showed a slight preference for the upper slope (Table 4, Figures 2 and 3). Weimerskirch et al. (1986) found that Yellow-nosed Albatrosses showed a similar zonal preference in the Crozet Islands region during the breeding season. Cox (1976) however, and Barton (1979a) assessed that a high proportion of Yellow-nosed was confined to neritic waters off South Australia and Eden respectively. Adults and sub-adults were not censused separately but immature birds were often observed. Many 360° scans produced about half as many sub-adults as adults. All individuals but one belonged to the subspecies *D.c. bassi*, which is endemic to islands in the southern Indian Ocean (Brooke et al. 1980). The sole adult *D.c. chlororhynchos*, from islands in the South Atlantic Ocean, was present during the cruise in August 1986 (Reid & Carter 1988).

Shy Albatross *Diomedea cauta*

Almost the entire 'cauta' population (88% of birds counted) arrived and departed in winter with distinct peaks in July 1985 and 1986. The species remained abundant in August 1985 but not in August 1986 (Figure 1). This disparity is masked in Figure 4 which shows, for both years combined, that Shy Albatrosses comprised 11% of *Diomedea* individuals in flocks during August. The highest number of birds seen together around the vessel was ten in July 1985.

As with other *Diomedea* species, Shy Albatrosses foraged predominantly over pelagic waters (Table 4, Figure 3). Their affinity for it was greater than that of Black-browed or Yellow-nosed, but somewhat less than that of Wandering Albatrosses. Such zonal preference may explain why Milledge (1977) saw a total of only eight individuals during his 12-month study over the continental shelf. Although Barton (1979a) made no mention of the depths at which the species was present off Eden, Morris et al. (1981) considered it to be moderately common in 'continental shelf (mainly offshore) and pelagic waters' off New South Wales. Brothers (pers. comm. in Blakers et al. 1984) suggested that Shy Albatrosses were 'usually inshore from the edge of the (Australian) continental shelf'. Elsewhere, the species has been reported as scarce in pelagic waters (references in Marchant & Higgins 1990). About 5% of birds had grey heads and necks, suggesting that various age classes and races were present (Johnstone et al. 1975, Barton 1979a, Harrison 1983). At least five birds were identified as adult *D.c. salvini*. Most individuals foraged in the distant wake (100-200 m) with Wanderers, whereas smaller (more manoeuvrable) mollymawks foraged closer to the stern.

Light-mantled Sooty Albatross *Phoebetria palpebrata*

Individuals observed on 21 September 1985 and 27 October 1985 were both identified as adults. The former was viewed for about four minutes, initially flying towards the boat (to within 25 m) then away from it. I concurrently censused 23 albatrosses, 37 shearwaters, four Crested Terns *Sterna bergii* and seven other petrels, including a Southern Fulmar *Fulmarus glacialoides*. Clear views of a uniform whitish-coloured mantle and lower back allowed specific identification. As for the Southern Fulmar, this albatross may have been forced into the study area by prolonged adverse weather in the western Tasman Sea (refer Wood 1990). The second bird was seen for about six minutes, mainly in flight but also while settled on the water. On a number of occasions it approached to within 25 m, allowing colour transparancies to be taken. Its plumage differed from the former individual in that its body, dorsum and crown were much whiter. The primaries, primary coverts, underwing and tail were dark grey; the secondary coverts were light grey. I was unable to determine if the mandibular sulcus was light or dark-coloured in either bird. Weather during the preceding week was normal. There are about 20 records of this species in Australia (Lindsey 1986) of which five were between 1977 and 1981 (Blakers et al. 1984). Van Tets & Fullagar (1984) consider it a regular visitor.

Temperature preferences

The distribution and abundance of Procellariiformes is influenced by sea or air temperature. Certain *Diomedea* species exhibited a preference for particular ranges of sea surface temperatures off Argentina (Rumboll & Jehl 1977), Chile (Jehl 1973) and in the Southern Ocean (Szijj 1967). In the north-east Pacific Ocean, Sanger (1970) concluded that Black-footed Albatrosses *D. nigripes* favoured relatively high water and air temperatures. In the study area, albatrosses were most abundant in months when sea and air temperatures were lowest. Because 88% of all individuals were Black-browed or Yellow-nosed Albatrosses, the abundance of these two species was tested for correlation with temperature. Ten-year mean monthly sea surface temperature at 34°30'S, 151°30'E (Edwards 1979) and 30-year mean monthly average air temperature at 34°26'S, 150°54'E (Boyd 1978) were plotted against abundance (Figure 6). Average air temperature is daily maximum plus daily minimum divided by two. In conducting the analysis, the mean number of individuals per 20-minute census was transformed to control variance (square root transformation, Zar 1984, p.285). A significant negative correlation was found between the abundance of both species and both temperatures ($p=0.001$, Figure 6). Multi-year mean temperatures were used because real-time sea temperatures were not available. The model therefore assumes that multi-year mean temperatures are statistically representative of values which would have been measured *in situ*.

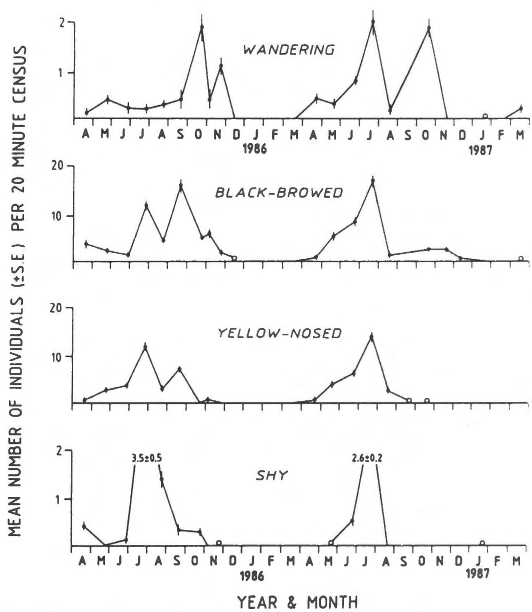


Figure 1. Seasonal abundance of common albatross species off Wollongong between April 1985 and March 1987 (23 cruises).

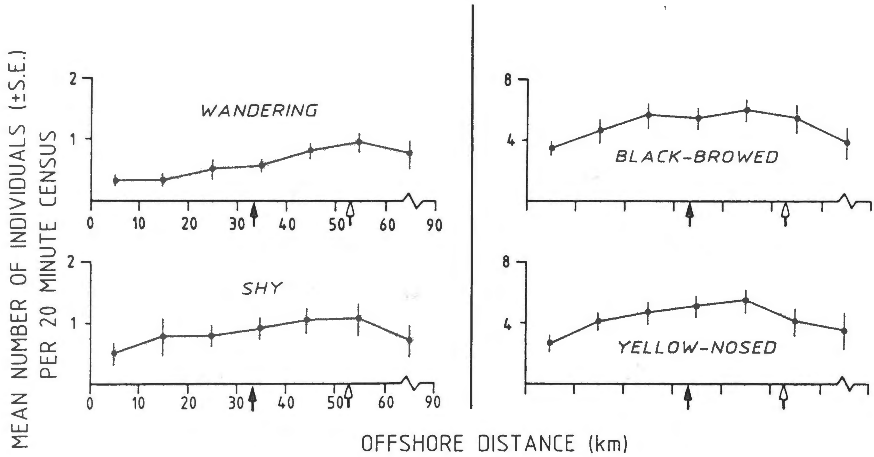


Figure 2. **Zonal distribution of common albatross species off Wollongong between April 1985 and March 1987 (23 cruises). Closed and open arrows indicate approximate positions of 200 m and 1500 m isobaths respectively.**

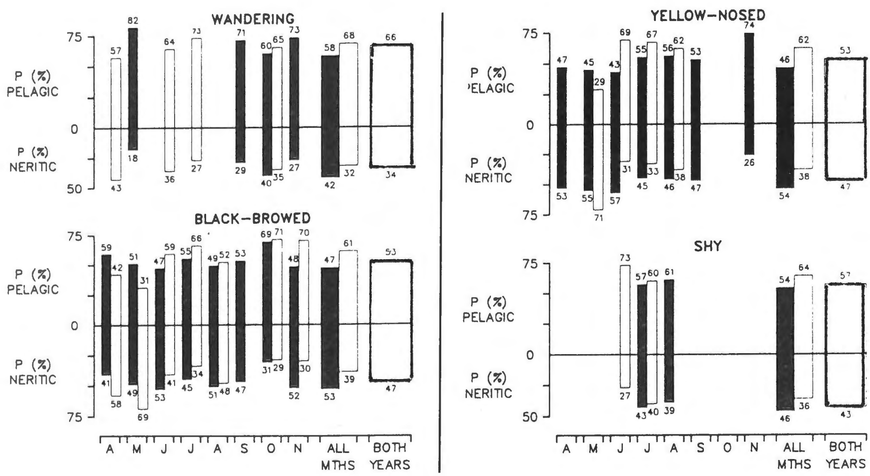


Figure 3. **Monthly distribution of 4493 albatross individuals in neritic and pelagic zones off Wollongong between April and November of 1985 and 1986. P is percentage of individuals per 20-minute census calculated as in Tables 3 and 4. Monthly values are listed left and right respectively. Data are omitted for months in which fewer than 10 individuals were censused.**

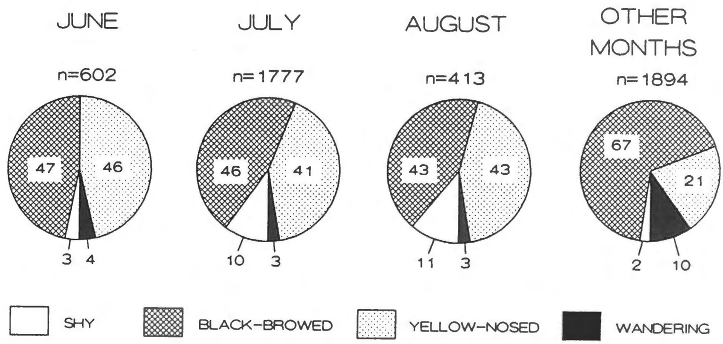


Figure 4. Composition of albatross flocks off Wollongong between April 1985 and March 1987 (23 cruises). Percentages shown are cumulative over the 24 month period.

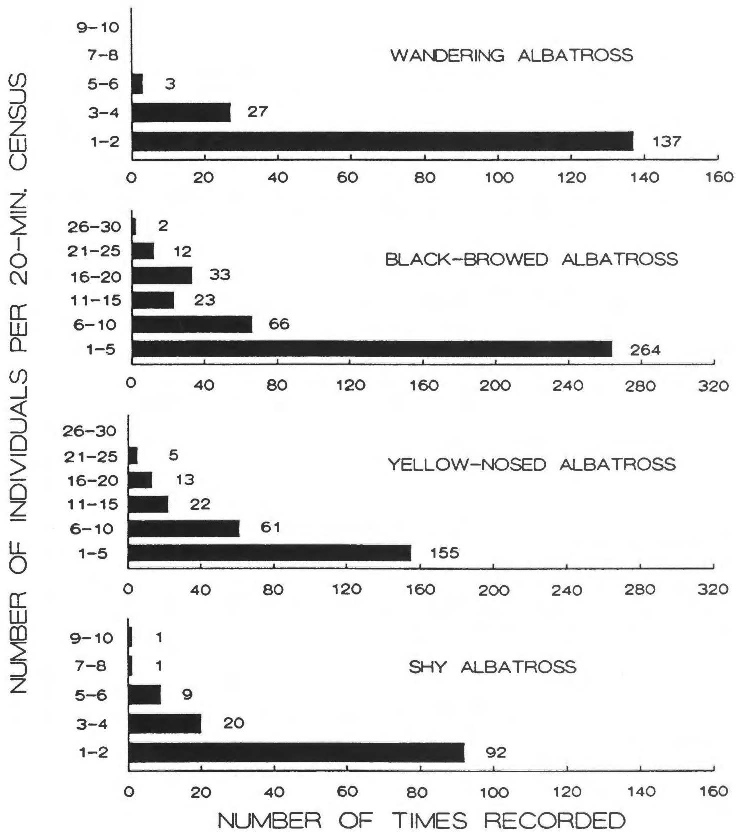


Figure 5. Frequency at which various numbers of common albatrosses were counted off Wollongong between April 1985 and March 1987 (23 cruises).

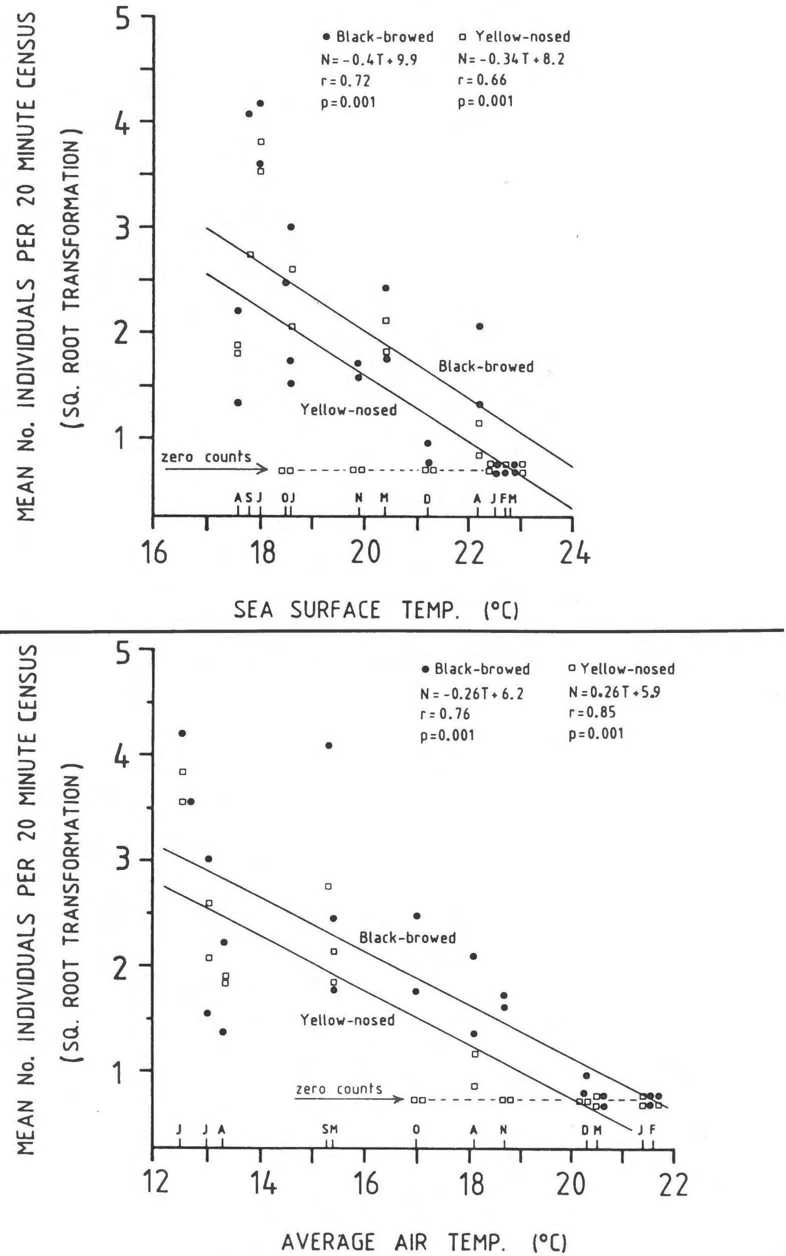


Figure 6. **Abundance of Black-browed and Yellow-nosed Albatrosses vs 10-year mean sea surface temperature and 30-year mean average ambient air temperature. Abscissa values are plotted after square-root transformation. The increase in abundance of both species is closely correlated with a decrease in sea and air temperature.**

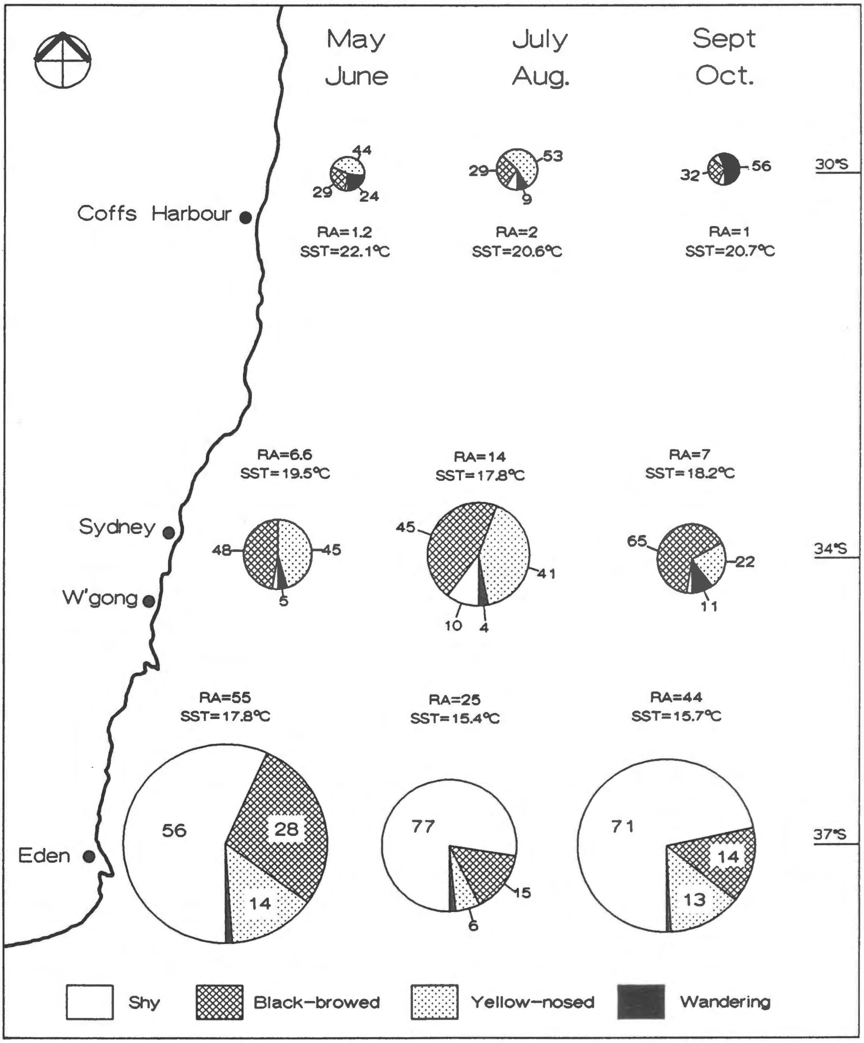


Figure 7. **A preliminary assessment of the normal abundance of common albatross species over the N.S.W. continental shelf betwen May and October. The relative abundance (RA) of all species combined off Coffs Harbour in September-October is arbitarily set at unity. Species abundance is in per cent. Sea surface temperatures (SST) are 10-year mean averages at 200 m depth (from Edwards 1979). This assessment is based on data presented by Holmes (1977), Milledge (1977), Barton (1979a) and the present study.**

Black-browed and Yellow-nosed Albatrosses were present when sea-surface temperatures were in the range 22.2 °C (April) to 17.6 °C (August). Yellow-nosed were recently encountered in a similar range of surface temperatures (21.7-19.3 °C) in the eastern Indian Ocean in October (Dunlop et al. 1988). Differences in the responses of each species to temperature were noted. Whereas Black-browed were present over a wide range of air temperatures (20.3-12.5 °C, December-July), Yellow-nosed were present in a more restricted range (18.1-12.5 °C, April-July). Moreover, preferences for sea and air temperatures were more clear-cut for Black-browed than for Yellow-nosed Albatrosses. The latter species was present in late autumn yet absent in late spring when temperatures were similar. For this reason, zero counts were included in the correlation analyses of Figure 6. If zero counts are excluded, a significant correlation still exists for both species at both temperatures, but with a lower probability (Table 5).

Significant correlation does not imply causal relationship. High albatross abundance and low sea temperatures may coincide by chance. Alternatively, these two variables may each be more closely related to a third independent variable. The increase in albatross abundance in winter is more likely to be related to the quantity or type of food which is produced at lower sea temperatures.

Discussion

Biases

The census method has unavoidable biases (Tasker et al. 1984), some of which have been exaggerated by the tossing of offal (Griffiths 1982). Many birds were probably recounted because albatrosses are well known to be avid boat-followers, sometimes for days (Harper 1987). In the Southern Ocean, Griffiths (1982) observed Wandering, Shy and Black-browed Albatrosses following a research vessel for averages of 80.5, 34 and 17.8 minutes respectively. Off southern Africa, Ryan & Moloney (1988) determined (theoretically) that Shy and Black-browed Albatrosses were attracted to trawling operations from average radii of 3.6 and 4.6 km respectively. Attraction to the *Sandra K* could also have differed temporally.

Moreover, albatross distribution along the transects off Wollongong may have been influenced by scale-dependent factors (Hunt & Schneider 1987), resulting in patchiness and masking of the overall abundance pattern off central New South Wales. On the other hand, biases which are introduced by discarding fluctuating quantities of offal, conducting one-way transects or using a number of observers have been minimised. Censuses were conducted when meteorological conditions at sea were tolerable, certainly not when they were so severe as to have markedly affected the results. Overall, data obtained from this study are considered comparable with those of other seabird surveys in which similar methods were adopted.

Latitudinal variation in abundance off New South Wales

Some assessments of the abundance of albatross species off the coast of New South Wales have been based on data from beach patrols and sea watches from shore. Few regular cruises have been conducted in neritic waters and even fewer beyond the shelf-break. By sampling in the pelagic and neritic zones off Wollongong Yellow-nosed and unusual albatrosses were found to be more numerous than previously reported. Shy Albatrosses were slightly more abundant (refer Milledge 1977).

If the present data are analysed in conjunction with those of earlier shipboard surveys, albatross abundance over the continental shelf off southern, central and northern N.S.W. can be assessed. Barton (1979a and pers. comm.) tallied the number of individuals each month by cumulatively adding end-of-day estimates. The average number of sightings per hour was calculated by dividing by the number of hours of observation in each month (Barton 1979a, Figure 4). Milledge (1977) calculated mean numbers of birds per five-hour observation period in each month (less 10% to correct for repeated sightings). Holmes (1977, Table 1 and in litt.) presented the daily highest number of individuals in each month. Notwithstanding that each of the above surveys employed different census methods, all of them attracted albatrosses in common with the present study, by tossing offal or conducting fishing operations. A valid but preliminary assessment of latitudinal abundance off New South Wales ought therefore to be possible.

In making the assessment, three bi-monthly periods were considered from May to October. Abnormal influxes such as that of Shy Albatrosses off Eden in October 1976 [Barton (1979a) Figure 4 and pers. comm.] were smoothed to emphasise normality. I then estimated the daily highest number of individuals present off Wollongong in each bi-monthly period (boat-following excluded). These totals were compared with D.H. Fischer's unpublished data (acquired while onboard similar *Sandra K* cruises) and Milledge's (1977) neritic data. Adjustments were made where large discrepancies existed. The resulting daily highest totals off central New South Wales were between 20 and 25 times ($\bar{x}$=23, n=12) the mean number of individuals per 20-minute census. Corresponding daily highest totals off Eden were calculated similarly. Correction factors which were applied to Barton's (1979a) mean number of individuals per hour ranged between 14 and 20 ($\bar{x}$=16, n=12). This technique provided a direct comparison with Holmes' (1977) results, while maintaining the relative abundance of each species at each latitude.

In the period May to October, the overall albatross abundance ratio (all species combined) is assessed to be about 30:7:1 at latitudes 37°S, 34°S and 30°S respectively (Figure 7). Annually it is about 50:10:1. The most common species at 30°S is Yellow-nosed; at 37°S Shy is commonest and at 34°S Black-browed and Yellow-nosed are most common. Morris et al. (1981) and Lindsey (1986) considered that numbers of Yellow-nosed Albatrosses along the coast showed no discernible variation with latitude. My assessment indicates that the overall abundance ratio of *D. chlororhynchos* is about 9:6:1 at 37°S, 34°S and 30°S respectively. Because Black-browed and Yellow-nosed were counted in reasonable numbers in all studies, their latitudinal abundance is probably more accurate than that of Shy and Wandering.

Abundance by depth in the Tasman Sea

Affinities of Diomedeidae for shelf and slope domains have not been investigated previously in Australia. Four species were numerous over both domains off Wollongong. Black-browed, Yellow-nosed and Shy Albatrosses were most abundant over the upper slope whereas Wandering Albatrosses were most abundant over the lower slope (Table 4). Significant differences were evident in the comparative abundances of the four species in the four defined depth zones. N.G. Cheshire (in litt.) has kindly supplied additional data on albatross abundance in the Tasman Sea within the sector: North Cape, New Zealand (34.3°S, 173°E) to Brisbane, North Cape to Hobart (Table 6). Of 413 birds censused in seven cruises, Wandering comprised 71%, Black-browed 26%, Yellow-nosed 2% and Shy 1%. Wandering and Black-browed were present at all depths but the former species outnumbered the latter in 20 of 23 grid squares traversed. The average abundance ratio of Wandering to Black-browed was 2.7 to 1. Cheshire's data are consistent with the results of zonal abundance determined in the present study. In combination, the two data sets suggest that the lower continental slope off New

South Wales is a transitional zone in which the abundance of the four regular species changes noticeably. By comparison with abundance over the shelf, Wanderer numbers increase and are greatest over the open ocean whereas Black-browed numbers decrease and are lowest at sea. Yellow-nosed and Shy numbers decrease so dramatically that they are virtually nomads of the ocean. Barton (1979a) and Summerhayes (1969) published results which concur with this conclusion. Off southern New South Wales, Barton found that Wandering and Black-browed Albatrosses were more abundant over the outer shelf (depth 100-500 m) than closer to shore. Yellow-nosed Albatrosses were clearly most abundant over the inner shelf (ratio 12:1, at depths <100 m: depths >100 m). In the north Tasman, Summerhayes (1969) observed a total of 113 albatrosses (100 Wandering and 13 Black-browed) at various depths during a 30-day cruise from Noumea to Auckland via Brisbane. Gibson (1967) also studied the distribution of albatrosses around the Australian coast and in the central Tasman Sea. No distinction was made between shelf, slope or ocean domains but Gibson's results appear to agree with the above conclusion. Wanderers were present throughout the Tasman, Black-browed were 'probably most numerous' around the coast and Yellow-nosed were 'by far the commonest species on the Indian Ocean side', extending 'in diminishing numbers to the Tasman Sea'.

Published abundance data from the south Tasman Sea are few but the more southerly composition of *Diomedea* species appears to be different from that to the north. Over the continental shelf off south-east Tasmania, Carter (1981) found that Shy (74%) was by far the most abundant species followed by Royal (13%), Black-browed (9%) and Wandering (2%). Over nearby deeper water (1500-3400 m), Blaber (1986) reported that Shy, Royal and Yellow-nosed were virtually absent but Black-browed outnumbered Wandering by about 1.4 to 1. Several of the above studies fail to address temporal variations in abundance. However, it seems likely that Wandering is generally more numerous than Black-browed in the central and northern Tasman Sea but not in the southern Tasman. Shuntov (1974) investigated albatross abundance in the Australasian sector of the Southern Ocean and reached similar conclusions (refer Table 1, p.32 and Table 5, p.53).

Latitudinal movement along the New South Wales Coast

Off New South Wales, Barton (1979a) suggested that most Yellow-nosed Albatrosses moved northwards past Eden in May-June and southwards in September-October. However, monthly abundances of Wandering, Black-browed and Shy Albatrosses off Eden were also bimodal (Barton 1979a, Figure 4), suggesting that these species may undertake a similar movement. Results of the present study and that of Holmes (1977) support the pattern of movement proposed for Yellow-nosed and Shy Albatrosses as both species were most abundant in July-August off Wollongong and Coffs Harbour (Figure 6). It seems likely that Yellow-nosed Albatrosses which migrate to and from the feeding grounds off New South Wales do so via the continental shelf off South Australia and Bass Strait (refer Simpson 1976, Cox 1976, Blakers et al. 1984). Migration is funnelled close to the coast off southern New South Wales (Barton 1979a) with dispersal over slope waters off central New South Wales. In July and August, relative abundance off Coffs Harbour is about one-fifth that off Wollongong (Figure 6). Some birds cross the Tasman Sea and winter over the continental shelf off the North Island of New Zealand (mainly north of 37°S, Cheshire 1978, Booth 1982). Gibson (1967, Figure 1) produced a bimodal graph of the abundance of Wandering Albatrosses in the western Tasman Sea. He proposed that movement of Wanderers through the area 30° - 40°S, 150° - 155°E was northwards in May and southwards in September-October.

Gibson (1967) also showed that the number of Wanderers in the central Tasman was highest in August-September. In Shuntov's (1974) study, Wanderers were most abundant in the central Tasman in late autumn-early winter. Off Wollongong, they were most abundant in spring (Table 3, Figure 6). Neither Shuntov's (1974) data nor those presented here support the pattern of movement proposed by Gibson (1967). Further investigation is recommended. Barton (1979a) also suggested that immature Yellow-nosed moved northwards through Eden before adults; yet evidence of the southerly return of the adults in September-October is lacking (Barton 1979a, Figure 4). Because adult and immature Yellow-nosed were not separately censused in the present study, no conclusion can be made regarding their relative movements off Wollongong. Additional data are needed to determine the precise movements of age classes of all *Diomedea* species off New South Wales.

Utilisation of food resources

In ecological communities, habitat is often used to partition food resources. At Crozet and Kerguelen Islands, Weimerskirch et al. (1986, 1988) concluded that albatrosses segregated marine habitats during the breeding season. Black-browed Albatrosses foraged almost entirely over the surrounding continental shelves (depth <500 m). Yellow-nosed at the Crozet Islands had similar diet, but foraged beyond the shelf, presumably flying past feeding Black-browed to reach their food. Wandering Albatrosses were absent from the Kerguelen shelves but present in all marine habitats around the Crozet Islands. Yet within the present study area, the abundance patterns of the regular albatrosses were so similar that they did not suggest partitioning of resources by habitat over the continental shelf or slope (Table 4). Moreover, inter- and intraspecific competition for discarded offal from commercial trawlers and the *Sandra K* was continually observed. So too was close competition for floating moribund cuttlefish. As at the Shetland Islands (Hudson & Furness 1989) a foraging hierarchy was evident. Moving boats which were discharging offal favoured smaller, more manoeuvrable mollymawks whereas larger albatrosses were dominant around stationary cuttlefish. The foraging hierarchy which existed behind moving fishing boats was reversed when food was at rest. Noticeably, the four common species were ranked in dominance over stationary prey according to size (Wandering 8.2 kg, Shy 3.3 kg, Black-browed 3 kg, Yellow-nosed 2.3 kg, Lindsey 1986). These features of behaviour appear to be the most obvious isolating mechanisms in the partitioning of food off Wollongong.

About 950 000 breeding Black-browed Albatrosses forage over the vast Falkland Islands shelf (including South Georgia) compared with only 6 000 over the medium-sized Kerguelen shelf and 2 000 over the small Crozet shelf (Weimerskirch et al. 1986). At South Georgia, dietary overlap exists between Black-browed, Grey-headed and Light-mantled Sooty Albatrosses. These three species probably feed together at sea in the surrounding waters over the shelf (Croxall & Prince, pers. comm. in Weimerskirsch et al. 1986). Weimerskirch et al. (1986) proposed that a superabundance of food, as exists around the Falklands and South Georgia, 'might possibly result in a reduction or even disappearance of interspecific competition'. Weimerskirch et al. also found that Black-browed Albatrosses which breed at two separate Kerguelen colonies, forage in separate areas for natural prey but overlap in the area where trawlers provide additional food. Fish comprised 87% of Black-browed diet at Kerguelen colonies compared with 58% at Crozet where trawling is prohibited over the shelf. In the Wollongong study area, a rich source of natural cuttlefish exists in winter and large quantities of seafood are discharged from trawlers. The port of Wollongong has 19 fishing boats (>10 m) landing an average of 1800 tonnes of commercial fish annually (Anon. 1985). Availability of this large food resource off Wollongong may substantially reduce competition between the albatrosses present. Indeed, the New South Wales fishery as a whole provides substantial quantities of fish and squid discharged from about 480 vessels (>10 m) operating from 30 major ports distributed along the coast. The total average annual harvest is 21 000 tonnes (Anon. 1985). Scavenging behaviour, as typified off Eden, has been documented by Barton (1979a, 1979b). Competition between seabirds and fish for common live prey might also be diminished where trawlers release substantial quantities of discarded fish and offal.

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