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ZOOPLANKTON ABUNDANCES IN BASS STRAIT AND WESTERN VICTORIAN SHELF WATERS, MARCH 1983

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ABSTRACT: Three sets of zooplankton samples taken during a cruise to central Bass Strait and on a transect from central Bass Strait to Portland, Victoria have been analysed. Bass Strait holozooplankton consisted of few species, with salps, larvaceans, cladocerans, euphausiids and the copepods *Calanus australis*, *Paracalanus indicus* and *Oithona* spp. most abundant. Zooplankton of the western Victorian shelf resembled that of the Bass Strait neritic zone.

Little is known of the zooplankton of Bass Strait or of the Victorian continental shelf. Dall (1957, 1958) briefly described the distribution of crustacean zooplankton, mainly copepods, and identified several distinct water masses on the basis of zooplankton species composition. Noone (1979) described the composition of zooplankton in a series of summer cruises throughout the Strait. Watson and Chaloupka (1983) presented a species list for the Strait on the basis of four cruises; they listed 85 species of copepods and 39 other holoplankton species from their samples. Abundance data from that study, and from a more recent study of neritic zooplankton in Bass Strait, are in preparation (G. F. Watson, pers. comm.).

We report here a study of zooplankton taken on Cruise 83-K-2 of HMAS *Kimbla*. Three series of zooplankton samples were collected: twelve horizontal tows near a drogue; sixteen stratified tows for depth profiles; and 70 pump samples taken along a transect from central Bass Strait to Portland, Victoria. The aim of this study was to provide data on small-scale variability in plankton abundances within Bass Strait, to complement the larger-scale studies described above. Data on phytoplankton productivity and zooplankton growth rates taken during this cruise will be presented elsewhere (R. A. Congdon and W. J. Kimmerer, unpub. data).

METHODS

A drogue was launched at 0800 on 9 March 1983 at 39°29.5′S, 144°58.6′E (Fig. 1). The drogue consisted of a 9 m parachute attached to a weighted wire suspended 30 m below a surface float. Zooplankton samples were taken near the drogue until 1925 hours on 13 March, when the transect was started. Throughout the cruise temperature profiles were taken with expendable bathythermograph (XBT) drops, and surface temperature was recorded from a temperature gauge on the ship.

Zooplankton samples at the drogue were taken twice daily using a 0.5 m mouth, 100 μm mesh conical net towed horizontally at 30 m depth. We collected stratified samples by duplicate horizontal tows with 30 cm mouth, 190 μm mesh Clarke-Bumpus nets at 0, 15, 30 and 50 m depth; one set of samples was collected around noon on 12 March, and one around midnight on 12-13 March. Volumes filtered were measured by flowmeter for both drogue and stratified samples.

The transect began at 1930 hours on 13 March and ended at 0530 hours on 15 March, covering 120 km of Bass Strait and 160 km of western shelf waters (Fig. 1). The ship's firemain system, with an intake 2 m below the surface, was used to collect samples. Water from this system was passed through one of a pair of 190 μm mesh nets and into a bucket. At half-hourly intervals, we switched nets, collected the zooplankton sample and took 1 litre of water from the bucket for chlorophyll, and measured the flow rate by timing the filling of the bucket. Each of the 70 samples represented about 1 m^3 of water filtered, and about 4 km traversed.

Chlorophyll samples were collected by filtering 1 litre of water through glass fibre filters, which were frozen and later analysed by fluorometry (Strickland & Parsons 1972).

All zooplankton samples were preserved immediately in buffered 2% formaldehyde. We counted either whole samples or took aliquots to get 300-500 animals. We identified cladocera and copepods to genus or species, and other taxa to a higher taxonomic level; although we counted meroplankton we excluded them from the analysis. We calculated abundances as number per cubic metre; for the stratified series we calculated integrated abundances (number.m^{-2}) by dividing the water column into four strata: e.g. the surface sample represented 0-7.5 m, the 15 m sample 7.5-22.5 m, and so on. All parametric tests were based on log (N+1) transformed abundance data. We combined adjacent samples from the transect into nine segments of 8 samples (6 in the last segment) for presentation of data.

RESULTS

Weather conditions were typical of Bass Strait, with sustained wind speeds between 9 and 50 knots. Surface water temperature in Bass Strait was 19-20°C; a thermocline was present at 40-50 m throughout the Bass Strait portion of the cruise.

The drogue meandered within 10 km of the launch position until 10 March, when it abruptly proceeded south westward at 1 km.h^{-1} (Fig. 1). On 11 March it was retrieved and reset 15 km north east, after which it meandered generally north east.

Zooplankton samples near the drogue (Table 1) con-

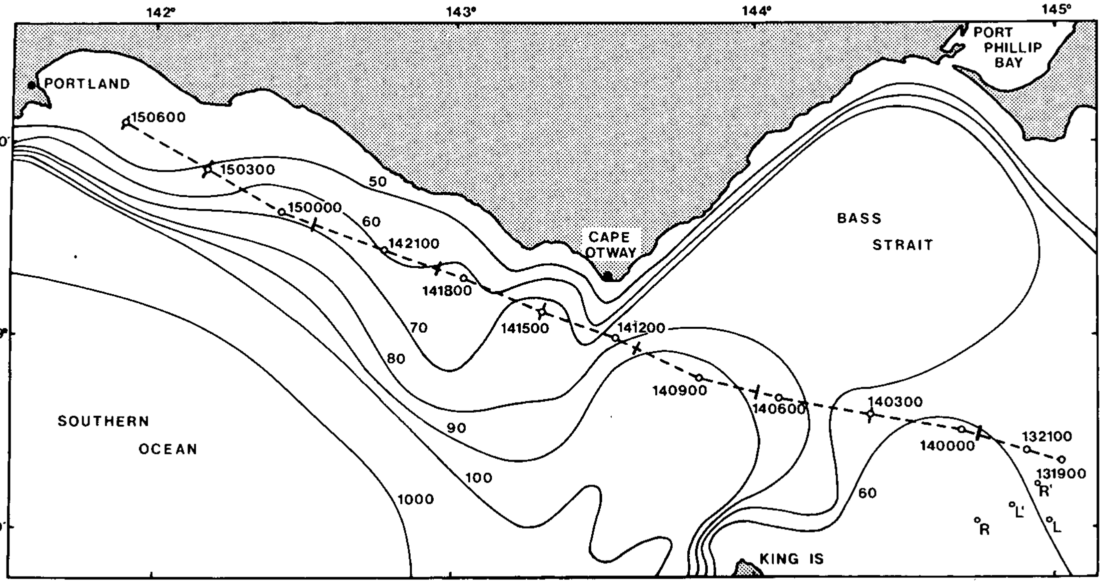

Fig. 1 — Location map showing drogue launch and recovery sites and transect. Bars across the transect line delineate segments. Drogue launch 9 March 1983 (L) and recovery 11 March (R); 11 March reset (L') and final recovery 13 March (R').

tained relatively few holoplanktonic species. Although abundances of common taxa were variable, the order of relative abundance was reasonably consistent between samples. There was no trend in abundance with time for any taxon ($p>0.10$, rank correlation coefficient), nor was the abundance of any taxon significantly different before *vs* after the drogue was reset ($p>0.10$, *t*-test). Euphausiids and *Synopia* (Amphipoda) were absent in samples taken by day; otherwise, day and night abundances were not significantly different.

Abundance patterns that can be seen in the stratified samples (Fig. 2) must be interpreted cautiously since they come from samples taken on one day only. In a few cases, the patterns were clearly the result of vertical migration. For example, *Oithona plumifera*, euphausiids (all that could be identified were *Nyctiphanes australis*), and *Penilia avirostris* were nearly absent and *Calanus australis* and salps (mainly *Thalia democratica*) uncommon, in the surface samples by day.

All of these taxa were common in the surface night samples and in the day samples at greater depths. Limited migration out of the surface layer by day is also suggested for *Paracalanus indicus*. *Synopia* sp. was collected in all night samples and only one 50 m day sample, so these amphipods are probably demersal. None of the other rarer taxa could be identified as vertical migrators. The only clear pattern was that of *Ctenocalanus vanus*, which was collected in low numbers in 3 samples from 30 m and all 4 from 50 m.

Antilogs of standard deviations of the log-transformed abundances for common species in the 30 m samples were at most equal to, and usually less than, the values shown in Table 1 for the 30 m drogue samples.

The temperature profile along the transect (Fig. 3a) shows a thermocline in Bass Strait at about 45 m. A strong surface front southwest of Cape Otway was crossed at 1500 hours on 14 March (sample 40). Shelf waters west of Cape Otway (Fig. 1) were cooler; the dome of $<14°C$ water below 50 m near the western end of the transect may have resulted from upwelling off the shelf.

Chlorophyll (Fig. 3b) showed no trend except for a sharp peak extending 12 km west from the front. Otherwise values were low, with a mean of 0.24 mg m^{-3} exclusive of the peak.

Geometric mean abundances of taxa in each segment of the transect are presented in Table 2. The most abundant taxa within Bass Strait (i.e. in segments 1-2) were the cladocera *Evadne spinifera* and *Penilia avirostris* and the copepods *Calanus australis* and *Paracalanus indicus*. *Oithona* spp. were abundant throughout the transect, *O. plumifera* over the first 40 km and *O. similis* thereafter. On the western shelf (segments 6-9) the numerically dominant taxa were the copepods *P. indicus, Acartia tranteri, C. australis* and *Clausocalanus* spp.

Total holoplankton was lower during the day segments (4-6) than during either night because of reduced abundance of many taxa. In particular, the common taxa that showed a clear migratory pattern in the stratified samples were less common or absent by day than at night.

The common taxa can be assigned to groups based on their abundance patterns. The first group consisted of taxa that were abundant only at the beginning of the transect, and absent or rare thereafter. This group included all of the cladocera, chaetognaths, *Pontella* sp.

TABLE 1

ABUNDANCES OF HOLOPLANKTONIC TAXA COLLECTED IN 30 M HORIZONTAL NET SAMPLES AT THE DROGUE.

The asterisk denotes a change in drogue position. Also shown are geometric means and geometric standard deviations (antilogs of standard deviations of log-transformed values), for taxa occurring in at least 10 samples.

Date	8/3	9/3		10/3		11/3				12/3	13/3			Mean	Std. Dev.
Time	1109	0027	1335	0108	1142	0044	1642	*	2004	1335	0112	1242	1925		
COPEPODA															
Calanus australis															
(Nauplii)	281	1232	295	2387	2195	1197	2963		728	1025	397	466	401	829	2.3
(C & A)	180	251	83	617	240	248	634		261	293	186	214	171	244	1.7
Paracalanus indicus	367	276	274	741	552	212	350		301	248	330	133	216	303	1.6
Acartia sp.										11					
Clausocalanus	7	8	16	21	12						8				
Ctenocalanus vanus		8													
Corycaeus spp.	7	25	16	103	60	56	241		24	158	93	37	37	47	2.7
Oncaea spp.	22	25	16	21		10			8	23	8	15	7	12	1.8
Oithona plumifera		16	21		36	15	87		55	68	17	22	30	22	2.6
Oithona similis	1288	947	1028	2346	1343	495	1312		1069	2175	1387	613	662	1110	1.6
Sapphirina angusta			5								8				
Clytemnestra rostrata				21	48	35	77		24	56		15	7		
Euterpina acutifrons	7	50	5	41	24	5	44					22	15		
Microsetella rosea		8	5		24		33		8	68	25	7	15		
Copepod nauplii	72	8	36	144	108	10	44		32		42	30	22	31	2.7
CLADOCERA															
Podon intermedius							11					15	7		
Evadne tergestina			5		24	5	55			11	17		7		
Evadne spinifera	7	34	10		24	146	350		158	101	135	111	394	61	4.1
Evadne nordmanni						5	44				8		30		
Penilia avirostris	7	201	72	268	264	96	394		95	90	25	325	387	118	3.4
OTHER TAXA															
Euphausiid calyptopis	7														
furcilia	22	42	5	247		56			111		17		30		
Synopiid amphipod									8		8		15		
Pteropod				21	12										
Siphonophore	14	8	47	103	24	15	11		48	11	17		15	18	2.5
Salp (mainly *Thalia democratica*)	345	59	367	679	120	116	317		958	158	617	244	141	254	2.3
Larvacean (*Oikopleura* spp.)	727	461	444	720	972	242	383		721	631	457	244	1189	538	1.6
Chaetognath	50	34	36		168	5	109		32	90	76	74	52	44	2.7
Ctenophore				21											
Total copepod taxa	9	12	12	10	11	10	10		10	10	11	11	11		
Total holoplanktonic taxa	16	19	20	17	19	19	19		17	17	20	17	21		
Total holoplanktonic animals m^{-3}	3410	3693	2786	8501	6250	2969	7459		4633	5217	3870	2587	3835	4285	1.5

and *Corycaeus* spp. The second group comprised the vertical migrators, which were abundant at both ends of the transect but not in the middle during the day. These were *Calanus australis*, *Oithona plumifera*, *Synopia* sp. and euphausiids. The third group consisted of taxa that were abundant only near the end of the transect: *Clausocalanus* spp., *Ctenocalanus vanus*, Oncaea spp., *Microsetella rosea* and a group of copepods, rare in these samples and normally associated with oceanic waters (e.g. *Mesocalanus*, *Calocalanus*, *Eucalanus*, *Pleuromamma* spp., etc.). The remaining taxa showed few similarities in abundance pattern, except that the abundances of *Paracalanus indicus* and *Acartia tranteri* were highly correlated ($r = 0.84$, $p < 0.01$) in samples taken after the front had been passed.

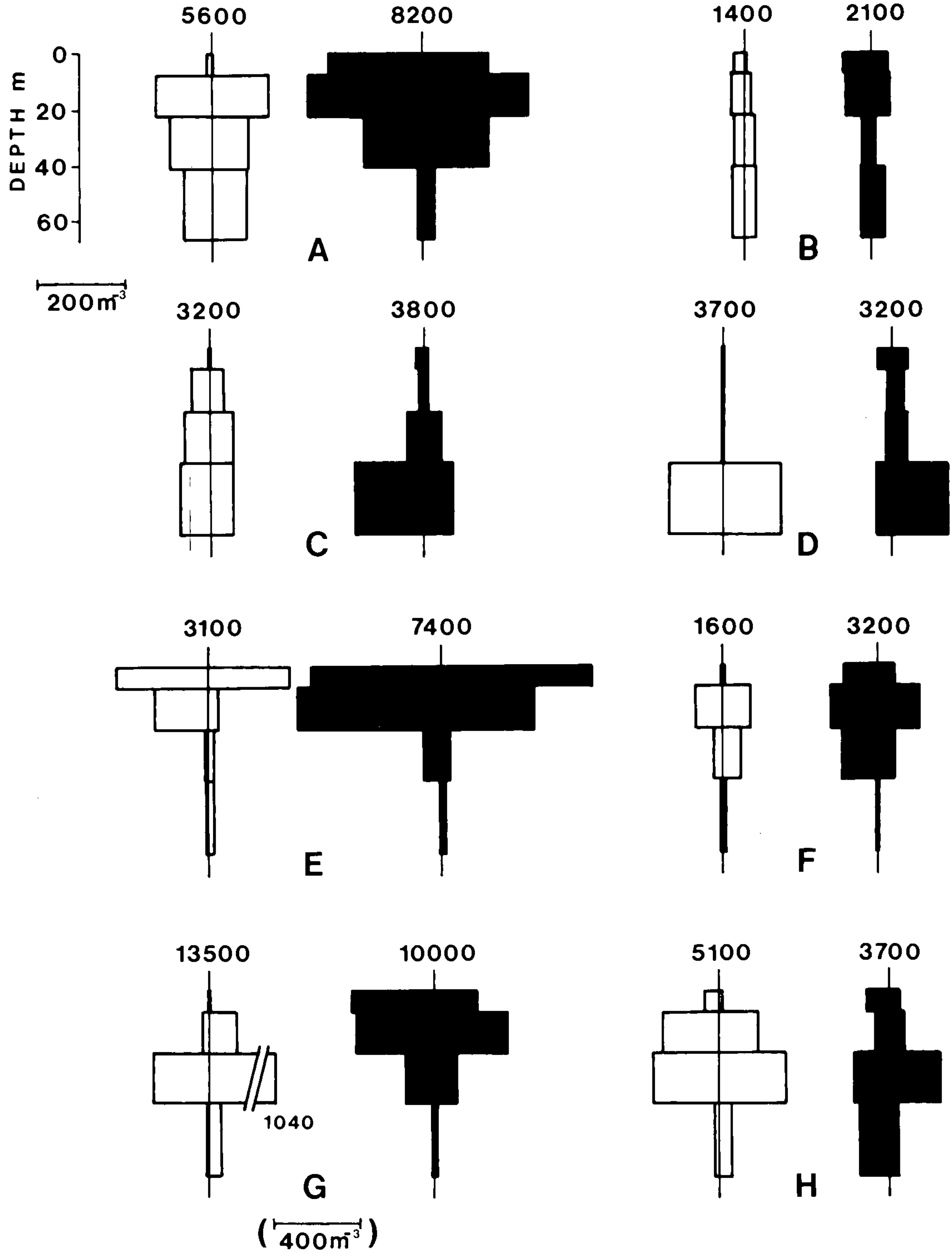

Fig. 2—Vertical distribution of the eight most abundant holoplankton organisms in the stratified samples, 12 March 1983. Each bar represents one of two replicate samples in the depth band indicated; open bars are day samples and filled bars, night. The numbers are mean integrated abundances (number.m²). A, *Calanus australis*; B, *Paracalanus indicus*; C, *Oithona plumifera*; D, Euphausiids; E, *Evadne spinifera*; F, *Penilia avirostris*; G, Thaliacea; H, *Oikopleura* spp.

DISCUSSION

The variability in abundances of common species among the drogue samples was at least as great as, and usually greater than, the variability among the four 30 m stratified samples for the same species. Although we used the drogue to track and, presumably, sample in a single water mass, the water we were actually sampling in, no doubt changed during the drogue series. The presence of a thermocline, strong winds, and the westward displacement of the drogue on 10-11 March all suggest strong current shear and mixing. There was no detectable change in plankton abundances with the change in drogue position, further suggesting that we were in fact sampling in a general region, but not at a point in a water mass.

The differences in species abundances between the three series of samples taken within Bass Strait (Table 3) result largely from differences in mesh size and sample depth. The most abundant species in the 100 μm drogue samples was *Oithona similis*, which was absent from both the stratified samples and the first group of transect samples. Although it was present in all subsequent transect samples its abundance is probably underestimated because of its small size.

Comparison of abundances on transect segment 1 with surface abundances in the night stratified series reveals few striking differences except that *Oikopleura* and *Thaliacea* are under-represented in the transect samples. This may have resulted from the damage by the pump, since many of the soft bodied animals collected were badly damaged and some may have been destroyed.

Cladocera were very abundant in Bass Strait, and all species had the same abrupt decrease in abundance in segments 2 and 3 of the transect. These decreases cannot be attributed to any observed change in water depth, temperature, stratification or chlorophyll.

Many of the copepod species in Table 2 were oceanic species that occurred only in the last few samples of the transect. These may have been associated with the intrusion of cold water into the shelf; their presence at the surface at night could result from their migrating out of that water mass.

The data listed in Table 3 can be compared with historical data taken with nets of similar mesh size. Noone (1979) found *Paracalanus indicus*, *Oithona* spp., *Calanus australis* and *Acartia tranteri* (as *A. clausi*) the most abundant during summer at the three stations nearest the drogue position. G. F. Watson (pers. comm.) found the most abundant species in the same region in autumn to be *P. indicus*, *O. similis*, *A. tranteri*, *Clausocalanus* spp., and *Ctenocalanus vanus*; *Calanus australis* was rare in those samples. Neritic samples in Bass Strait are dominated by *O. similis*, *Oikopleura* spp., *P. indicus*, *C. australis*, Cladocera and *A. tranteri* (G. F. Watson, pers. comm.), while the zooplankton of nearby Port Phillip Bay is dominated by *P. indicus*, *Oikopleura dioica*, and *A. tranteri* (Arnott 1974, Kimmerer & McKinnon in press). In the earliest record of Bass Strait zooplankton abundances, Dall

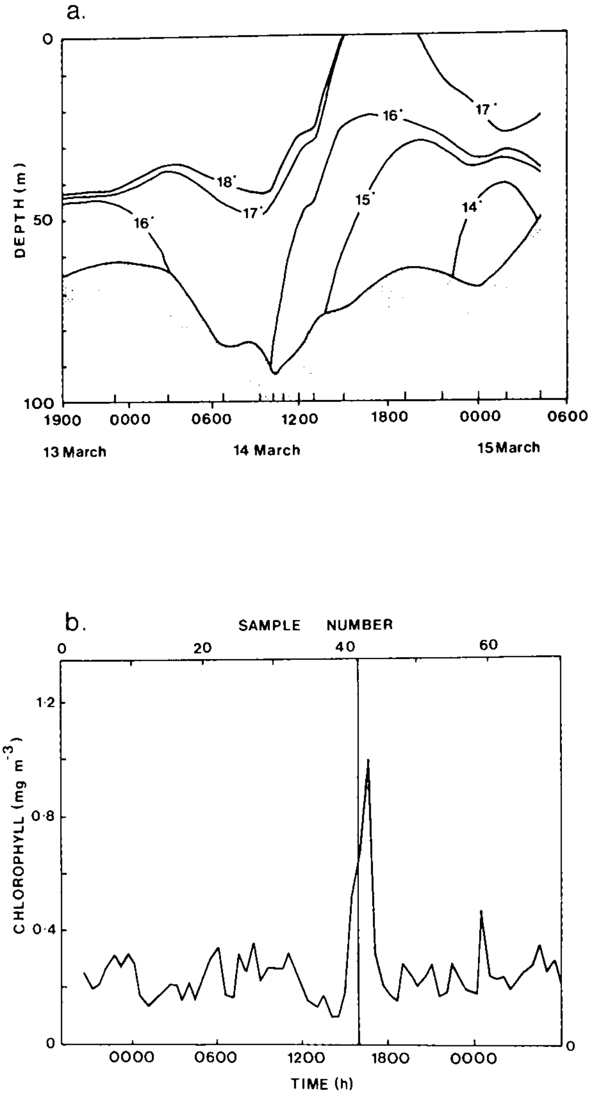

Fig. 3 — Data from transect, 12-14 March 1983.
a: Temperature profiles; tick marks on the ordinate represent points of XBT drops.
b: Chlorophyll. The vertical line is the position where the front was crossed at the surface.

(1957, 1958) found *C. australis* (as *C. helgolandicus*), *Ctenocalanus vanus*, *Labidocera cervi*, and the amphipod *Parathemisto* sp., to be the most abundant crustacea, but he apparently used nets of larger mesh size.

With the exception of the last two species, which have not been common in any other study, the taxa listed above appear to represent a distinct Bass Strait fauna. *Paracalanus indicus*, *Acartia tranteri* and *Oithona similis* seem to be a neritic element, while *Calanus australis*, *Nyctiphanes australis*, *Oithona plumifera* and *Oikopleura* spp. are more widely

TABLE 2

GEOMETRIC MEAN ABUNDANCES (M^{-3}) OF HOLOPLANKTON TAXA IN NINE SEGMENTS ALONG THE TRANSECT.

Segments 1-8 consist of eight samples, segment 9 of six. Segments 4-6 were day samples, and others night. The front was crossed between segments 5 and 6.

Taxon	Segment								
	1	2	3	4	5	6	7	8	9
COPEPODA									
Calanus australis	213.8	33.4	20.3	3.2	0.6	52.2	96.6	17.1	51.2
Mesocalanus tenuicornis	0	0	0	0	0	0	0	0.1	0
Calocalanus tenuis	0	0	0	0	0	0	0.2	0.9	0.9
Mecynocera clausi	0	0	0	0	0	0	0	0.3	0
Paracalanus indicus	51.9	17.2	72.8	58.5	75.5	444.0	584.5	298.5	248.9
Eucalanus sp.	0	0	0	0	0	0	0	0.2	0
Clausocalanus spp.	1.4	1.3	1.2	1.0	1.3	2.0	16.0	39.7	23.7
Ctenocalanus vanus	0	0.1	0.6	0	0	0.2	1.6	17.5	9.9
Aetidiopsis sp.	0	0	0	0	0	0	0	0.1	0
Chiridius sp.	0	0	0	0	0	0	0.2	0.4	0.2
Centropages australiensis	0.2	0	0	0	0.2	0.7	0.4	0.6	1.9
C. bradyi	0	0	0	0	0	0	0.1	0.5	0.4
Acartia tranteri	1.0	2.1	6.1	15.6	28.9	77.3	78.2	37.6	43.4
Labidocera tasmanica	0	0.2	1.8	0	0.1	1.0	1.3	0.8	0.2
Pontella sp.	1.2	2.0	1.4	0	0.1	0	0	0.1	0.3
Candacia sp.	0.1	0.4	0.1	0	0	0	0	0	0
Pleuromamma gracilis	0	0	0	0	0	0	0.1	0.4	0.1
P. abdominalis	0	0	0	0	0	0	0	0.3	0.3
Corycaeus sp.	18.8	4.3	0.7	0.2	0.1	0	0	0	0
Oncaea sp.	0.8	0.7	0.2	0	0	0	3.0	39.6	26.4
Oithona plumifera	31.3	8.7	1.1	0.3	0	0	1.2	0.5	19.2
O. similis	0	2.4	14.6	16.6	3.0	4.0	4.6	5.1	33.4
O. rigida	0.1	0	0	0	0	0.4	0.2	0.1	0
Sapphirina angusta	0.1	0	0	0	0	0.7	1.3	0.2	0.3
Clytemnestra rostrata	0.5	0.1	0.6	0	0.1	0	0	0	0.4
Microsetella rosea	0	0	0	0	0	0	0	1.8	2.6
Euterpina acutifrons	0	0.1	0	0	0	0	0	0	0
CLADOCERA									
Podon intermedius	2.7	1.2	0	0	0	0	0	0	3.5
Evadne tergestina	1.9	0.7	0	0	0	0	0	0	0
Evadne spinifera	177.7	17.0	0.1	0	0	0	0	0	0
E. nordmanni	2.3	3.2	0.1	0	0	0.4	0	0	0.3
Penilia avirostris	234.2	62.9	0.1	0	0	0	0	0	0
OTHER CRUSTACEA									
Synopia sp.	2.8	1.2	0.5	0	0	0.1	0.2	0.1	0.5
Hyperiid amphipod	0	0	0	0.3	0.1	0	0.1	0.2	0.3
Euphausiid									
Metanauplius	0	0	0.1	0	0	0	1.6	0.4	0
Calyptopsis	0	2.6	15.2	0.2	0.2	0.2	32.4	24.0	17.4
Furcilia	13.9	2.9	2.3	0	0	0.2	4.6	2.4	12.3
OTHER TAXA									
Pteropoda	0	0.2	0	0	0	0	0	0	0
Siphonophora	5.1	2.8	2.0	1.3	1.9	1.9	6.0	5.6	4.0
Thaliacea (mainly *Thalia democratica*)	0.3	1.6	0.2	0	1.4	4.7	3.2	0.5	0
Oikopleura spp.	1.3	6.4	3.4	1.3	1.0	9.5	1.7	2.3	7.5
Chaetognatha	7.8	7.3	1.8	0.4	0	0	0.3	0.3	0.5

TABLE 3
ORDER OF ABUNDANCE OF THE EIGHT MOST ABUNDANT SPECIES IN BASS STRAIT.
For transect samples, only Segment 1 is used. Abundances in stratified samples are based on the entire water column.

Drogue Samples	Stratified Samples	Transect Samples
Oithona similis	Thaliacea	*Penilia avirostris*
Calanus australis	*Calanus australis*	*Calanus australis*
Oikopleura spp.	*Evadne spinifera*	*Evadne spinifera*
Paracalanus indicus	*Oikopleura* spp.	*Paracalanus indicus*
Thaliacea	*Oithona plumifera*	*Oithona plumifera*
Penilia avirostris	Euphausiids	*Corycaeus* spp.
Evadne spinifera	*Penilia avirostris*	Euphausiids
Corycaeus spp.	*Paracalanus indicus*	Chaetognaths

distributed. Bass Strait has complex physical oceanography, and adjoins very different water masses to east and west (Godfrey *et al.* 1980, Jones 1980, Baines 1983, Baines *et al.* 1983). Thus, it should be expected, and it is suggested by the above comparison, that large differences in the order of abundance of the major species should occur between seasons or between cruises.

The front off Cape Otway contained an elevated concentration of chlorophyll, but no species of zooplankton had a peak of abundance at the front. Several species, though, shared a change in abundance pattern after the front was passed. In particular, *Calanus australis*, *Paracalanus indicus*, *Acartia tranteri* and Thaliacea all increased in abundance. In addition, *P. indicus* and *A. tranteri* had closely correlated abundance patterns west of the front, suggesting possible physical control of abundance. The species composition in the samples taken west of the front resembled that of neritic samples from Bass Strait (G. F. Watson pers. comm.), except for the presence of oceanic copepods. Thus, in addition to the fauna typical of open waters in Bass Strait, there is a neritic species group that extends west at least as far as Portland. We expect that this species group will also occur in other southern Australian shelf regions.

The diversity of the Bass Strait zooplankton is low, with 7 species making up 80% of the individuals in the drogue samples. This is typical of continental shelf areas around the world, where relatively few species dominate the numbers (e.g. Deevey 1960, Eriksson 1973, Bainbridge *et al.* 1978, Peterson *et al.* 1979, Stepien *et al.* 1981).

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