

# Distribution of mesopelagic decapod Crustacea in and around a warm-core eddy in the Tasman Sea

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**ABSTRACT:** Nocturnal distributions of mesopelagic penaeid, sergestid, and carid crustaceans were determined in the upper 300 m inside, outside and at the edge of warm-core eddy F in December 1978. The 3 sites sampled represent 3 different domains within the Tasman sea water mass. Twenty-five species (2025 specimens) were caught. *Systellaspis debilis*, *Funchalia villosa* and *Sergestes stimulator* were most abundant inside the eddy, whilst *Sergestes disjunctus* was most abundant outside. *Acanthephyra quadrispinosa*, *Gennadas gilchristi*, *Sergestes armatus*, *S. disjunctus*, and *Sergia prehensilis* were more numerous in cold (<16 °C) water, while *Funchalia villosa* was more numerous in warm water. The abundance of *Oplophorus spinosus*, *S. debilis*, *S. armatus*, *Sergestes corniculum*, *S. disjunctus* and *S. prehensilis* increased with depth. Three communities, corresponding to the outside, inside, and edge domains, were found. *O. spinosus*, *S. prehensilis*, and *S. debilis* were the dominant species in this study (72.2% of the total individuals) and all had evidence of population differences across the eddy boundary. *S. prehensilis* and *O. spinosus* were generally larger outside the eddy and tissue carbon levels and carbon/nitrogen levels were higher at the eddy edge than elsewhere. Proportionately more male and female *S. prehensilis* and female *O. spinosus* were in breeding condition outside the eddy and at the eddy edge than inside the eddy. Fecundity of *O. spinosus* was also higher outside the eddy. *S. debilis* females were larger at the eddy edge, but the proportion of breeding females was greatest inside the eddy. These differences are discussed in relation to the different thermal environments of the domains.

## INTRODUCTION

Eddies or rings are common features of major western boundary currents including the Gulf Stream (Fuglister, 1972), East Australian (Andrews and Scully-Power, 1976), Kuroshio (Tomasada, 1978) and Somali (Bruce, 1979) currents. Recent work shows that much of the mesoscale variability in plankton distribution in the western North Atlantic ocean is due to the existence of cold-core rings shed by the Gulf Stream (Wiebe et al., 1976, Boyd et al., 1978, Ortner et al., 1978, Wiebe and Boyd, 1978, Ortner et al., 1979, the Ring Group, 1981) and that the physical and biological properties of the Slope water core of a cold-core ring are gradually replaced by those of the Sargasso Sea. The mechanisms of these replacements are believed to be horizontal mixing in the mixed layer, and exchange due to movement of water into and out of the ring below 400 m (Wiebe and Flierl, in press). Brandt and Wadley, (1981) believe biological factors may also be affecting communities in warm core rings.

Warm-core eddies form an important part of the circulation in the western Tasman Sea. They have diameters of 200 to 300 km, extend to 1500 m depth (Hamon, 1965), and form when a meander of the southward flowing East Australian Current (EAC) breaks off to form a closed eddy (Nilsson and Cresswell, 1981). These authors have shown that eddies can move at least  $0.15 \text{ m s}^{-1}$  ( $13 \text{ km d}^{-1}$ ) and persist for between 500 and 800 d if they are not recaptured by the EAC.

Warm-core Eddy F was formed by the subdivision of a larger eddy, Eddy D, between May and September 1978 (Tranter et al., 1979; Brandt, 1981). Eddy D originated as a meander of the EAC in February 1978 (Boland and Church, 1981). Eddy F moved in a southerly direction between September 1978 and February 1979, and was centred at  $36^{\circ}30' \text{ S}$ ,  $151^{\circ}30' \text{ E}$  on 25 February 1979 (Nilsson et al., 1982). This eddy was not followed after February 1979 but may have decayed via upwelling from below the seasonal thermocline (Nilsson and Cresswell, 1981).

A generalized circulation pattern for the Coral and

Tasman Seas is given in Fig. 1. Briefly, the EAC forms north of 25°S and flows south near the eastern Australian coast until it swings east between 30° and 34°S and forms the Tasman Front. The EAC and the Tasman Front form the boundary between the Coral and Tasman Seas. The eddy and the Coral Sea are areas of higher dynamic height than the Tasman Sea. A more detailed discussion of the circulation in the Coral and Tasman Seas is given by Nilsson and Cresswell (1981) and references cited therein.

The physical and biological environments of warm-

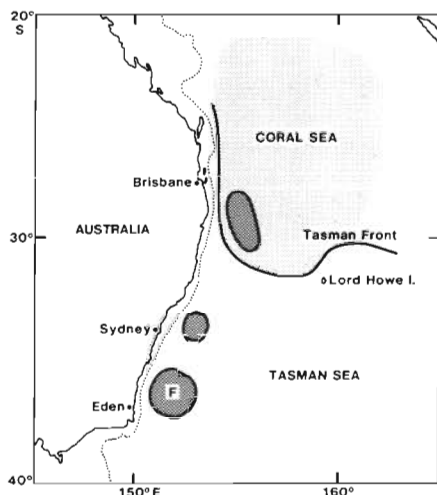


Fig. 1. Generalized circulation patterns in Coral and Tasman Seas, November/December 1978. The East Australian Current (heavy line) forms the Tasman front as it moves eastwards and separates Coral ( $T_{250} > 17^\circ\text{C}$ ) and Tasman Seas ( $T_{250} < 17^\circ\text{C}$ ). Shaded areas: highest dynamic height. Based on data from cruises in November and December 1978.

Boundaries east of 156° are largely conjectural

core eddy Eddy F differed from both the surrounding Tasman Sea and the EAC. The major physical differences were the formation of an isothermal core in the eddy by surface cooling and convective overturn during winter 1978 (Nilsson and Cresswell, 1981) and the different distribution of temperature and salinity with depth (Fig. 2). The major chemical difference was in nutrient cycling (Scott, 1978). The biological differences include phytoplankton levels (Tranter et al., 1980a) and species composition (Jeffrey and Hallegraeff, 1980), copepod species distributions (Tranter et al., in press), midwater fish community structure and distribution (Brandt, 1981) and mesopelagic squid distribution (Brandt, in press).

Mesopelagic decapods were sampled at a site inside, at the edge of and outside warm-core Eddy F. Each site was in a different domain (Dodimead et al., 1963) of the Tasman Sea water mass. The 2 questions posed in this study were: (1) Was there a separate decapod community in each domain? (2) Did size, reproduction, and chemical composition of selected species reflect the different physical and biological environments of the different domains of the Tasman Sea water mass?

## METHODS

### Study area

Warm-core Eddy F was centred at 36°30'S, 151°42'E in the Tasman Sea (Fig. 3) during the sampling period 1 to 10 December 1978. The vertical thermal structure of Eddy F was mapped to 450 m using expendable bathythermographs (XBTs): Brandt (1981) gives the XBT positions. Detailed salinity and temperature pro-

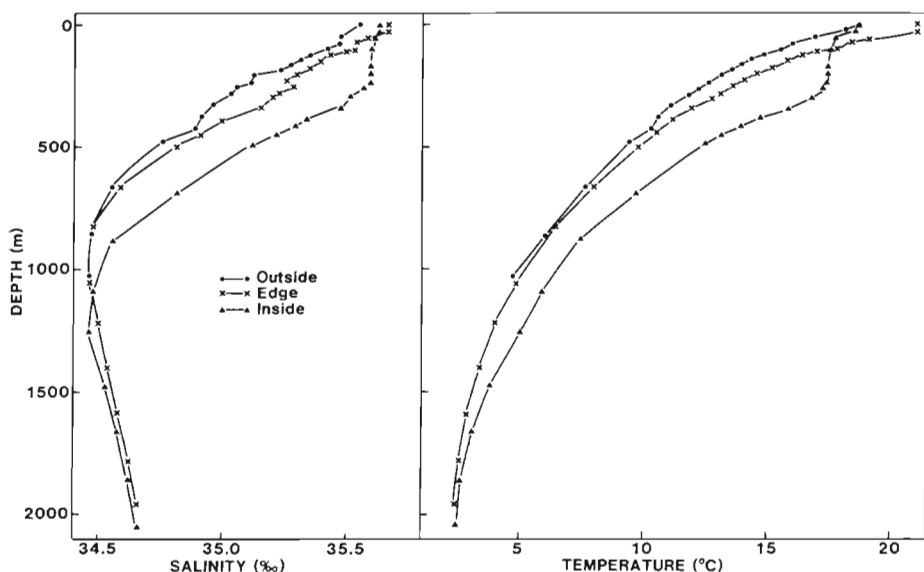


Fig. 2. Salinity and temperature profiles from hydrology stations inside (302, Fig. 3), outside (296) and at the edge (305) of Eddy F

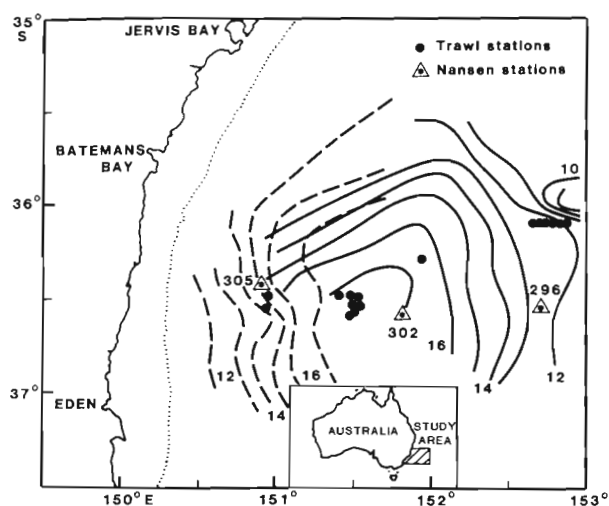


Fig. 3. Location of trawl and hydrology (Nansen) stations relative to temperature at 250 m between 28 November and 4 December (solid lines) and 8–13 December 1978 (broken lines). (After Brandt, 1981, modified)

files were taken at three stations using reversing Nansen bottles at 25 m intervals from the surface to 300 m, at 50 m intervals to 500 m, and at 200 m intervals to either 1100 m or 2000 m during 1 to 7 December 1978.

### Faunal collections

Animals were collected using the FRV *Courageous* and a 308 meshes X 800 mm Engel midwater trawl having a 10 mm mesh liner in the cod end. The mouth

area of this net is about 450 m<sup>2</sup>. A Simrad FB trawl eye mounted on the headrope of the trawl provided a continuous record of trawl depth, trawl vertical opening (about 12 m) and water temperature. Horizontal tows of 30 min duration were made at depths of approximately 50 m, 150 m, and 250 m at a speed of 1.5 m s<sup>-1</sup>. Three sampling sites were defined on the basis of the temperature at 250 m ( $T_{250}$ ): < 14 °C, outside the eddy; 14 to 16 °C, eddy edge; and > 16 °C, inside the eddy (Table 1). Boland (1973) and Nilsson (1977) found that the fastest surface currents were at the eddy edge, above a temperature of 15 °C at 250 m. Samples were allocated to one of these sites on the basis of the  $T_{250}$  measured by an XBT immediately before each sample was collected. At least 2 samples were taken at each of the 3 depths inside and outside the eddy, and at 250 m in the eddy edge. No crustacean samples were collected using the Engel trawl from 50 m and 150 m at the eddy edge. Brandt (1981) has discussed the limitations of this sampling program and the contamination problem caused by using a non-closing trawl. The sampling order for the three depths at each site was chosen at random between 30 min after sunset and 30 min before sunrise. Crustacea were sorted from the samples on board ship. The mesopelagic decapods from one 250 m sample at each site were frozen at -30 °C within 1 h of the catch coming on board, and animals from all other samples were fixed in borax buffered 4% formaldehyde. Only night samples are discussed in this paper since only 6 decapods (*Oplophorus spinosus*) were caught in the 18 daytime samples.

Table 1. Trawl station information and biomass (g) of crustaceans. All samples taken between sunset (1959 to 2009 h) and sunrise (0539 h) Australian Eastern Summer Time. New, first quarter and full moon occurred on 1 December, 7 December and 12 December, respectively. Geographic coordinates of trawl stations given in Brandt (1981)

Position	$T_{250}$ (°C)	Depth (m)	Temp. (°C)	Time (h)	Date Dec.	Moonset	Crustacean biomass (g)		
							Carids	Penaeids	Sergestids
Inside eddy	17.4	32	18.3	2350	1	2110	0	165.1	0
	17.3	45	18.1	2050	8	0152	6.4	101.1	1.2
	17.4	50	18.0	0120	9	0228	10.5	6.1	0.5
	17.3	155	17.5	2150	8		81.7	27.9	12.3
	17.4	158	17.4	0015	9		139.7	16.6	23.1
	17.3	255	17.3	2305	8		92.3	25.5	22.7
	17.3	255	17.3	0240	9		220.8	28.4	52.8
Eddy edge	15.7	245	15.8	0105	10	0304	95.7	6.2	11.9
	15.7	260	15.6	2345	9		44.0	11.8	50.5
Outside eddy	11.3	52	17.5	0315	3	2303	0	2.6	0
	11.5	55	17.5	0150	3		0	0	0
	12.2	150	13.4	0005	3		103.9	5.2	164.0
	11.3	152	12.8	0420	3		40.8	0	2.9
	13.2	255	13.1	2130	2	2209	16.1	9.6	151.4
	12.5	255	12.4	2250	2		97.8	9.7	160.3

### Abundance, distribution and community structure

Decapods were identified using keys in Yaldwyn (1957), Kensley (1968, 1971a, b, 1972) and Crosnier and Forest (1973). The wet weight of each species in each sample was measured about 15 mo after preservation to determine the total biomass and biomass dominants. Biomass comparisons for each major taxon (carids, penaeids, and sergestids) were made between the inside and outside sites (all depths combined) and among 250 m samples taken inside, at the edge, and outside of the eddy by summing the individual species weights.

Mills (1969) defined a community as 'a group of organisms occurring in a particular environment, presumably interacting with each other and with the environment, and separable by means of ecological survey from other groups'. We adopted this definition to distinguish communities in this report. Community structure at each site was determined after including only those species that represented > 1 % of the total catch at that site. Frequency, abundance, and dominance (Fager, 1963) were used as community measures to compare species assemblages among the 3 sites. Frequency was calculated by counting the number of samples containing a given species. Abundance was the number of individuals of a species in a sample. Dominance was determined in 2 ways: using counts and biomass. The numerically dominant species at each site were found by summing the abundance of all species in order starting from the species having the highest abundance at each site. Those species included when the summation reached 50 % of the total individuals were considered to be the numerical dominants at the site. The biomass dominants were found similarly.

The species used to examine community structure were also examined to see if there was any relationship with temperature, depth or position. The Kruskal-Wallis test, followed by Dunn's multiple comparison test (KW-D) was used to determine if the abundance differences found with depth, or with temperature (temperature at trawl depth > 16 or < 16 °C) were significantly different. The Mann-Whitney test (MW) was used to determine if the abundance differences for each species found between the inside and outside sites were significantly different. The edge site was omitted from this last comparison because of the lack of samples. A significance level of 0.05 was used for all tests.

### Size, reproduction and chemical composition

Carapace lengths of *Sergia prehensilis*, *Oplophorus spinosus*, and *Systellaspis debilis* were measured ( $\pm 0.16$  mm) from the posterior margin of the orbit to a

line perpendicular to the dorsal end of the carapace using an eyepiece micrometer in a Wild M7A stereomicroscope. We compared the size-frequency structure of males and females of each species separately between the 3 domains using the Median Test (MT). The proportions of breeding females, and breeding males of each species in the 3 domains were compared using a contingency table analysis ( $\chi^2$ ). Fecundity of *O. spinosus* and *S. debilis* was estimated by counting the number of eggs attached to the ventral abdominal surface and pleopods of females and compared among domains (KW-D).

Carbon and nitrogen analyses were done on *Oplophorus spinosus* and *Sergia prehensilis*. The frozen samples were thawed, and the sex of 10 individuals of each species was determined, weighed, and measured, refrozen in liquid nitrogen, freeze dried to a constant weight and stored in desiccators. Muscle tissues removed from the first 2 abdominal segments were weighed (300 to 1500  $\mu\text{g} \pm 1 \mu\text{g}$ ) and analyzed in a Hewlett-Packard model 185B CHN analyzer. Acetanilide and cyclohexanone-2, 4 dinitrophenyl hydrazone were used as standards. The precision of the method was determined by analyzing 17 replicates from one *O. spinosus*. The mean carbon content ( $\pm 1$  s.d.) was 41.0 %  $\pm 1.1$  %, and the mean nitrogen content was 13.4 %  $\pm 0.4$  % of the dry weight of the muscle tissue.

## RESULTS

### Eddy structure

Eddy diameter based on the 15 °C isotherm at 250 m depth was about 120 km (Fig. 3). The eddy moved about 55 km north-northwest during the study at an average rate of 6 km d<sup>-1</sup> (Brandt, 1981). We cannot be certain that the eddy was closed during the study because no temperature data were taken from the southern part of the eddy although Tranter et al. (1980b) have shown that Eddy F was closed on the southern perimeter on 18–19 November 1978.

Temperature and salinity profiles to 1100 m outside, and 2000 m inside and at the edge of the eddy are shown in Fig. 2. The maximum difference in temperature (4.7 °C) and salinity (0.47 ‰) was at 250 m between inside and outside the eddy. Salinity and temperature profiles from the eddy edge were most similar to the outside profiles. The major difference in water structure between the 3 domains was the isothermal (17.3 to 17.6 °C), isohaline (35.59 ‰ S) eddy core found between 50 and 290 m inside the eddy (Fig. 2). There were still substantial differences in temperature (1.5 °C) and salinity (0.2 ‰ S) between the outside and eddy domains compared with the inside domain at

Table 2. Abundance of each species for pairs of samples (3 samples at 42 m inside eddy). Numbers represent catches of individuals. Blanks: no specimens caught; single value: specimens caught in only 1 of the trawl samples

Taxa	Outside eddy			Edge	Inside eddy		
	54 17.5	151 13.1	255 12.8		252 15.7	42 18.1	156 17.4
<b>Decapoda: Caridea</b>							
Family Oplophoridae							
<i>AcanthePHYra quadrispinosa</i> Kemp 1939		4	6	1-1			3
<i>Oplophorus spinosus</i> (Brulle 1839)		37-47	29-38	19-55	14	30-54	41-106
<i>O. novazeelandiae</i> de Man 1931			3	1			
<i>Systellaspis debilis</i> [A. Milne Edwards 1813]		5	5-7	24-26	1-1	39-66	31-59
Family Pandalidae							
<i>Plesionika</i> sp.		1-2					1
<i>Parapandalas richardi</i> (Coutiere 1905)			1-1	1			2
<b>Decapoda: Penaeidea</b>							
Family Penaeidae							
Subfamily Penaeinae							
<i>Funchalia villosa</i> (Bouvier 1905)	1	1		2-3	2-36-50	5-9	7-10
Subfamily Aristaeinae							
<i>Gennadas bouveri</i> Kemp 1909			1	1			
<i>G. clavicornis</i> de Mann 1907				3		1-2	
<i>G. gilchristi</i> Calman 1927		4	34-78	2-9			2
<i>G. incertus</i> Balss 1927		2	1	1			
<i>G. scutatus</i> Bouvier 1906			1	1			
<b>Decapoda: Sergestidea</b>							
Family Sergestidae							
Subfamily Sergestinae							
<i>Sergestes armatus</i> Kroyer 1855		2-11	8-15	1-4	1	1-1	1-7
<i>S. corniculum</i> Kroyer 1855		4	2-19	3-9		2-4	1-3
<i>S. disjunctus</i> Burkenroad 1940		1-13	17-42	1-1			1-1
<i>S. orientalis</i> Hansen 1919			1	1-2			1
<i>S. pectinatus</i> Sund 1920			1	1		1-2	1-1
<i>S. sargassi</i> Ortmann 1893		1				1	
<i>S. seminudus</i> Hansen 1919			2				
<i>S. stimulator</i> Burkenroad 1940			1-3	2-2	1-3	5-12	7-8
<i>Sergia grandis</i> Sund 1920			2				
<i>S. prehensilis</i> Bate 1881		2-206	115-136	65-76	1	10-36	40-44
<i>S. regalis</i> Gordon 1939			1				
<i>S. scintillans</i> Burkenroad 1940			2-3	3		1-2	2
<i>S. splendens</i> Sund 1920			1-3	1-1		4-4	1

1000 m (Fig. 2). A thermal cross-section of Eddy F and the surrounding Tasman Sea waters to 450 m depth is given in Brandt (1981). The temperature-salinity diagrams given in Brandt (in press) for the 3 regions show that all sampling was done in a single water mass. However, the substantial differences in temperature with depth, and salinity with depth (Fig. 2) suggest each of the sampling sites was in a different domain within the Tasman Sea water mass.

#### Abundance, distribution, and community structure

We caught 2025 individuals belonging to 25 species of carids, penaeids, and sergestids (Table 2). *Systellaspis debilis*, *Funchalia villosa*, *Gennadas gilchristi*, and

*Sergestes disjunctus* showed abrupt abundance changes between domains, while *AcanthePHYra quadrispinosa*, *Sergestes armatus*, *S. corniculum*, and *S. stimulator* were approximately equally abundant in all 3 domains (Table 2). *Sergia prehensilis* and *Oplophorus spinosus* showed abundance clines across the domain boundaries. The 5 most abundant species were *Sergia prehensilis* (36.0% of the total catch), *Oplophorus spinosus* (23.2%), *Systellaspis debilis* (13.0%), *Gennadas gilchristi* (6.4%) and *Funchalia villosa* (6.2%).

The 11 species found in abundances greater than 1% of the total at any one site are given in Table 3. When species counts from the same depths inside and outside the eddy were combined, the abundance of

Table 3. Percent composition of abundant species (> 1% of total number at each site) outside, inside and at the edge of Eddy F.

Species	Percent of total		
	Outside eddy	Eddy edge	Inside eddy
<i>Sergestes disjunctus</i> <sup>O, C</sup>	7.8		
<i>Acanthephyra quadrispinosa</i> <sup>C</sup>	1.1		
<i>Gennadas gilchristi</i> <sup>C</sup>	12.6	3.4	
<i>Sergia prehensilis</i> <sup>C</sup>	49.6	43.7	16.8
<i>Oplophorus spinosus</i>	16.4	22.9	31.4
<i>Systellaspis debilis</i> <sup>I</sup>	1.8	15.5	25.1
<i>Sergestes armatus</i> <sup>C</sup>	3.9	1.5	1.4
<i>Sergestes corniculum</i>	2.7	1.5	1.3
<i>Funchalia villosa</i> <sup>I, W</sup>		1.5	15.2
<i>Sergestes stimulator</i> <sup>I</sup>		1.2	4.5
<i>Sergia splendens</i>			1.2
Total number of individuals	921	323	781

O: outside species; I: inside species; C: cold-water species; W: warm-water species

*Oplophorus spinosus*, *Systellaspis debilis*, *Sergestes armatus*, *S. corniculum*, *S. disjunctus*, and *S. prehensilis* increased with increasing depth (KW-D). *Acanthephyra quadrispinosa*, *G. gilchristi*, *S. armatus*, *S.*

*disjunctus*, and *S. prehensilis* were significantly more abundant in cold water (< 16°C), while *Funchalia villosa* was significantly more abundant in warm (> 16°C) water (MW). Using only the inside and outside samples, *S. debilis*, *F. villosa*, and *S. stimulator* were more abundant inside the eddy, while *S. disjunctus* was more abundant outside (MW). A comparison between the 250 m samples from each domain showed that *S. debilis* and *F. villosa* were more abundant inside and *S. prehensilis* was more abundant outside the eddy (KW-D). There was a significant difference in penaeid biomass (MW, Table 1) between inside and outside sites. No other significant biomass differences among sites or between depths in the 3 families were found (Table 1). There were separate communities inside and outside the eddy, and although the edge site was intermediate in species composition (Table 3) it was considered a separate community. *S. disjunctus* and *A. quadrispinosa* were abundant only outside, and *Sergia splendens* was abundant only inside the eddy. *Gennadas gilchristi* was common outside and at the edge, while *F. villosa* and *S. stimulator* were common both inside and at the eddy edge. The remaining 5 species were present in abundances > 1% of the total at each of the 3 sites.

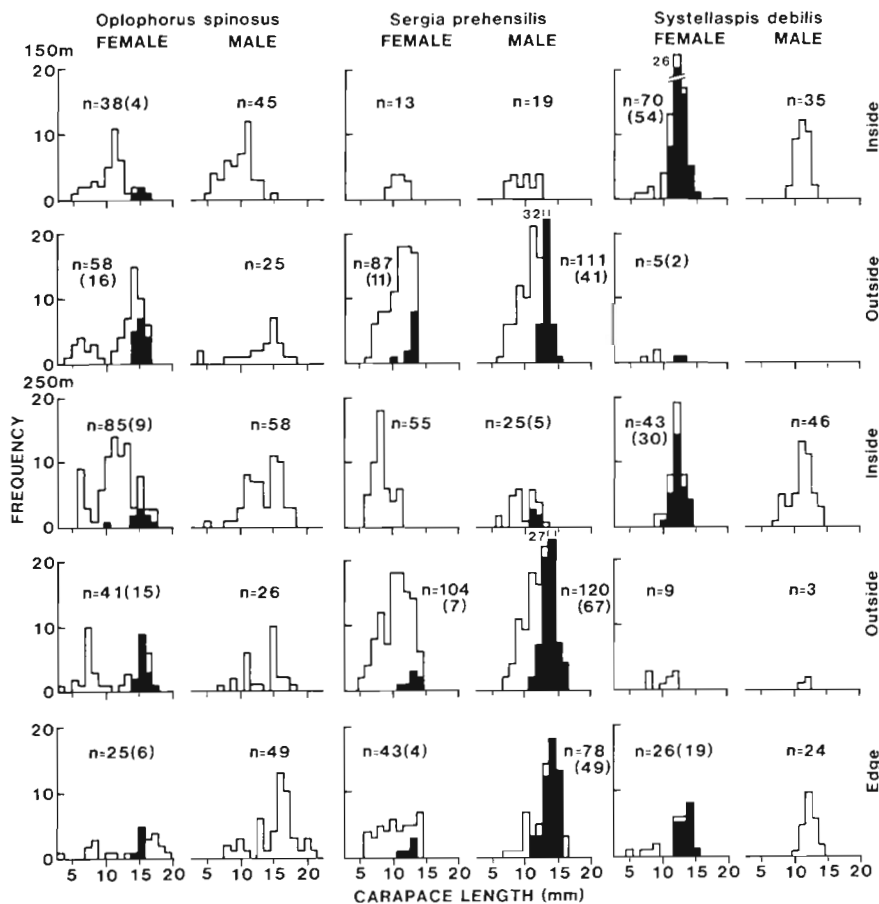


Fig. 4. *Oplophorus spinosus*, *Sergia prehensilis* and *Systellaspis debilis*. Carapace-length frequency distributions of females and males caught at 150 m inside and outside the eddy, and at 250 m at all 3 sampling sites. n: total number measured; numbers breeding (solid bars) in parentheses

Table 4. *Oplophorus spinosus* and *Systellaspis debilis*. Comparison of ovigerous females outside, at edge and inside Eddy F

	<i>Oplophorus spinosus</i>			<i>Systellaspis debilis</i>		
	Outside	Edge	Inside	Outside	Edge	Inside
Number of ovigerous females	31	6	13	2	10	84
Percent of total	20.5	8.1	5.3	8.7	37.2	42.9
Carapace length (mean $\pm$ 1 s. d.)	15.4 $\pm$ .8	15.1 $\pm$ .5	15.1 $\pm$ 1.0	12.8 $\pm$ .5	13.2 $\pm$ 1.0	13.0 $\pm$ 1.0
range	14.0 - 17.7	14.5 - 15.8	10.0 - 17.3	12.5 - 13.2	12.3 - 15.0	11.3 - 15.8
Egg count (mean $\pm$ 1 s. d.)	23.9 $\pm$ 7.7	20.7 $\pm$ 6.5	17.9 $\pm$ 8.0	10.5 $\pm$ 3.5	13.3 $\pm$ 3.9	13.8 $\pm$ 3.8
range	6 - 36	10 - 29	3 - 30	8 - 13	6 - 19	2 - 23

The numerical dominants outside the eddy were *Sergia prehensilis* and *Gennadas gilchristi* while *S. prehensilis* and *Oplophorus spinosus* were the dominants at the eddy edge. *Oplophorus spinosus* and *Systellaspis debilis* were the numerical dominants inside the eddy. The biomass dominants outside the eddy were *S. prehensilis* (47.9 % of the total crustacean biomass outside the eddy; Table 1) and *O. spinosus* (31.0 %), while *O. spinosus* (34.2 %) and *S. debilis* (30.5 %) were the biomass dominants at the eddy edge. *Funchalia villosa* (35.7 %) and *O. spinosus* (28.0 %) were the biomass dominants inside the eddy.

#### Size, reproduction and chemical composition

We compared size, reproductive condition, and chemical composition of the 3 most abundant species among sites, and the chemical composition of *Sergia prehensilis* and *Oplophorus spinosus* from 250 m among sites. Juveniles of *S. prehensilis*, *O. spinosus* and *Systellaspis debilis* were found at all sampling sites.

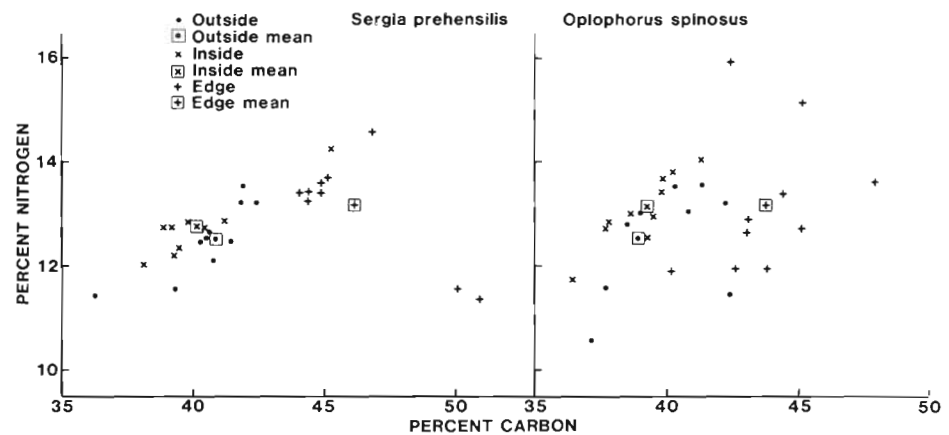
*Sergia prehensilis* was larger outside than inside the eddy (MT). For all samples combined median sizes of females and males were 12 mm and 11 mm respectively outside the eddy and 9 mm for both sexes inside

the eddy. At 250 m, the outside and edge females (11 mm and 10 mm) and males (13 mm and 14 mm) were significantly larger than females (8 mm) and males (9 mm) inside the eddy and showed several cohorts (Fig. 4). Proportionately more breeding males were found outside and at the edge than inside the eddy ( $\chi^2$ ) and no breeding females were caught inside Eddy F (Fig. 4). Carbon levels and C/N ratios were higher in *S. prehensilis* at the eddy edge than elsewhere (Fig. 5); the chemical composition of this species inside and outside the eddy did not differ (KW-D).

*Oplophorus spinosus* was significantly larger outside than inside Eddy F (MT). Median sizes of both males and females were 13 mm outside the eddy and 11 mm inside. At 250 m, specimens of both sexes caught at the eddy edge had a median size of 15 mm and were larger than outside (13 mm) and inside (11 mm) specimens. Females had a bimodal (juvenile and adult) length frequency distribution outside the eddy which was less apparent than in other domains or in males (Fig. 3). Proportionately more females were breeding ( $\chi^2$ ) and mean egg count was higher (KW-D) outside the eddy than inside or at the eddy edge (Table 4). Carbon levels and C/N ratios were higher at the eddy edge (Fig. 4) than elsewhere (KW-D).

At 250 m, female *Systellaspis debilis* were larger at the eddy edge (13 mm) than inside (12 mm) or outside

Fig. 5. *Oplophorus spinosus* and *Sergia prehensilis*. Carbon and nitrogen (% of dry weight in freeze-dried muscle tissue) of individuals caught outside, inside and at edge eddy. Mean  $\pm$  1 s.d. carbon in *O. spinosus* was 39.9  $\pm$  1.0% outside, 39.1  $\pm$  1.4% inside, and 43.8  $\pm$  2.0% at the eddy edge; mean nitrogen levels were 12.5  $\pm$  1.0% outside, 13.1  $\pm$  0.6% inside, and 13.2  $\pm$  1.3% at the eddy edge. In *S. prehensilis* carbon levels were 40.6  $\pm$  1.8% outside, 40.2  $\pm$  2.0% inside, and 46.1  $\pm$  2.4% at the edge; nitrogen levels were 12.5  $\pm$  0.7% outside, 12.7  $\pm$  0.6% inside, and 13.1  $\pm$  1.0% at the edge



(11 mm) the eddy (MT). Males did not differ in size among sites (Fig. 3). Proportionately more females were breeding inside the eddy and at the eddy edge than outside ( $\chi^2$ ). Breeding size and fecundity did not differ among sites (Table 4, KW-D).

## DISCUSSION

Sampling was limited to a single cruise, and by a small number of samples (Brandt, 1981). Our sampling design also assumed that each animal maintained a constant depth throughout the night. Sampling biases among sites may have resulted from the continuous migration of individuals through the night (Roe, 1974), size stratification with depth (Omori, 1969; Donaldson, 1975; Walters, 1976) and the effects of moon phase on vertical migration patterns (Walters, 1976). Our study was not designed to investigate these questions, and the consistency of the results suggests that the differences in crustacean communities among domains were not due entirely to such sampling biases. As far as is known, all of the species recorded in this study live at depths greater than 600 m by day and migrate to above 300 m at night (Foxton, 1970a, b; Roe, 1974; Donaldson, 1975; Walters, 1976).

Crustacean species assemblages differed across the Eddy F boundary. Seven of the 11 abundant species showed abrupt or clinal changes in abundance across domains analogous to the patterns across water mass boundaries shown by mesopelagic fish, crustaceans, and squid (McGowan, 1971; Jahn and Backus, 1976; Robertson et al., 1978; Fasham and Foxton, 1979; Brandt, 1981, in press). Brandt (1981) found distinct fish communities in each domain in and around Eddy F. Several fish species were dominant only at the edge of Eddy F, although no crustacean species showed this pattern. Some fish may have a more restricted habitat preference, and a better ability to select and maintain their position in the dynamic eddy edge region compared with Crustacea. Squid community structure also corresponded to Eddy F location and water temperature, although the patterns were not as distinct as for fish and Crustacea (Brandt, in press). The 3 Tasman Sea domains are basically indistinguishable on temperature-salinity relationships (Brandt, in press) but differ considerably in the distribution of temperature, and of salinity, with depth. We suggest that the distributions of Crustacea among the 3 domains are related, directly or indirectly, to differences in the vertical physical-chemical structure of the three different domains.

The 3 most abundant crustaceans, *Sergia prehen-silis*, *Oplophorus spinosus*, and *Systellaspis debilis* were widespread, but differed in size, fecundity, and percentage of breeding animals among domains.

These species have a 1 to 3 yr life span (Omori, 1974) and Eddy F was 6 to 10 mo old by December 1978 (Boland and Church, 1981). This period may be a sufficiently long exposure to an altered physical and biological environment to affect life history characteristics. Wiebe and Boyd (1978) and Boyd et al. (1978) found notable changes in abundance, sex ratios, and chemical composition of the euphausiid *Nematoscelis megalops* trapped in cold core rings for a similar period. The general lack of baseline life history studies on these mesopelagic crustaceans in the Tasman Sea limits our ability to determine what caused the differences. For example, size differences across domains could be due to different breeding times or growth rates, and these in turn may be influenced by differences in environmental temperature or food availability among domains. The presence of juveniles of all 3 species suggests these crustaceans reproduced in each domain as there is little evidence of extensive physical mixing between one domain and another (Scott, 1978).

To estimate the potential importance of temperature in contributing to size differences, a 'mean habitat temperature' was calculated for migrating Crustacea in each domain using data from Fig. 2 and assuming that an average animal spent 8 h at 200 m (night), 12 h at 750 m (day) and 4 h vertically migrating. The mean habitat temperatures were 9.6 °C outside, 10.2 °C at the eddy edge, and 12.4 °C inside Eddy F in December 1978. Sergestid and euphausiid growth rates have been shown to differ significantly with temperature differences of 3 to 4 °C (Lasker, 1966; Omori, 1971, 1979; Ross, 1981). Thus the thermal contrasts could be sufficient to contribute to the size differences seen between crustaceans caught inside and outside the eddy.

Temperature may affect the breeding cycle as well. Omori et al. (1974, quoted in Omori and Gluck, 1979) have shown that spawning times and larval survival of *Sergia lucens* are more closely related to ambient temperature than food abundance. There is no evidence that fecundity in mesopelagic Crustacea is affected by either temperature or food availability although Omori (1974) found that fecundity is usually greater in larger females. A time-series study would be necessary for a comparison of growth rates, fecundity and breeding seasons among the 3 domains; with a single cruise we can only highlight differences observed.

Growth rates of Crustacea can also vary in response to food quality and quantity (Omori, 1970; Ikeda, 1971; Boyd et al., 1978; Ross, 1981). There is some evidence that potential food resources for Crustacea did vary across the Eddy F boundary. Tranter et al. (1980a) have shown the spring phytoplankton bloom occurred 1 mo later inside Eddy F than outside. Tranter et al. (in press) found differences in copepod species distribu-



tion, but not biomass, between inside and outside Eddy F. Brandt (1982) found some myctophid fish were feeding on salps outside, but not inside the eddy, apparently in response to the increased salp abundance outside Eddy F. These differences in food resources may also contribute to differences in the growth and reproduction of crustaceans.

The higher tissue carbon levels found in *Oplophorus spinous* and *Sergia prehensilis* at the eddy edge suggest that some enhancement of physiological condition has occurred compared to the other 2 regions. A number of studies (Uda, 1959; Pingree et al., 1976; Savidge, 1976; Fourier, 1978; Simpson and Pingree, 1978; Iverson et al., 1979; Floodgate et al., 1981) have shown increased phytoplankton and zooplankton levels at oceanic fronts. If this also occurred at the eddy edge, phytoplankton and zooplankton concentrations may accelerate growth rates and improve the condition of animals further up the food chain. Boyd et al. (1978) have argued that reduced levels of tissue carbon found in *Nematoscelis megalops* in cold core rings were due to starvation. Perhaps the increase in tissue carbon found in our study may be due to increased food abundance at the eddy edge relative to the other areas. Tranter et al. (1980a) has shown the Eddy F edge had consistently larger phytoplankton standing stocks between September and December 1978; but the evidence for higher zooplankton biomass in this region is not as clear.

In summary, different crustacean communities were found outside, inside, and at the edge of warm-core Eddy F. The inside community may represent a community trapped when the eddy separated from the EAC. Eddy populations of cosmopolitan species showed abundance differences, changed size-frequency distributions, fecundity, and proportion of breeding individuals compared to edge, and outside populations. These differences may be caused, at least in part, by differences in the physical, chemical, and biological habitats in the 3 domains. Warm-core eddies may thus present a unique opportunity to study the effects of altered environments on oceanic micronekton species and communities.

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