

**Coastal zooplankton communities of south eastern
Tasmania**

by

Fabienne Cazassus,

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Statement

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18/08/2003



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Abstract

The spatial variations of zooplankton communities (i.e. dispersion and retention) between an inshore embayment and an adjacent offshore coastal site were investigated. Water enters the bay by its northern shore and circulates through it in a clockwise direction during an outgoing tide and an anticlockwise direction during an incoming tide.

Distribution of some species, such as *Calanus australis*, *Temora turbinata*, *Noctiluca scintillans*, *Podon* sp, *Penilia* sp., showed a retention time in the bay of around 4 to 6 weeks. Although there is clear evidence that mixing occurred between the bay and the channel via a complex combination of winds and tides, and no barrier or gradient could be identified, some species were found only in the bay: examples are *Oikopleura* sp., crustacean larvae, *Clausocalanus ingens*, and *Oithona* sp., which were retained in the bay probably through a combination of behavioural strategies e.g. vertical migration or selective predation. Some oceanic species even maintained their position outside the bay (*Labidocera cervi*), and were not found inshore.

Temporal and spatial variations of the surface zooplanktonic and neustonic communities of the south east coastal waters of Tasmania were studied. Data on the neuston in Australia are scarce and distribution and life history of most of these species are poorly known. *Pontella novaezelandiae* (Pontellidae, Copepoda) (Farran 1929) was recorded for the first time in Tasmanian waters. Fifteen specimens were encountered during summer 2000-01, whereas the previous records in the region were mostly in autumn-winter off the North Island, New Zealand. *In vitro* observations of another neustonic species, *Labidocera cervi* (Pontellidae, Copepoda) (Kråmer, 1895), revealed some diel migration patterns. Adults live within the surface 10 cm layer during daylight

and spread throughout the water column just after dusk, and juveniles spend most of their time at the surface, day or night. Some observations on the life history and ecology of these two neustonic species are described.

The data obtained during 2000-01 sampling season were compared with earlier data from 1971-73 sampled in nearby coastal waters. At the same site, using the same methodology, two distinct communities were obtained in 1971-73 and 2000-01. The importance of Antarctic and subantarctic species is greatly reduced compared to 1971-73 and the abundance of subtropical species has increased. These observations are supported by changes in sea surface temperature and salinity off this coast during the last 45 years. Changes in the zooplankton community cannot be explained by the ENSO cycle. These changes are consistent with a regime shift that has been described in the North Pacific.

Acknowledgements

This was such an incredible adventure ! An adventure with excitements, fear, doubts and finally accomplishments. There are so many people to thank, people who had make this adventure possible, and help me through it. My first thanks go to David Ritz, my supervisor, for his encouragement, his help in all little and big things and most of all for his tremendous patience with me. Many thanks to Graham Hosie and Kerrie Swadling too who taught me a lot about copepods. My colleagues and friends who were there at all the moments, sad or fun, and who gave me the courage to finish this project. I would like to give a special thanks to all the Zoology team; they have been so kind with me : Sherrin, Kate, Barry, Kit, Wayne and Simon. During all these moments at sea, fishing plankton, I met many friends, dolphins, seals and some humans, but one in particular I kept; thank you Richard for all these great drives. Finally I think the IS team is amazing, available, helpful and they keep a close watch on international students' needs. Thanks to Diane, Biddie and specially Rose. Keep up this great work!

Maintenant que tout est fini, je peux enfin vous dire comme cela a été dur mais en fin de compte ça en valait la peine. Vous m'avez permis de dépasser des limites dont j'ignorais tout. Vous m'avez donné les moyens matériels mais surtout la force morale de réaliser un rêve. Vous m'avez soutenu à chaque pas, même sans le savoir. Je vous dois tout ce que je suis, Papa et Maman. Mille mercis aux grands cœurs que sont mes sœurs, Sabine et Carole, sans vous je ne serais que la moitié de moi-même. Merci pour cette aventure.

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1 General Introduction

The island of Tasmania is at a crossroad of winds and ocean currents. Three major current systems converge around the island: the south-flowing East Australian Current (EAC) on the east coast, the Zeehan Current on the west coast; and the Antarctic Circumpolar Current that flows from west to east around the globe (Crawford et al. 2000). Interaction between these subtropical and subantarctic waters contribute to the subtropical front (convergence), the position of which varies seasonally (approx. 42°-45°S). Strength of the EAC varies according to El Nino/Southern Oscillation (ENSO) cycles, and largely controls the location of the convergence off Tasmania's east coast (Harris et al. 1987). The westerly wind belt of the southern hemisphere has a dominant influence on the climate of the island (Williams, 1987, Harris et al. 1988). As the westerly wind belt's position over Tasmania is determined by a continental high-pressure area, the Tasmanian climate is directly linked to ENSO events. Harris et al. (1988) demonstrated a clear cyclical pattern in these zonal westerly winds (ZWW), with a mean periodicity of 11 years.

Only a few (relatively) recent papers deal with research undertaken on the plankton communities of Tasmanian coastal waters and their hydrological affinities. Coastal waters of south east Tasmania were most strongly influenced by subtropical water in Feb-Mar and by subantarctic water from Aug- Jan according to Taw and Ritz (1979). Harris et al. (1987) demonstrated the seasonal and interannual variability of water masses and the correlation with the phytoplankton productivity on the east coast of Tasmania, using data collected at a monitoring station to the east of Maria Island in the south east of the State. The temporal variability of the krill (*Nyctiphanes australis*) population and its relationship with the Jack Mackerel (*Trachurus declivis*) fishery on the east coast of Tasmania were reported by Young et al. (1993). Despite the

complexity of the oceanography off the Tasmanian east coast, very few studies have been conducted on the role of such physical variability on the biology and ecology of the area.

Phytoplankton and zooplankton are strongly dependent on their environment, so they tend to become specialized for certain conditions (e.g. temperature, salinity, turbulence, etc.), and thus water bodies develop a characteristic community for each combination of ecological conditions. A study of the temporal and spatial variability of these communities would be a good indicator of the impact of physical variations on the biological elements. A comprehensive picture of the distribution of zooplankton communities along the Tasmanian east coast and in oceanic waters was provided by Taw (1975). He also conducted a thorough study on zooplankton distribution along the Derwent estuary. However, he did not investigate the role of behaviour in maintenance of these distributions. Moreover, he did not compare distribution of coastal and shallow inshore zooplankton, particularly where there is no salinity gradient. After more than 30 years, and in a context of global warming and climate changes, a temporal and spatial comparison of the zooplanktonic communities is considered valuable and relevant.

1.1 Zooplankton inshore-offshore distribution

Numerous studies have been undertaken on the vertical migrations of zooplankton (Hardy, 1947; Champalbert, 1977; Greenblatt, 1982; Harding et al., 1986; Nagasawa, 1991; Robinson et al. 1995; Hays, et al. 1996). Most of these studies were in the Northern Hemisphere, with the notable exceptions of Bradford-Grieve (1977) in New Zealand, and Greenwood and Othman (1979), Kimmerer and McKinnon (1985, 1987a,b) in Australia. They showed that some taxa undertake diel vertical migrations to avoid predation (particularly in the daytime), and also that some migrate vertically to

preserve their horizontal position in a bay or an estuary. But not many studies have tried to understand the horizontal migrations of zooplankton communities. Zooplankters have been considered "passive drifters" for a long time, but as Wiafe and Frid (1996) showed very clearly; physical factors such as wind field and rate of horizontal transport can account for more than 50% of the temporal variations of a zooplankton community structure. These structures lasted for at least 3 hours whether there was turbulent mixing or not and so we tend to accept the term "active drifters" nowadays (Wiafe and Frid 1996). Secondly observing the horizontal migrations of a particular zooplankton community tends to be difficult due to their naturally patchy distribution pattern. Nevertheless a few studies address the problem of inshore-offshore migrations where it is in an estuary or in a bay.

According to Archambault et al. (1998), dispersion of larvae released by benthic invertebrates does not depend on the shape of the bay, although the wider the bay the lower the abundance. This is because of a loss of larvae, whereas in a semi-enclosed bay the larval dispersion is limited. It was found that the biomass and abundance was always higher inside the bay than outside, and the ratio of meroplankton abundance/holoplankton abundance was always greater than 1, thus supporting the hypothesis of production and retention of larvae in the bay (Archambault et al. 1998).

In the case of holoplankton (or zooplankton in general), several studies were conducted in Australia in semi-enclosed bays with a small channel leading to the ocean (Kimmerer and McKinnon 1985, 1987b, 1988; Kimmerer 1993; Swadling and Bayly 1997). The mixing of zooplankton between bay and ocean is mostly the result of tidal currents and winds. In a semi-enclosed bay, retention time of the water is important and seems to increase with a decrease of the hydraulic connection with the ocean. Two distinct communities were found each time and the factors explaining these differences

cannot be due to hydraulic connection alone (Swadling and Bayly, 1997). The nature of the seabed could be a critical factor if it is based on seagrass, since many organic nutrients are released into the water from decaying leaves and provide a resource for microbes, protists and fungi. Seagrass also would provides habitat and protection for planktivorous fishes. Predation is possibly more important in shallow waters, due to higher individual density and hence greater encounter rate. Non-resident species would be more vulnerable than resident ones like *Acartia tranteri*, which was found to be well adapted to shallow coastal waters and which is predominant over *Paracalanus indicus* in a bay in Victoria (Kimmerer and McKinnon, 1987a). Lastly the variations in salinity and temperature, resulting from the freshwater supply, would limit the biodiversity of zooplankton, and keep the oceanic species outside the area of euryhaline influence (Kimmerer and McKinnon, 1987b; Greenwood, 1982).

Some species, like *Acartia tranteri*, are specialized and well adapted to embayment conditions, in that they avoid being washed outside by the tidal currents by migrating vertically (Mathivat-Lallier et al., 1990; Kimmerer and McKinnon, 1987a). They seem to use the turbulent motion to enhance their ability to move vertically and thus prevent the loss of adults from the bay through mixing. In response to the tides, they are more abundant in the water column on the flood than on the ebb. However, this phenomenon has not been observed amongst non-resident species to prevent them being displaced out of the bay (Kimmerer, 1989). Manuel and O'Dor (1997) even argue that all vertical or diel migration for the purpose of horizontal transport follows one stage or another of the lunar cycle.

Except for Archambault et al.'s study (1998), all data or observations obtained on plankton migration are limited to estuaries or semi-enclosed bays. Archambault et al. showed that even an open bay demonstrates a distinctive zooplankton community

structure compared with the outside. However, their work focused exclusively on larval dispersion and meroplankton.

1.2 Variations in zooplanktonic communities since the 1970s

A specific body of water has a characteristic zooplanktonic community. Thus zooplankton communities can generally be considered as indicators of their environment and inform us about its state of health or the environmental factors impacting on it. Using this concept, a survey of the zooplankton community of a specific area would show any variations in the water type in time and space and in the quality of the water (Colebrook, 1982; Brodeur et al., 1996; Hays et al., 1996; Sugimoto and Todokoro, 1997; Lindley and Batten, 2002). Such surveys exist for the North Pacific, the Bering Sea, the North Sea, but none exist for the Indian Ocean, the South Atlantic and the South Pacific. A common trend appears in all those surveys: a warming of the sea surface temperature within the last few decades. The interannual cycles described vary from place to place; their length varies from 9-10 years to 50 years depending on the study. In 2000, Hare and Mantua showed evidence of two regime shifts in the North Pacific; the first one happened in 1977 and the second one in 1989. These two shifts were apparently not part of a cyclical change since the climate before 1977 differed from the one after 1989. For the moment, no explanation has been advanced to clarify those shifts.

The east Coast of Tasmania is a very dynamic area, under a strong influence of ENSO events (Williams, 1987), and the presence of the subtropical convergence adds to the complexity of the system. The Australian Commonwealth Scientific and Industrial Research Organization (CSIRO Division of Marine Research) has maintained a coastal

monitoring station to the east of Maria Island ($42^{\circ}36'S$, $148^{\circ}16'E$) since 1944, and sea surface temperature (SST), salinity, nitrate and phosphate concentrations have been surveyed each year. Although Young et al. (1993) only studied the krill, (*Nyctiphanes australis*), distribution off the eastern Tasmanian coast, they also showed the influence of ENSO events on Tasmanian waters. Studies by Harris, et al. (1987; 1988) show the presence of 11 year cycles linked to the ENSO events, but superimposed on this cyclical pattern, the SST seems to have increased in the last 45 years (Rochford, 1981; Harris, et al. 1988).

The most complete description of Tasmanian zooplankton communities is that by Taw (1975). The dataset collected by Nyan Taw, provided me with an opportunity to compare the zooplankton community of 30 years ago with the present one, and to describe and quantify any possible changes.

On the basis of previous studies, the following hypotheses can be proposed:

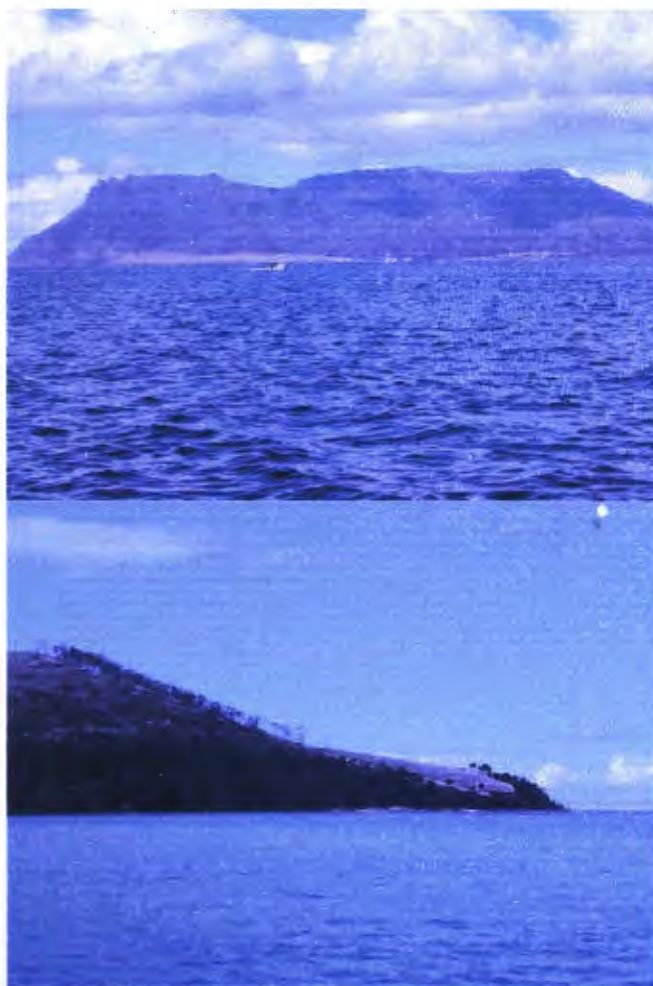
1. the zooplankton community of an inshore semi-enclosed bay will be significantly different to that of the adjacent coastal water.
2. There have been changes to zooplankton communities of the Tasmanian east coast over the past 30 years and these have been substantial enough to constitute a regime shift.

The objectives of the present study are

- to describe the zooplankton, including neuston, community of an inshore coastal region of south east Tasmania;
- to compare the zooplankton community of a shallow semi-enclosed bay with that of an adjacent coastal site;
- to compare the coastal zooplankton community with that described 30 years ago by Taw (1975).

situated only 13 km to the east. The high profile of the island reduces exposure to prevailing wind and current. So the oceanic influence is mitigated compared to a bay on an open coast, and there is no salinity gradient in the bay. Thus the physical factors influencing the community structure are limited to tidal current and wind from the channel (Mercury Passage) between Maria island and mainland Tasmania. This study aims to compare the zooplankton community of Okehampton Bay with the community in Mercury Passage, immediately outside the bay, throughout the year, and to relate these to currents and hydrography.

2.2 Methodology



Mercury Passage, with Maria Island in the background

Okehampton Bay, east coast of Tasmania.

Fig. 2.1 Study sites

2.2.1 Site description

Okehampton Bay ($S42^{\circ}31'38.5''$, $E147^{\circ}59'13.3''$, East Coast of Tasmania, Fig. 2.1, 2.2) was chosen as a sampling site because it is open and shallow (under 10 m

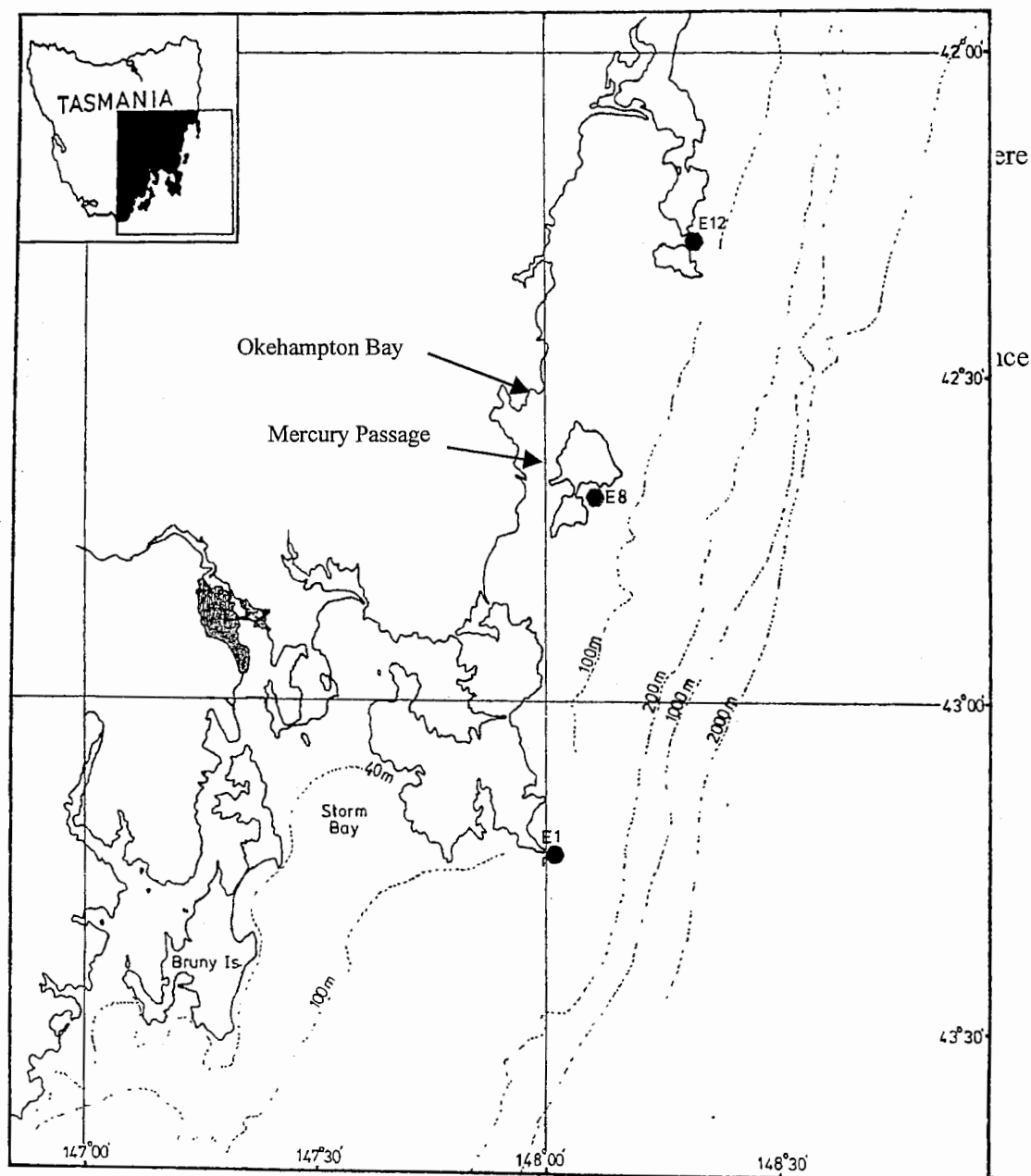


Fig. 2.2 Map showing location of Okehampton Bay and Mercury Passage (modified from Taw, 1975). ● 1971-73 stations occupied by Taw (1975).

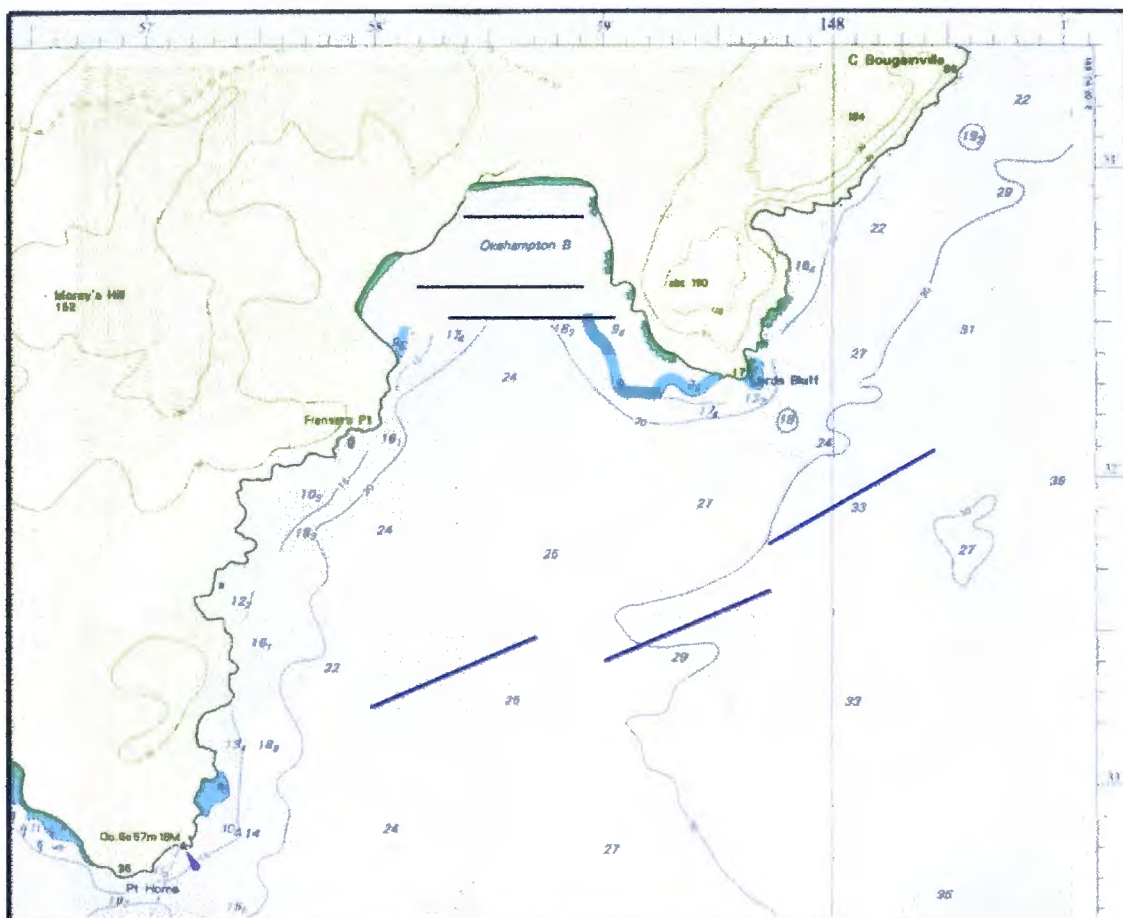


Fig.2.3 : Sampling sites showing replicate tracks in Okehampton Bay (black) and in Mercury Passage (blue).

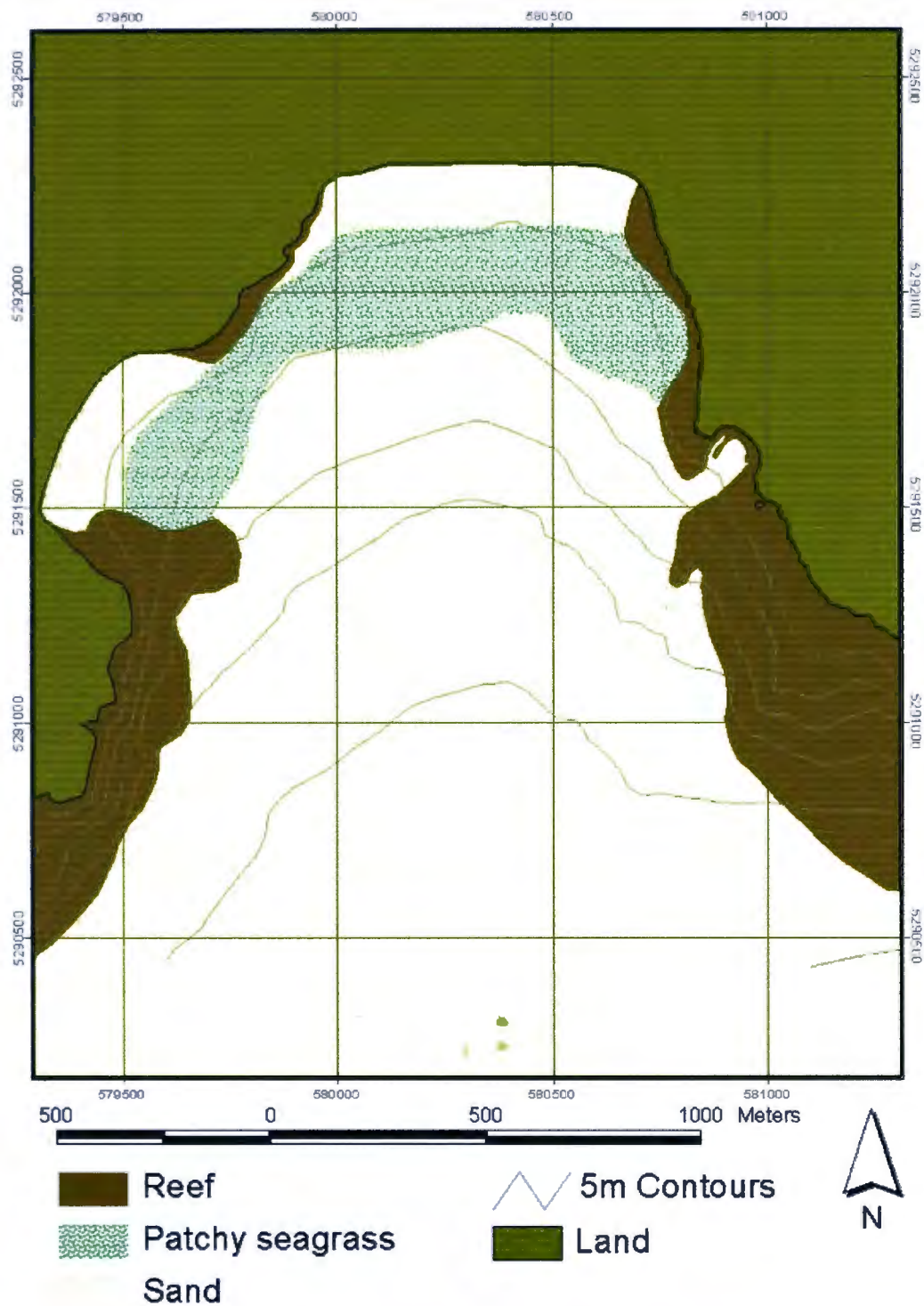


Fig.2.4 : Seabed characteristics of Okehampton Bay (provided by A. Jordan and M. Lawler, Tasmanian Aquaculture and Fisheries Institute).

2.2.2 Field procedure: sampling

Zooplankton samples were collected at two sites: Mercury Passage and Okehampton Bay (Fig. 2.2, 2.3), on seven occasions between March 2000 and March 2001. The net was towed horizontally through the surface waters of the bay, and along the tracks shown in Fig. 2.3. A double net (Figs 2.5, 2.6) was designed to sample planktonic and neustonic communities simultaneously. The apertures of each net were 100 cm wide by 10 cm high for the top net and 100 cm wide by 20 cm high for the bottom one. Both nets were 150 cm in length and the mesh was 300 μm .

To sample, the net was towed at the surface on a 15 m cable and at a speed of 1 m.s^{-1} . To maintain the net horizontal, floats were fixed on each side of the aperture and the sampling was mostly made when the sea was calm. The upper net was nearly fully submerged when underway. The volume filtered was given by a calibrated flowmeter (General Oceanics) fixed in the middle of the bottom net; depending on the abundance of zooplankton, the net was towed for 5 to 10 min for 3 or 4 replicates.

In addition to the above, zooplankton was sampled every 6 h for 48 h at the Mercury Passage site in November 2000. Due to time limitations, only ctenophores were enumerated from these samples.

Samples were preserved in 5% formalin immediately after return to the laboratory; they were then transferred to 70% alcohol prior to sorting.

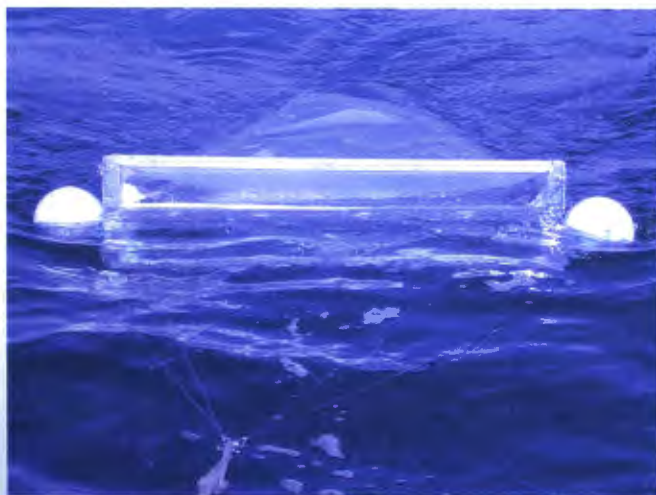
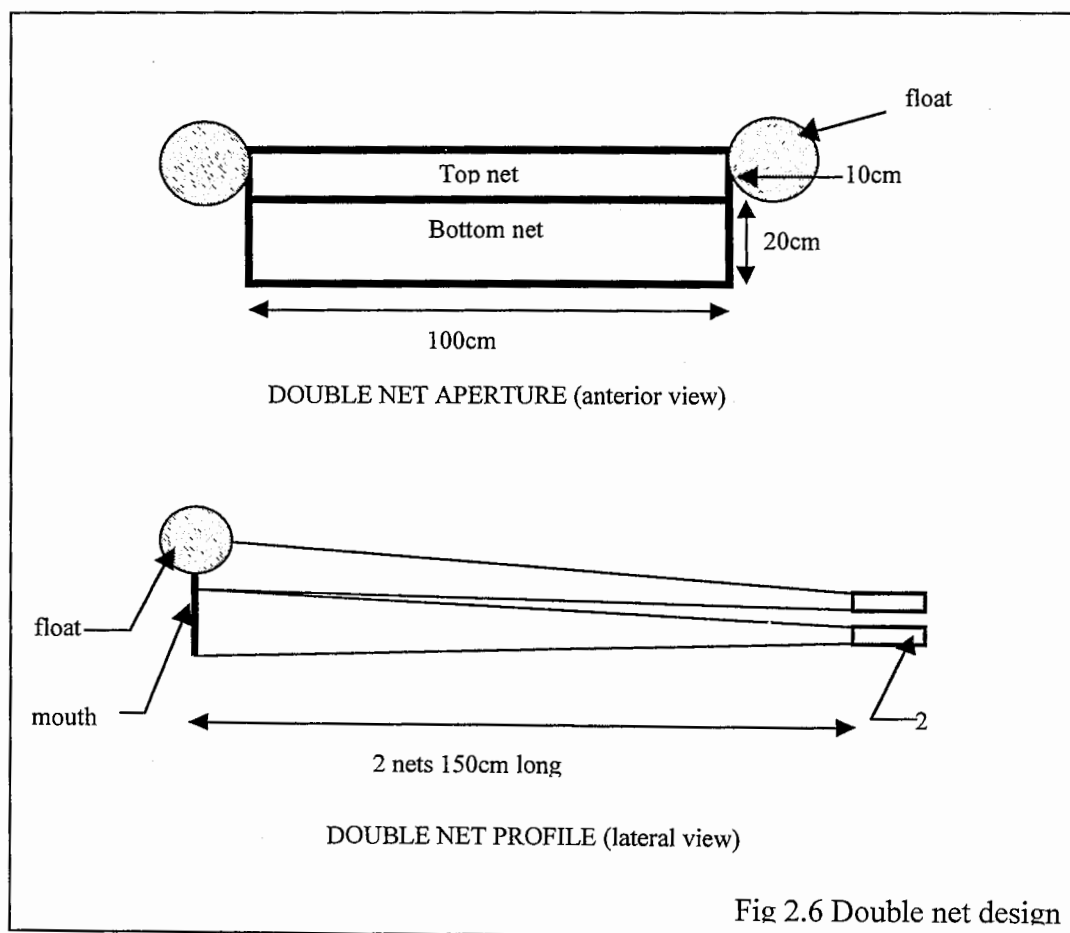


Fig. 2.5 Double-net towed behind a small boat.



Temperature and salinity were measured at each sampling date using a calibrated salinometer (WTW LF196).

A drogue (Fig. 2.7) was designed to follow the surface current in the bay and its surroundings. It was constructed from marine ply with an area of 1 m^2 and floated 10 cm below the surface by means of a float and a weight.

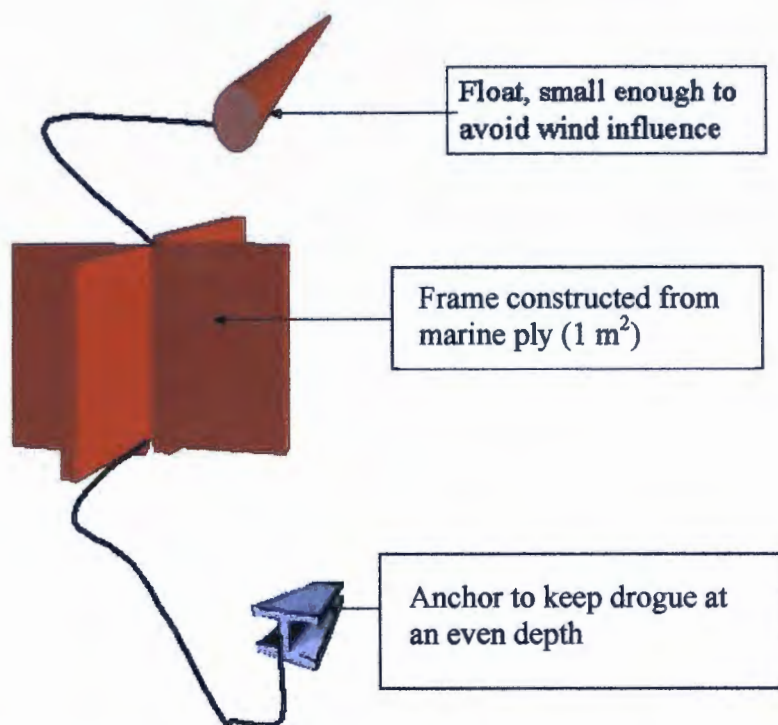


Fig 2.7 Construction of the drogue used to study tidal currents

The drogue was deployed at different points in the sampling area and allowed to drift for 1 h during both an incoming tide and an outgoing tide. Release and recovery points, and also positions in between at intervals, were identified using a GPS (Garmin GPS 12).

2.2.3 Laboratory procedure: sorting and identification

With dense samples, only 10% of the sample was sorted for the most abundant species; sample splitting was carried out using a Kott whirling subsampler (Kott, 1953) and the results of two replicates averaged. Then the whole sample was checked for rare species. Sorting was done using a stereo microscope (Nikon, SMZ-2T) and a 20cm diameter plankton wheel.

The organisms were identified to species where possible using a compound microscope (Nikon, Labophot) for some of the copepods. Keys described in Bradford-Grieve (1999) were used to identify the copepods, as well as those given by Taw

(1975). Dakin and Colefax (1940) was used for larvaceans, cladocerans and other crustaceans.

2.2.4 Biomass

Formalin preserved samples were filtered through a 60 μm sieve, rinsed with isotonic ammonium phosphate to wash the seawater, transferred to crucibles and weighed as an estimate of biomass. They were then dried in an oven between 60-70°C overnight, and weighed again, to give dry weight. Lastly they were burnt in a furnace at 450°C overnight and their ashes weighed.

2.2.5 Statistical analysis

The data are expressed as number of organisms 100 m^{-3} . Only two replicates were completely sorted for each set of samples, and the average was calculated. Samples were compared using a Bray Curtis dissimilarity index and results are displayed as a cluster diagram showing the relationship between sites, seasons and years.

2.3 Results

2.3.1 Salinity and temperature

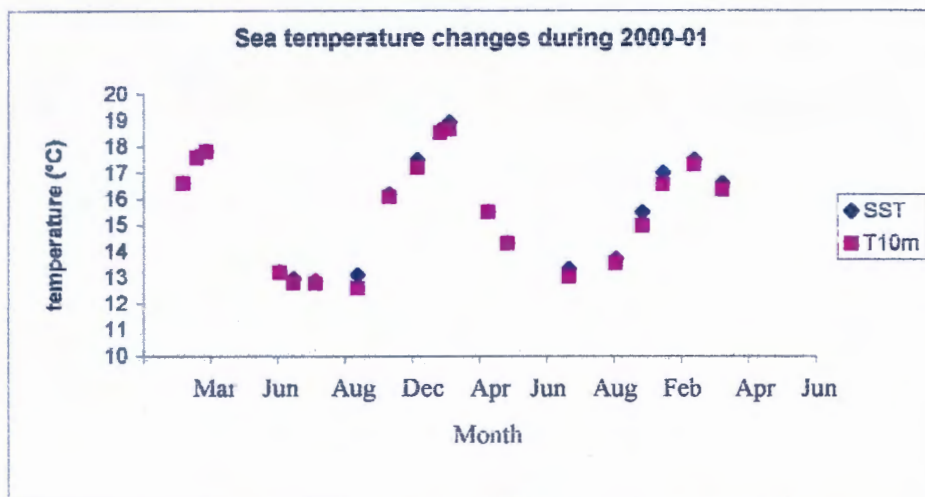


Fig.2.8 : Comparison of temperature at the sea surface and at 10m during 2000-2001.

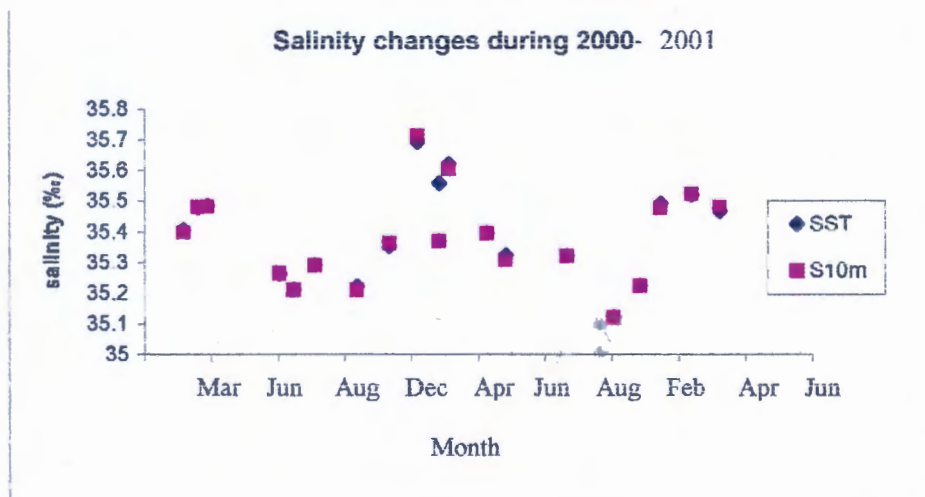


Fig.2.9 : Comparison of salinity at the sea surface and at 10m during 2000-2001.

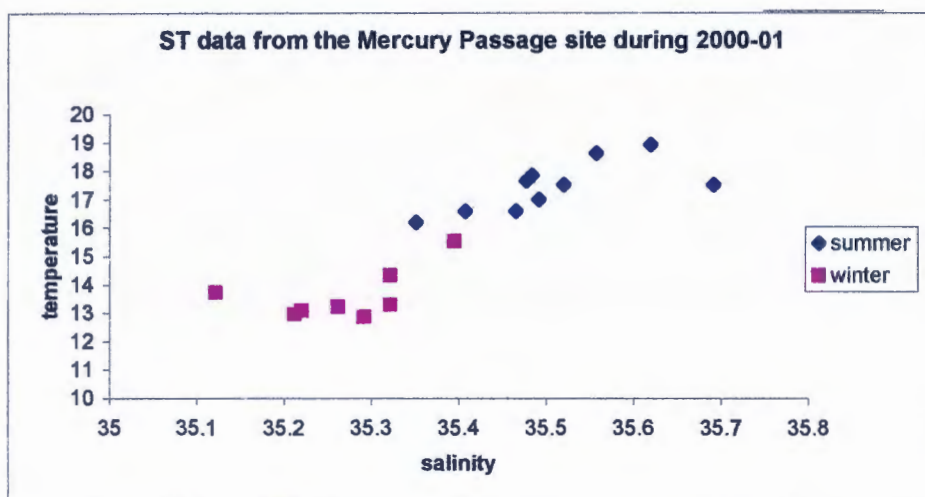


Fig. 2.10: Salinity/temperature relationship during 2000-2001.

The results for temperature and salinity were exactly the same for the two sites; only one dataset is shown here (Figs 2.8-2.10). The temperature clearly showed the seasonal pattern and there was no difference between the 2 depths (0, 10m), indicating a well-mixed water column.

The change in salinity throughout the year was quite variable but there were summer maxima (Dec-Mar) and winter minima (Jun-Aug) (Fig. 2.9). A ST graph showed a clear trend (Fig. 2.10) with a minimum in salinity and temperature in winter and a higher temperature and salinity in summer. The summer presumably reflects the influence of the East Australian Current, while the winter water may represent coastal water modified by additions from the Zeehan current and some contribution from subantarctic water.

2.3.2 Currents in the bay: Results of the drogue trials

Drift tracks of the drogue are shown in Figs. 2.11-2.14.

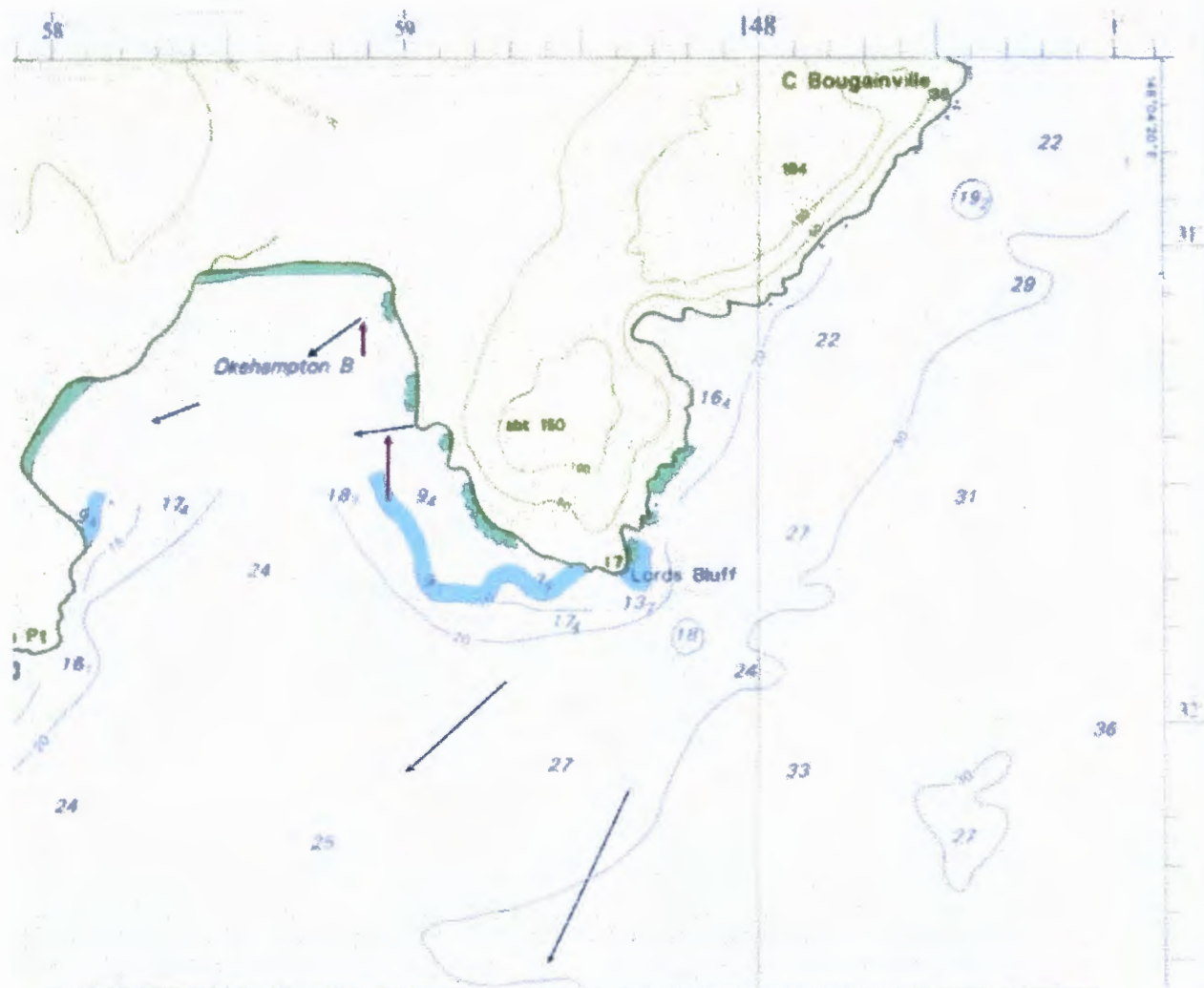


Fig 2.11 . Drift track of drogue on the 4th of July 2001 during an outgoing tide. Black arrows represent the movement of the drogue in one hour from its point of release to its point of recapture. Red arrows show the wind direction and strength for each trial. 1 cm corresponds to 1 knot for both current and wind speed.

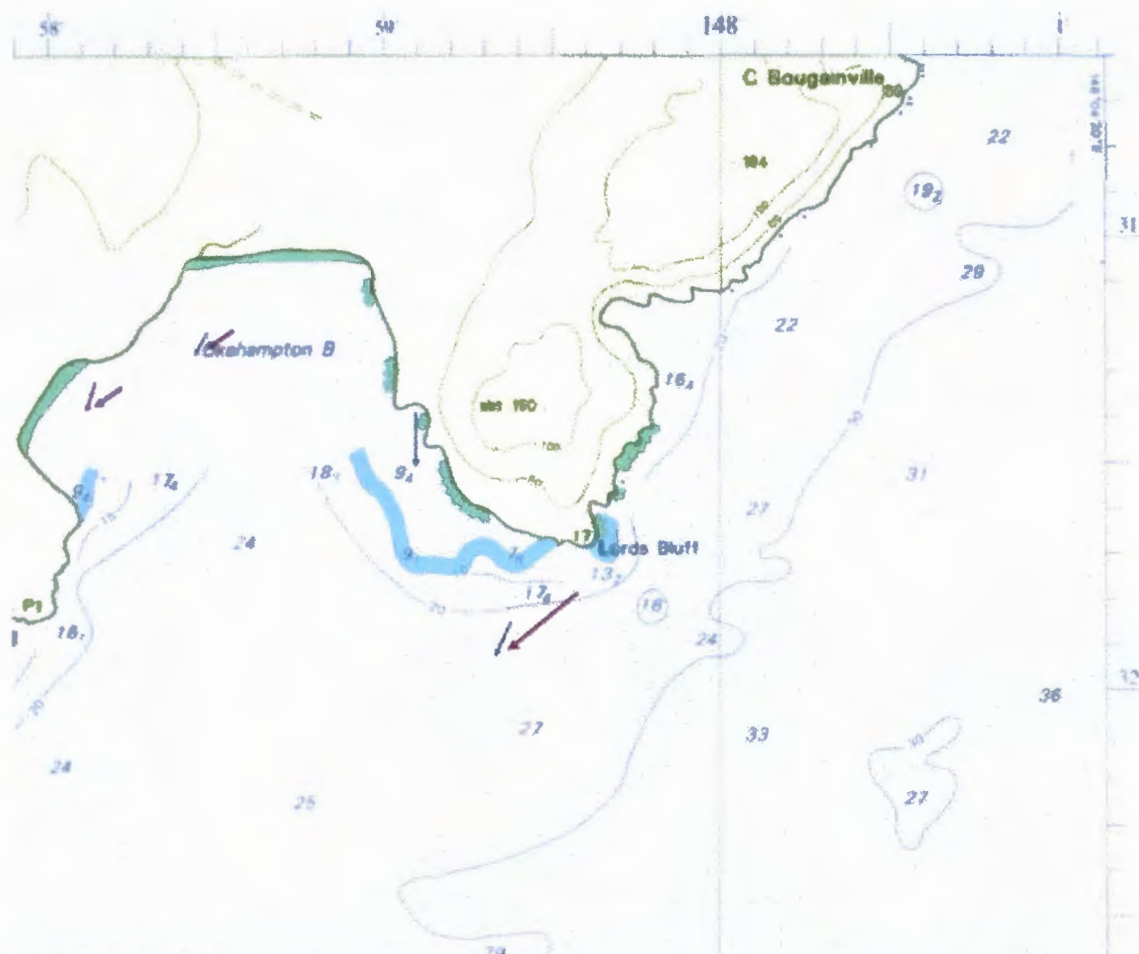


Fig 2.12 . Results from drogue trial on the 17th of December 2001. during an incoming tide. Black arrows represent movement of the drogue in one hour; Red arrows show the wind direction and strength for each trial.

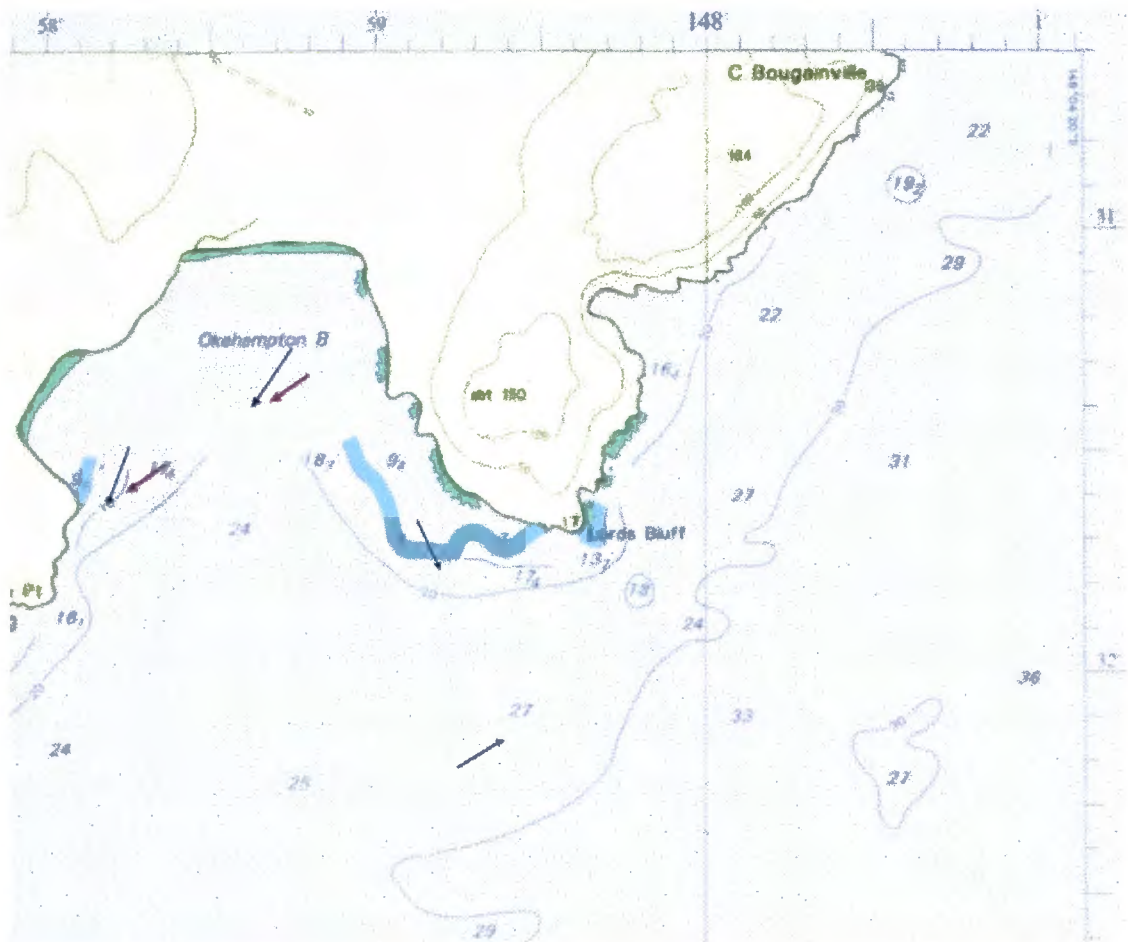


Fig. 2.13 : Results of drogue trial on the 23rd of April 2002 during an incoming tide. Black arrows represent movement of the drogue in one hour; Red arrows show the wind direction and strength for each trial.

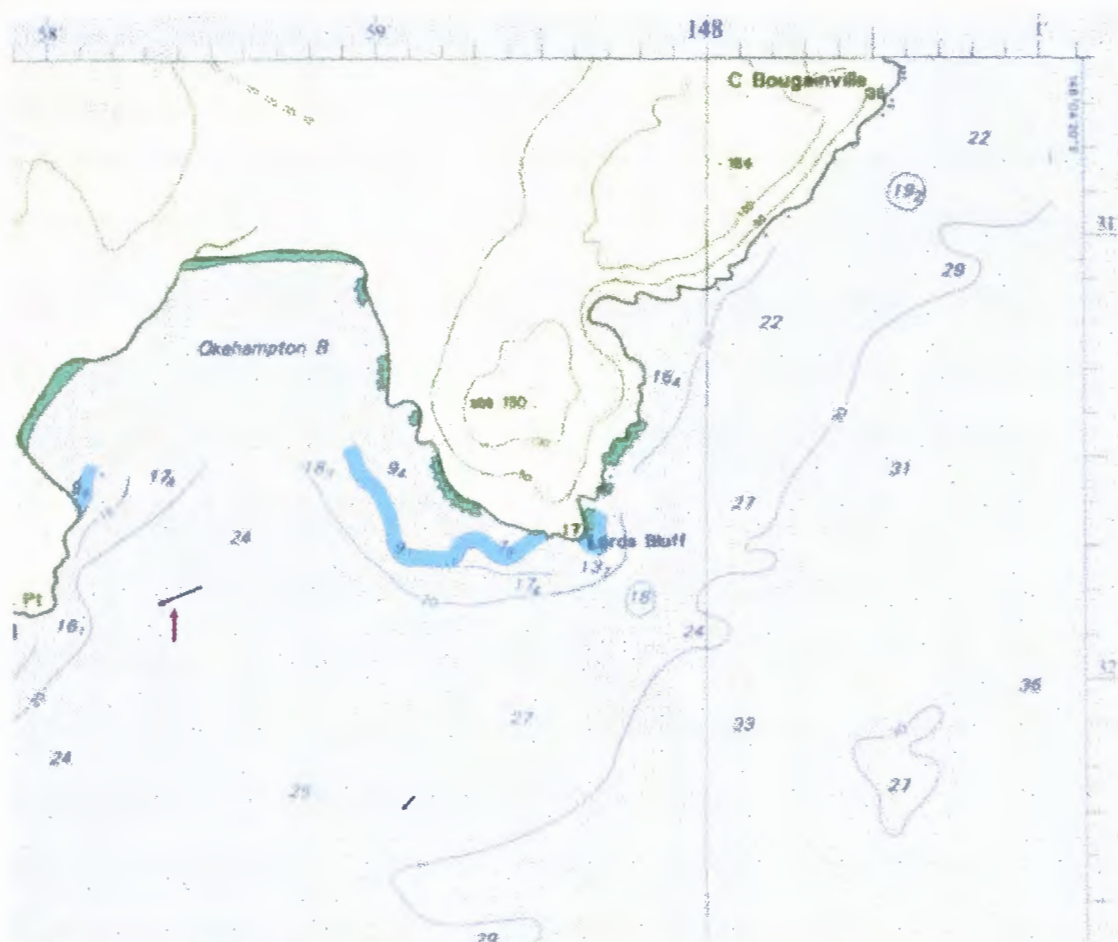


Fig. 2.14 : Results of drogue trial on the 27th of July 2001 during an incoming tide. Black arrows represent movement of the drogue in one hour; Red arrows show the wind direction and strength for each trial.

Drogue trials had to be conducted in the morning since this was the only time when the wind was sufficiently weak. Only 4 trials were completed; three during an incoming tide, and the last one during an outgoing tide.

Because there is no fresh water supply within the bay, the main abiotic influences on plankton are defined by the tidal movements and winds. Depending on the season, the winds can be from north west or from the south, and when present their influence will dominate the tidal current particularly at the surface.

Tidal currents were deduced from drogue studies and general patterns are shown in Figs 2.15 and 2.16. On an incoming tide, without wind effect, the drogue tended to

drift southward, even south east (Fig. 2.15). During an outgoing tide, the drogue drifted west-south westward (Fig. 2.16).

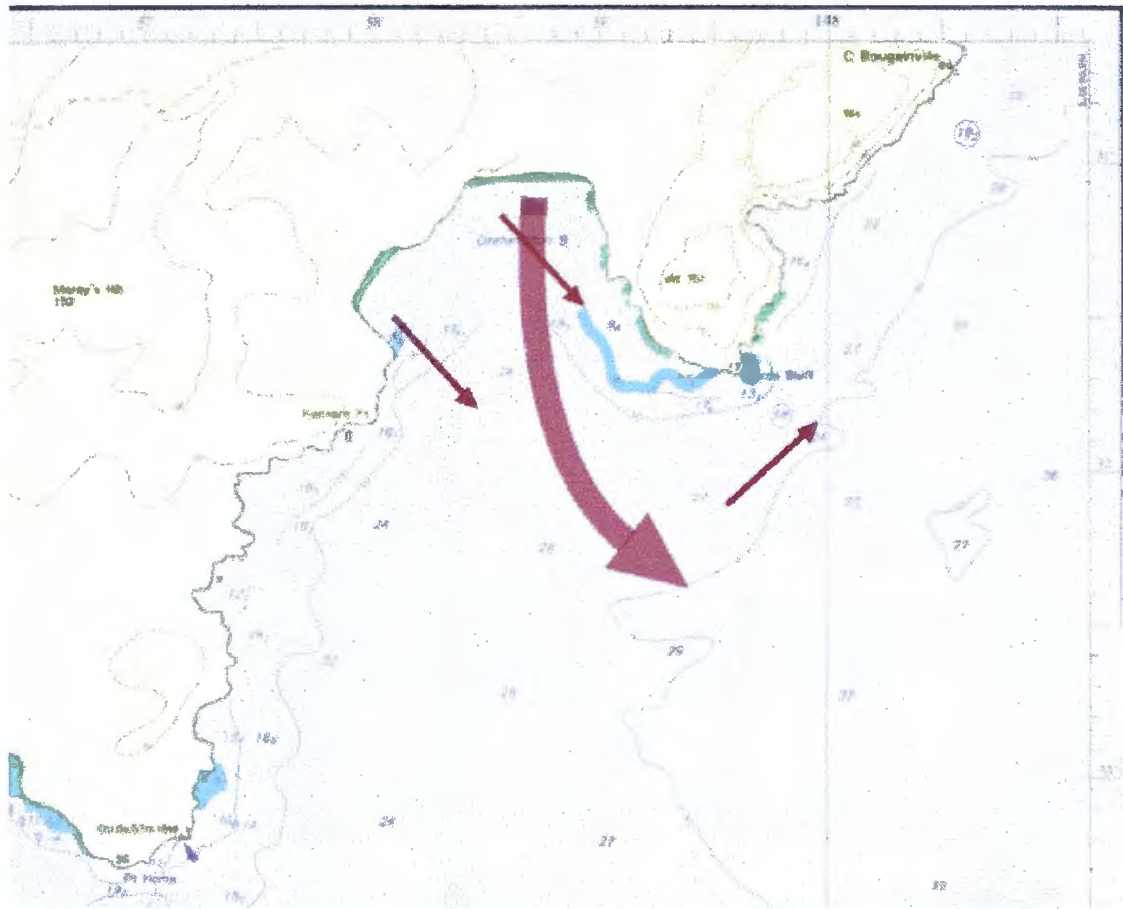


Fig. 2.15 : Generalised tidal flow (broad red line) in Okehampton Bay during an incoming tide.

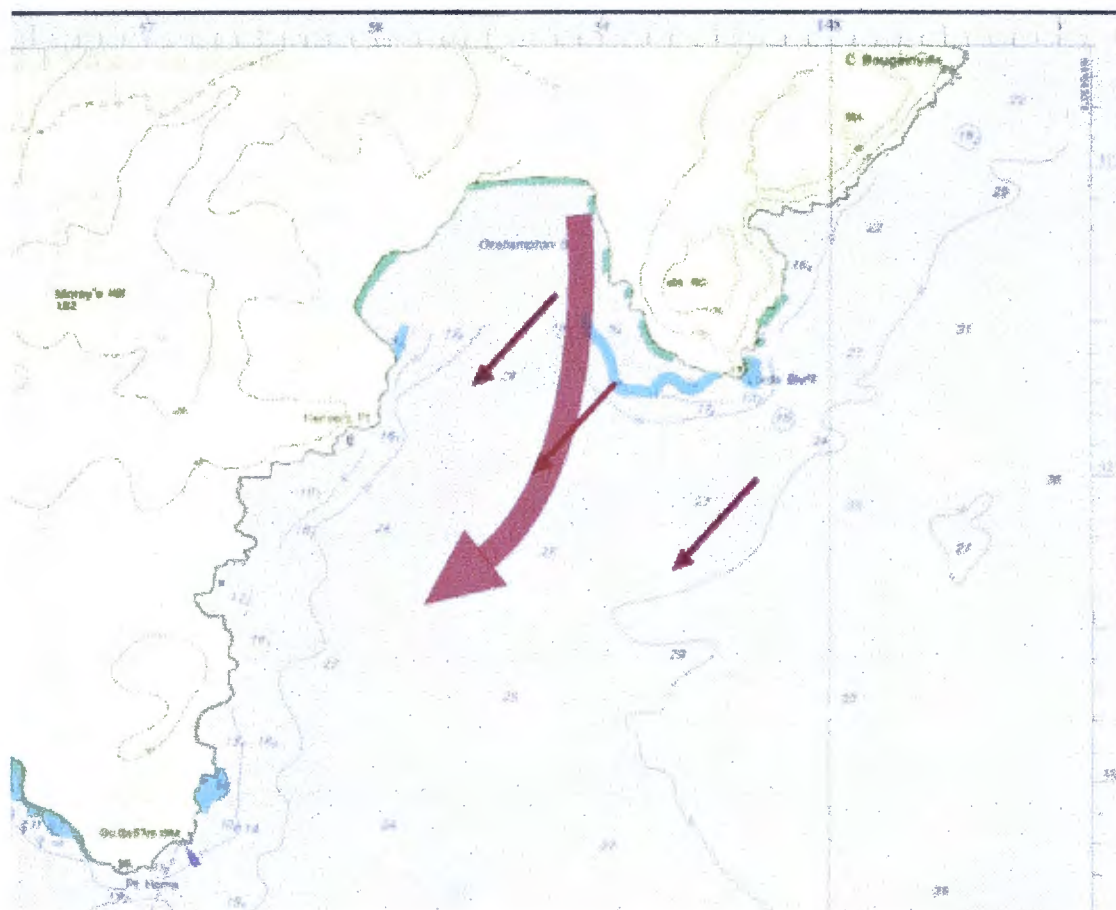


Fig. 2.16 : Generalised tidal flow in Okehampton Bay during an outgoing tide.

2.3.5 Biomass results

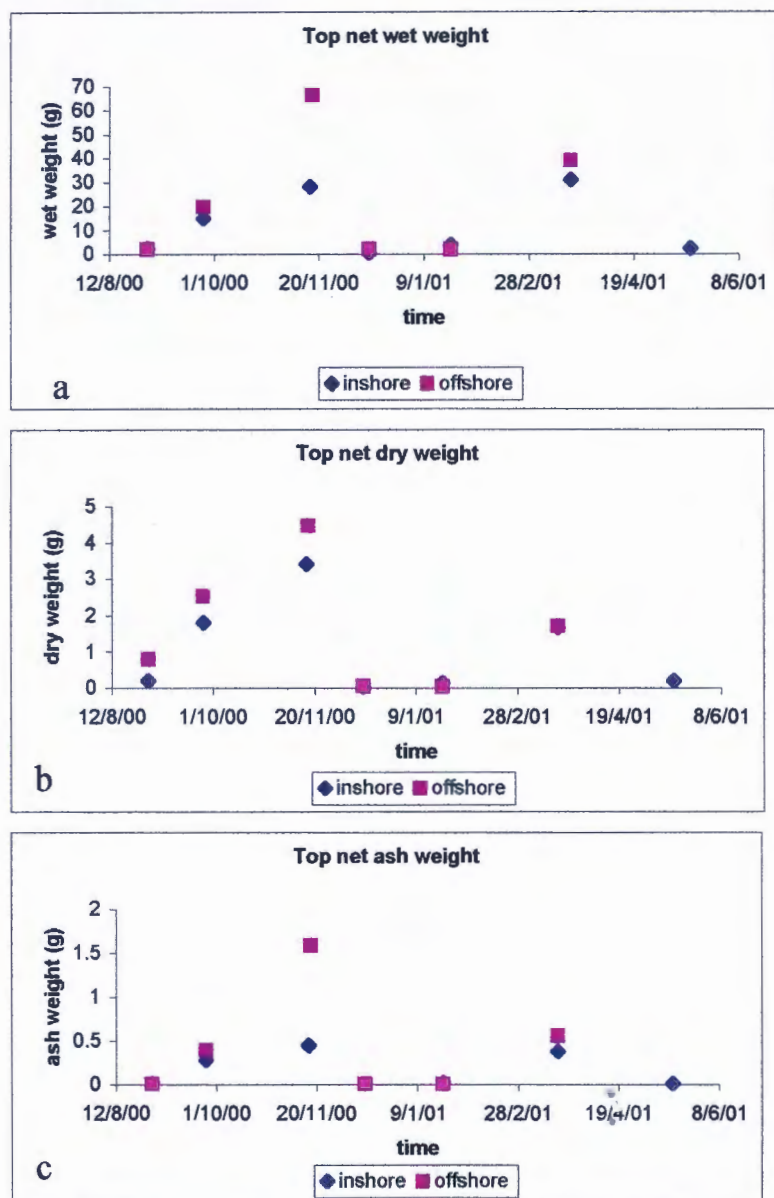


Fig. 2.17 Biomass (a), dry weight (b) and ash weight (c) of samples collected in top net.

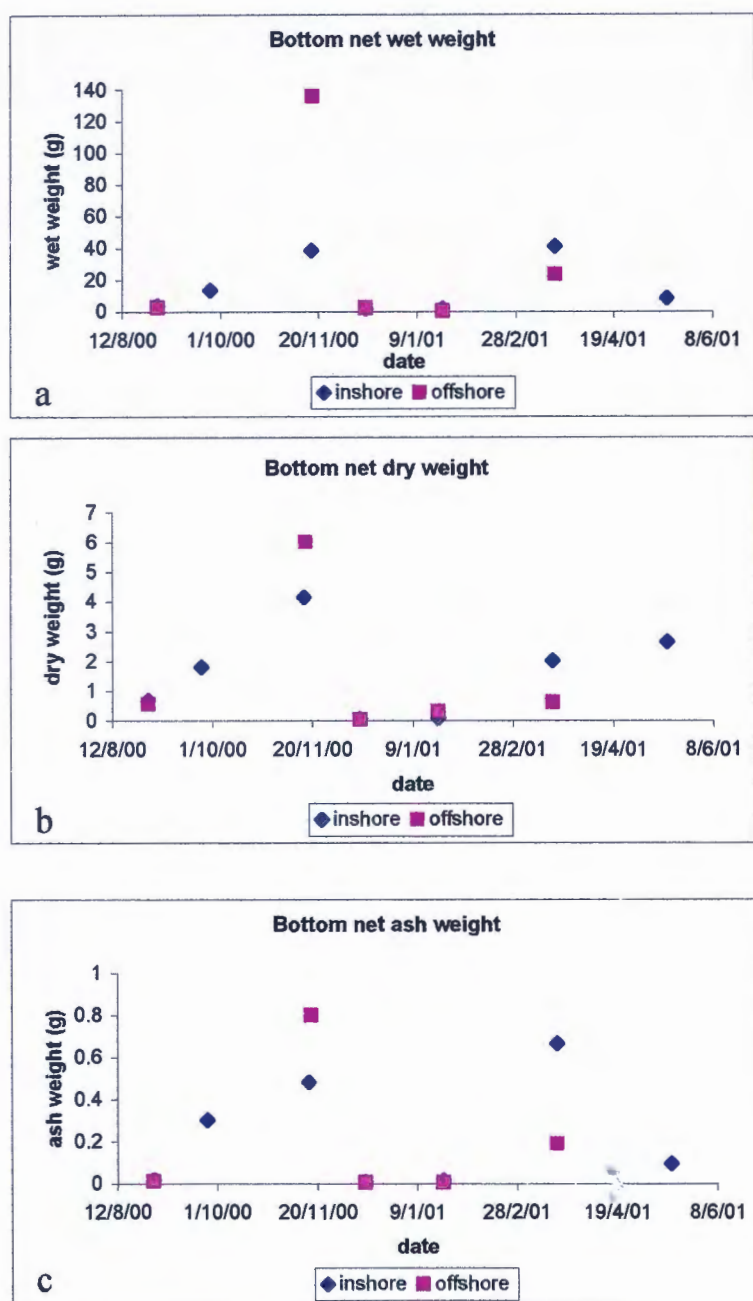


Fig. 2.18 Biomass (a), dry weight (b) and ash weight (c) of samples collected in bottom net.

In general, there was a higher biomass offshore than onshore in most samples, with one exception, but those differences were not significant (Table 2.1 $t_{22}=0.56$, $p>0.05$). The result was the same if top net and bottom net were considered separately or together. Biomass followed a similar pattern in the two sites but varied considerably

throughout out the year. Low biomass occurred in September 2000, December 2001 and January 2001, compared to the high values observed in October and November 2000.

Table 2.1. Results of t tests comparing seasonal change in biomass (dry weight) captured by both nets inshore and offshore.

	<i>Inshore / offshore all year</i>	<i>Inshore / offshore top net (all year)</i>	<i>Inshore / offshore bottom net (all year)</i>	<i>Top / bottom net (all year)</i>
degrees of freedom	22	6	6	22
t _{0.05} critical	2.07	2.23	2.23	2.07
t observed	-0.56 ns	-0.44 ns	-0.06 ns	-0.38 ns

Low catches also occurred in March 2001 and continued until May 2001 for the bottom net but not in the top net. However, the largest biomass recorded at dusk in November 2000 was the result of a dense but transient bloom of ctenophores; they were all gone by noon the next day. A low biomass throughout summer 2000-01 was characteristic of a strong La Nina influence at the time. It appeared that two peaks of biomass occurred in the year, one during spring and another smaller one at the end of the summer, beginning of autumn.

2.3.4 Seasonal changes in abundance of major species

In all, 75 taxa were identified, most of them occurring at a certain period of the year and absent the rest of the time. Species characteristic of both shallow inshore waters and oceanic waters were captured. *Acartia tranteri*, *Oithona* sp., *Euterpina acutifrons*, *Paracalanus indicus* and most larval stages, are typical of shallow coastal waters, while *Calanus australis* is an oceanic species. Their distribution throughout the year in both locations is shown in Figs 2.19a-t.

Table 2.2 shows the results of paired t-tests comparing abundance of each taxon between upper and lower nets and between inshore and offshore stations.

Table 2.2. Results of paired t-tests comparing abundance of zooplankton taxa in upper and lower nets and between inshore and offshore stations. Figures in bold are significant at $p=0.05$. Where there was insufficient data for analysis, this is indicated by -.

	Top/bottom net inshore	Top/bottom net offshore	Top /bottom net year	Inshore /offshore bottom net	Inshore /offshore top net	Inshore / offshore
to 05 critical	2,26	2,26	2,09	2,26	2,26	2,06
deg of freedom	9	9	19	9	9	25
Species or taxon						
<i>Penilia</i> sp.	1,37	-1,50	1,32	-1,50	-1,50	-2,37
<i>Evadne nordmanni</i>	2,68	1,16	2,40	2,28	1,82	1,55
<i>Evadne spinifera</i>	1,50	1,16	1,12	-1,36	-1,47	1,33
<i>Evadne tergestina</i>	-1,48	-1,68	-1,44	-1,48	-	-1,45
<i>Podon</i> sp.	1,53	-	2,57	0,19	-0,03	-0,53
L. Polychetes	0,96	2,28	1,32	-1,91	-1,63	-1,45
L. Gastropoda	0,01	2,13	1,58	-2,49	-0,30	-1,77
L. Bivalves	3,44	3,91	3,37	-1,63	-1,50	-1,94
L. Echinodermes	2,36	1,45	3,95	0,61	0,29	0,63
naup. Cirripedes	-0,29	3,37	-1,50	-1,29	-1,33	-2,53
Cypris Cirripedes	1,17	2,61	-0,77	0,18	-0,44	-0,89
Chaetognathes	1,55	3,03	1,82	-1,31	-1,32	-1,43
Cypho.						
Bryozoaires	1,15	0,70	0,60	-1,37	-1,41	-1,99
Meduses	2,33	2,17	2,92	-0,73	-2,37	-2,26
Siphonophores	-1,48	-1,49	-3,92	1,33	1,50	1,59
Salpa fusiformis	1,60	1,83	2,42	-1,81	-1,67	-2,75
Ctenophores	-	-	-	-	-	1
Calanus australis	1,72	1,36	1,85	-0,60	-1,13	-0,29
copepodits						
calanus australis	-0,84	0,53	0,27	-0,94	0,48	0,16
Calanus minor	-1,47	1,49	1,22	0,65	1,51	1,50
Neocalanus tonsus f.	-	-	-	-	-	1
<i>Calocalanus pavo</i>	-	-	-	-	-	<0.01
<i>Calocalanus styliremis</i>	-1,46	-	-1,41	-1,46	-	-1,41
<i>Eucalanus crassus female</i>	1,38	1,49	1,46	-1,54	-1,46	-2,32
<i>Eucalanus crassus male</i>	-0,56	-	-0,57	-1,48	-1,31	-1,39
<i>Eucalanus attenuatus female</i>	-1,90	-	-1,78	-1,81	-1,50	-2,02
Clausocalanus brevipes f.	-	-	-	-	-	-1,21
<i>Clausocalanus ingens</i>	1,55	-0,82	1,48	-1,56	-1,59	-1,65
<i>Clausocalanus jobei</i> f.	1,50	-	1,45	-	-1,50	-1,44
<i>Clausocalanus arcuicornis</i>	-	-	-	-	-	1,44
<i>Paracalanus indicus</i>	1,60	1,44	1,88	-1,36	-1,77	-1,83
<i>Ctenocalanus vanus</i> f.	-	1,53	1,48	1,63	1,57	2,00
<i>Ctenocalanus</i>	-	0,99	0,99	2,41	2,09	2,93

<i>vanus male</i>						
<i>Centropages bradyi</i>	-	-	-	-	-	1,61
<i>Centropages australiensis female</i>	-0,31	-1,87	-1,65	-0,67	-3,25	0,46
<i>Centropages australiensis male</i>	-1,55	0,96	0,73	1,27	1,27	2,42
<i>Labidocera cervi female</i>	1,72	-1,22	0,85	0,87	0,40	1,82
<i>Labidocera cervi male</i>	-1,10	-1,36	-1,37	1,08	1,13	1,42
<i>Labidocera sp juvenile</i>	0,82	2,97	1,32	-2,55	-2,57	0,75
<i>Labidocera tasmanica female</i>	0,24	-1,42	0,01	-2,76	-2,21	-2,97
<i>Labidocera tasmanica male</i>	1,51	-	1,46	-2,09	-1,91	0,28
<i>Pontella novae-zealandiae</i>	-	-	-	-	-	-
<i>Acartia danae</i>	1,34	-	1,31	-1,50	-1,49	-2,13
<i>Acartia tranteri</i>	2,21	1,53	1,88	0,37	0,98	1,12
<i>Temora turbinata</i>	1,26	-1,75	1,16	-2,40	-2,33	-1,22
<i>Glabidocera inermis</i>	-1,59	-	-1,53	-1,59	-	-0,78
<i>Oithona tenuis</i>	1,42	1,31	1,53	1,56	1,50	0,57
<i>Oithona sp.</i>	1,81	2,70	1,97	-1,24	-1,43	-1,80
<i>Oncea sp.</i>	1,77	1,46	1,68	-1,69	-1,76	-2,26
<i>Euterpina acutifrons</i>	1,60	1,84	1,95	-1,15	-2,15	-0,97
<i>z. Brachiura</i>	-0,17	-0,92	-0,25	-1,73	-1,90	-2,40
<i>z. Anomalocera</i>	2,10	-	1,94	-2,15	-2,52	-0,71
<i>z. Caridae</i>	0,30	-0,01	0,30	-2,44	-2,51	-3,42
<i>L. macrura</i>	1,44	-	1,41	-1,49	-1,49	-
<i>L. Stomatopoda</i>	-1,48	-	-1,44	-1,48	-	-
<i>L. Euphausiaceae</i>	0,61	0,62	0,78	-2,42	-1,71	1,19
<i>Megalopa</i>	-	1,50	1,45	1,48	1,49	2,42
<i>Mysidaceae</i>	1,31	0,17	1,33	-1,31	-1,50	1,00
<i>Lucifer hansenii</i>	-1,43	1,32	0,87	1,15	1,48	1,53
<i>Oikopleura sp.</i>	2,20	2,55	2,43	-1,54	-2,08	-3,03
<i>oe. Teleosteens</i>	0,76	0,43	0,87	3,10	1,02	2,25
<i>L. Teleosteens</i>	2,21	2,35	3,30	-1,18	0,09	-0,39
<i>Noctiluca</i>	-1,46	1,50	-0,53	-1,49	-1,37	1,24

Acartia tranteri (Fig 2.19a) was present the whole year and was the most abundant species of the inshore community, although it was quite rare in autumn (from March till June). Differences in abundance between inshore and offshore, and between top net and bottom net were not significant (Table 2.2). It was absent in the summer and autumn in the offshore samples, but very abundant during the end of winter to beginning of spring (September and October). It shows 2 peaks of abundance, one in September-October, the other much smaller one in December.

Oithona sp. (Fig 2.19b) shows quite a different pattern. It occurred in low numbers most of the year, appearing in September in the offshore station and in the inshore station later in November. It was absent until January where it occurred at more than 2000 100m^{-3} in the bay. Paired t-tests comparing top and bottom nets and inshore and offshore abundance were non-significant, but there was a significant difference between top and bottom nets for *Oithona* sp. in offshore waters (Table 2.2).

Paracalanus indicus (Fig 2.19c) appeared in August and numbers reached a peak in November before declining and disappearing by the end of summer (March). These differences were not significant, however (Table 2.2). This pattern was similar in the bay and the channel, although *P. indicus* was 2.5 times more abundant in the bay. The same pattern applied to *Clausocalanus ingens* (Fig 2.19d) (Fig 2.19e). However, all statistical comparisons were non-significant i.e. inshore/offshore and top net/bottom net (Table 2.2), as was also the case for, *C. jobei*, *C. arcuicornis* and *C. brevipes*. Abundance of *Ctenocalanus vanus* showed a similar seasonal pattern (Fig. 2.19e) but the inshore numbers of males were significantly higher than offshore (Table 2.2).

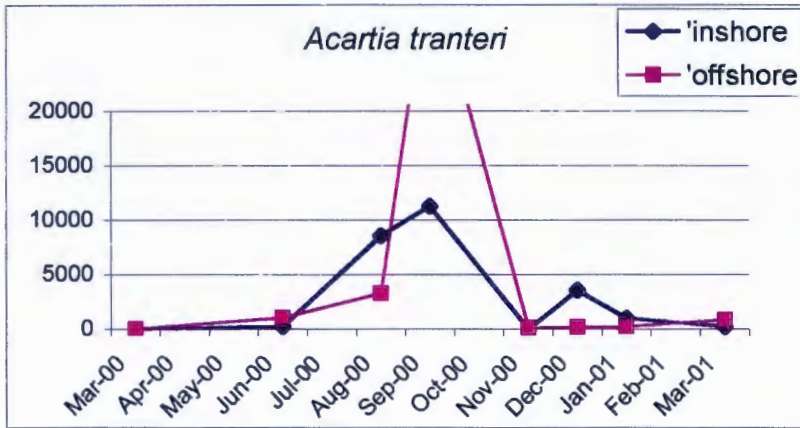


Fig. 2.19a Change in abundance of *Acartia tranteri*. Abundance is expressed as average Nos 100 m⁻³ in 2 replicates from each of top and bottom nets in all graphs.

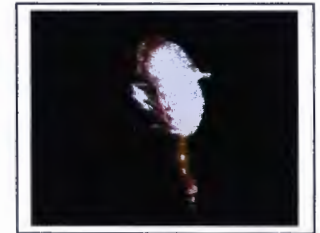
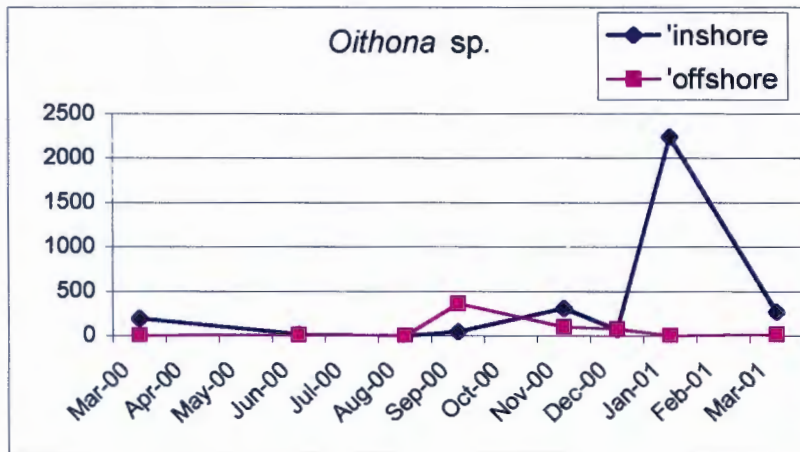


Fig. 2.19b Change in abundance of *Oithona* sp.

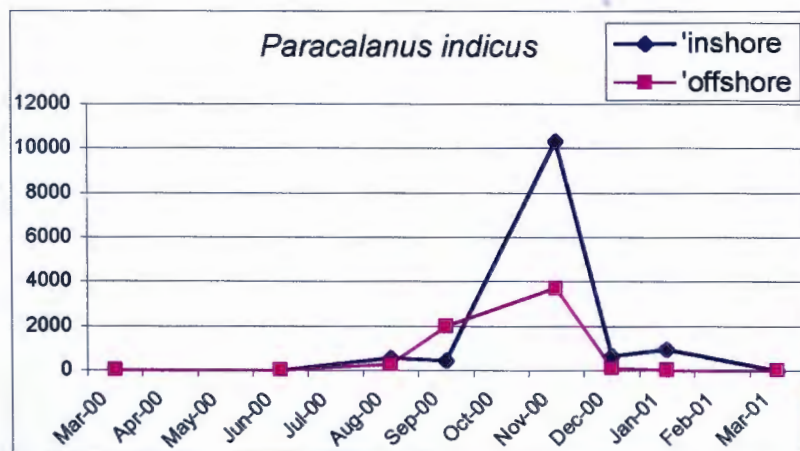


Fig. 2.19c Change in abundance of *Paracalanus indicus*

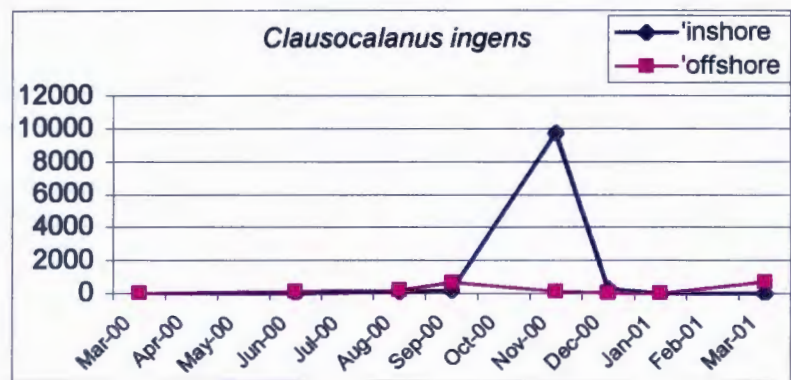


Fig. 2.19d Change in abundance of *Clausocalanus ingens*

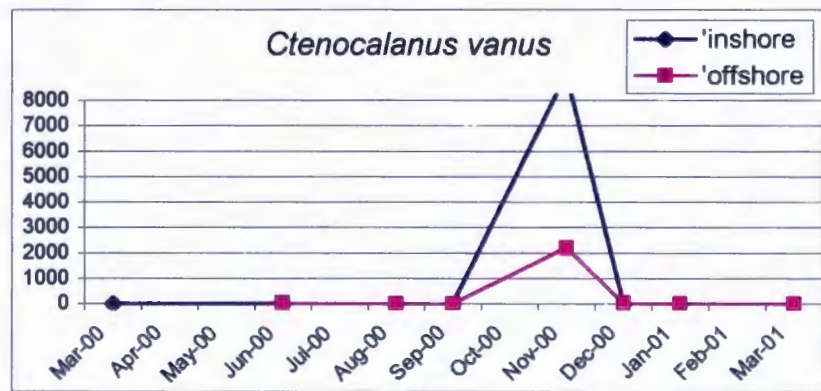


Fig. 2.19e Change in abundance of *Ctenocalanus vanus*

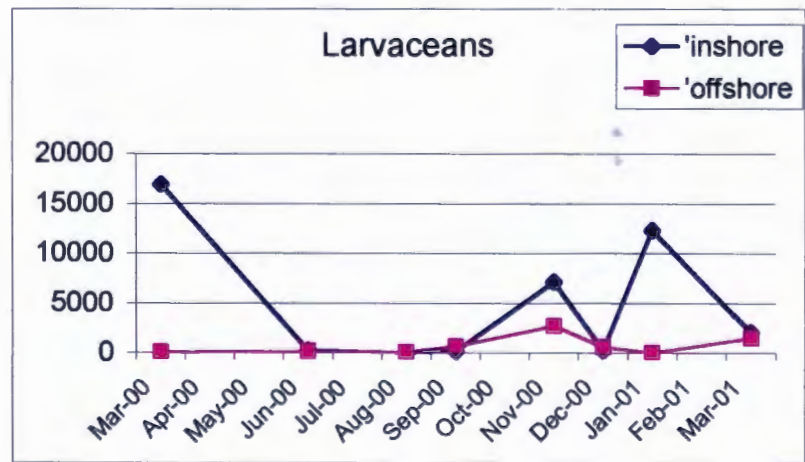


Fig. 2.19f Change in abundance of Larvaceans

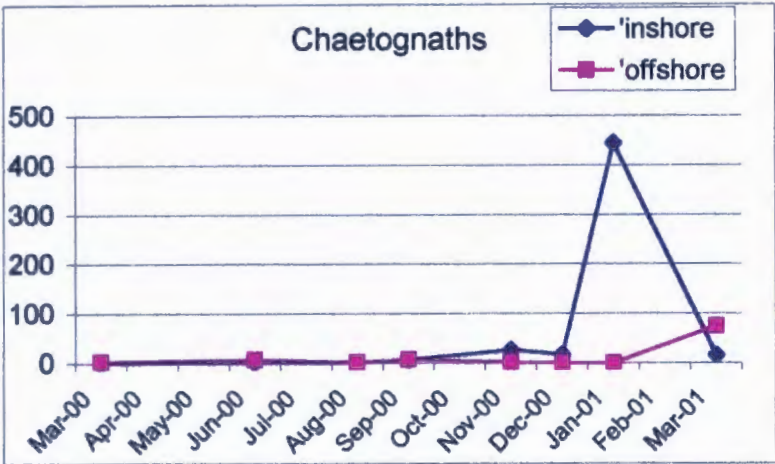


Fig. 2.19g Change in abundance of chaetognaths

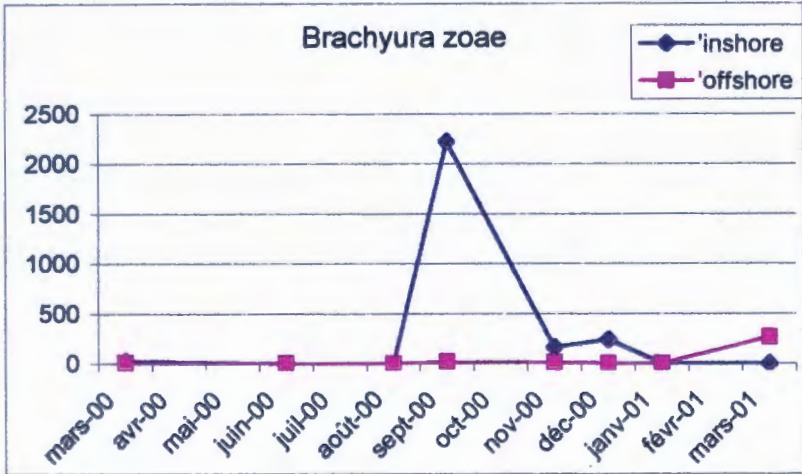


Fig. 2.19h Change on abundance of brachyuran larvae

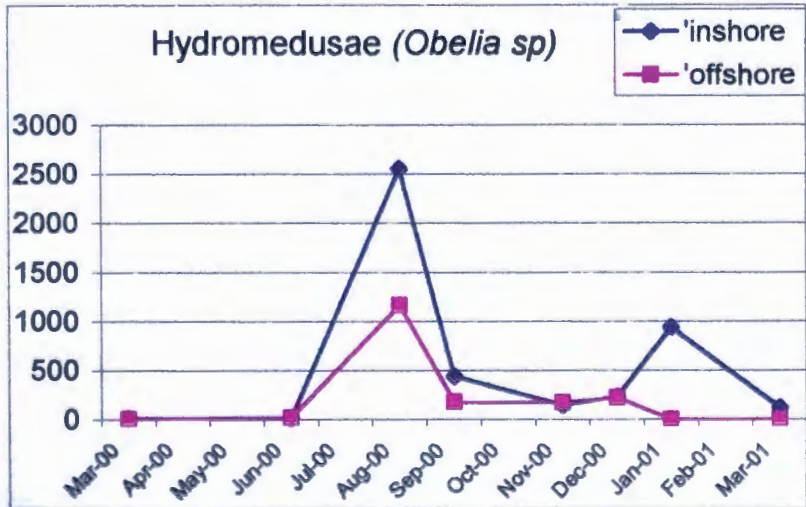
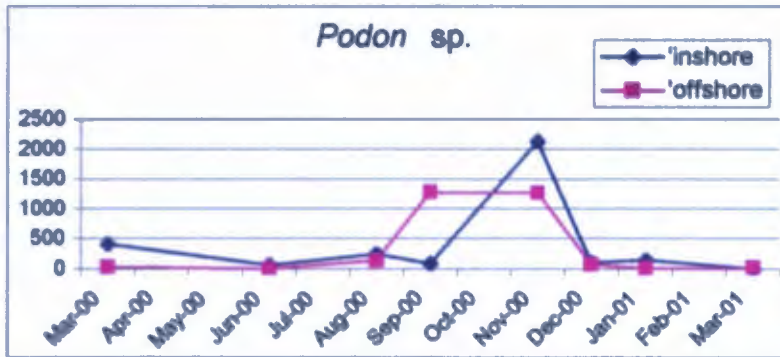
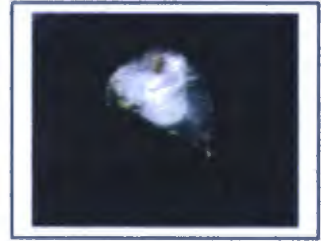
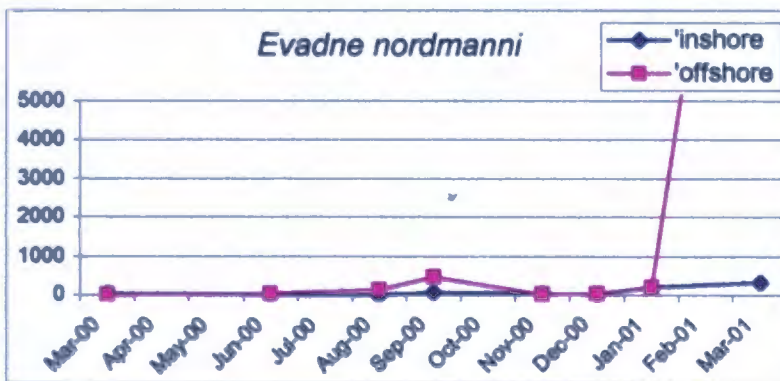
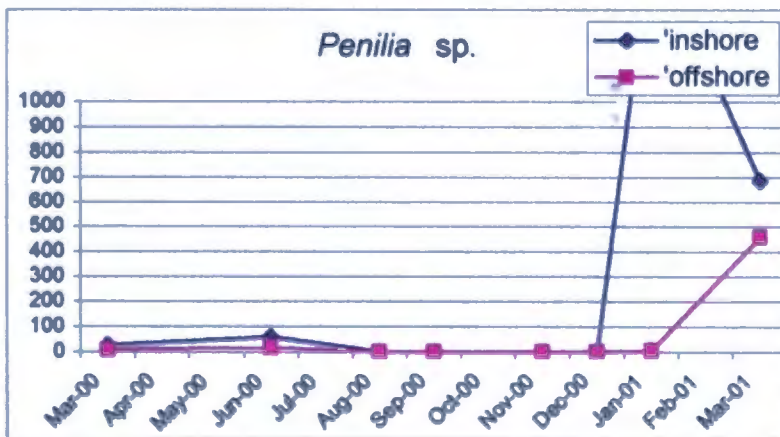


Fig. 2.19i Change in abundance of hydromedusae

Fig. 2.19j Change in abundance of *Podon* sp.Fig. 2.19k Change in abundance of *Evadne nordmanni*Fig. 2.19l Change in abundance of *Penilia* sp.

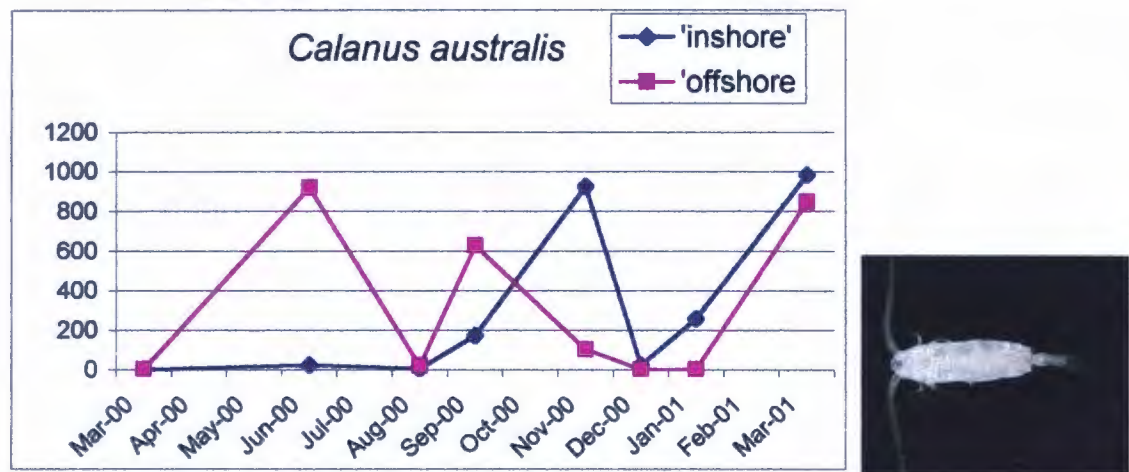


Fig. 2.19m Change in abundance of *Calanus australis*

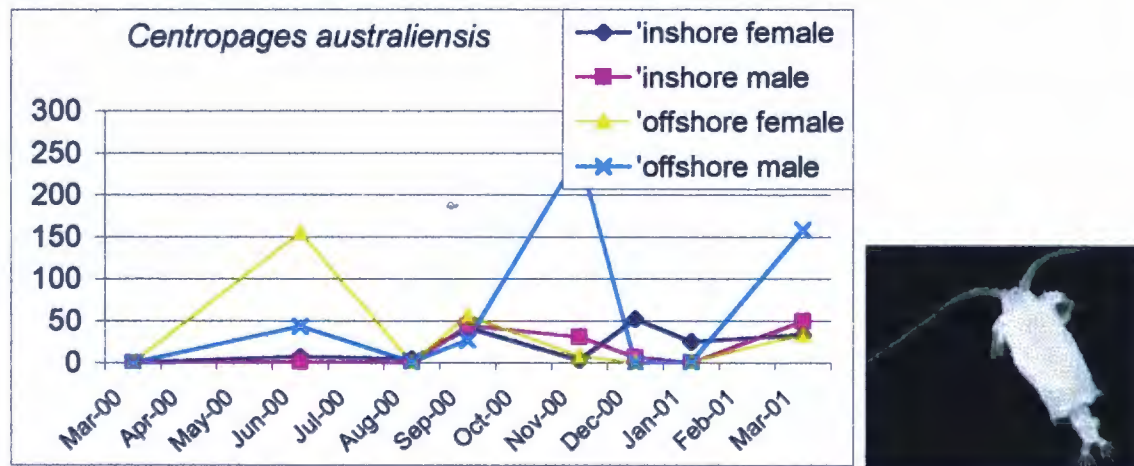


Fig. 2.19n Change in abundance of *Centropages australiensis*

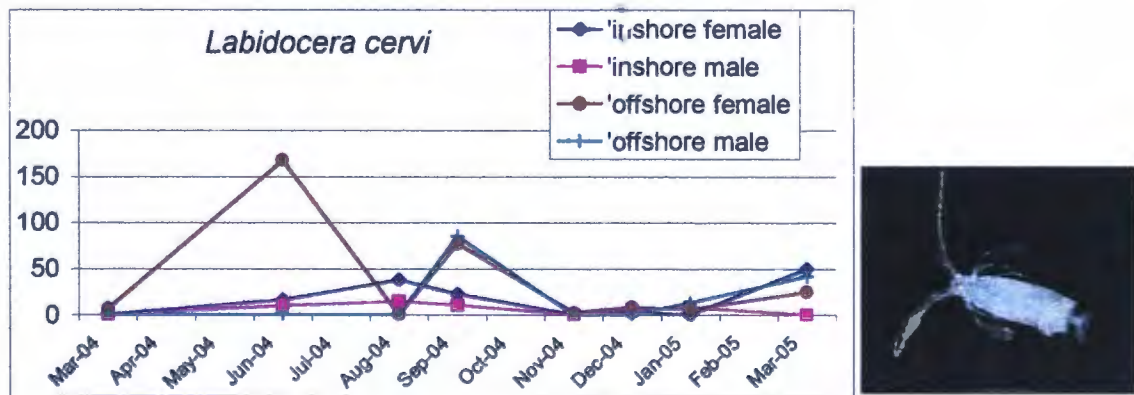


Fig. 2.19o Change in abundance of *Labidocera cervi*

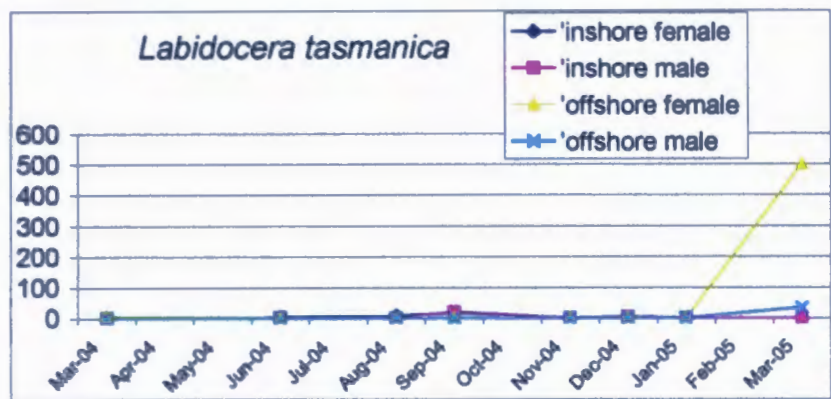


Fig. 2.19p Change in abundance of *Labidocera tasmanica*

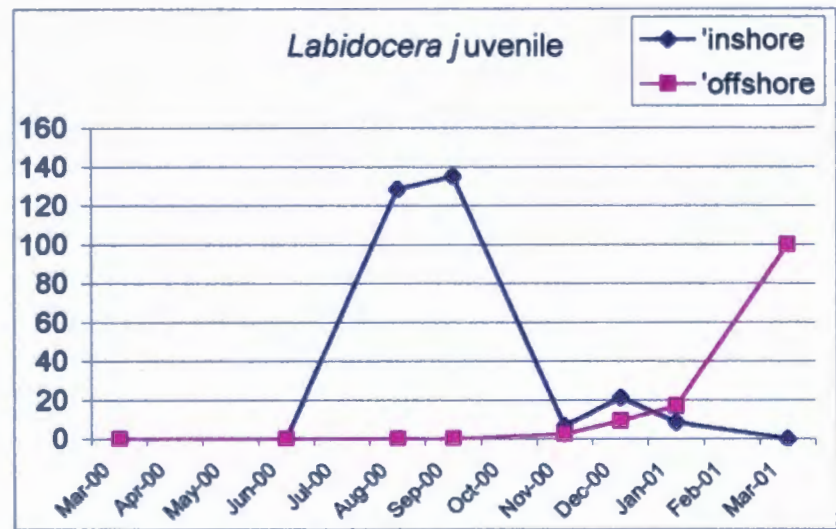


Fig. 2.19q Change in abundance of *Labidocera* juveniles

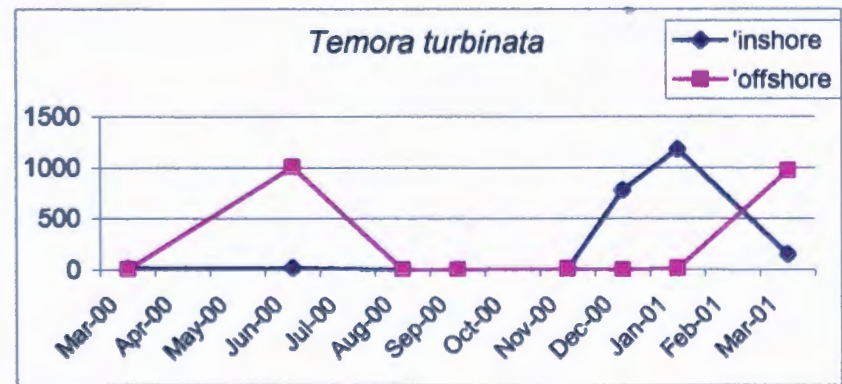


Fig. 2.19r Change in abundance of *Temora turbinata*

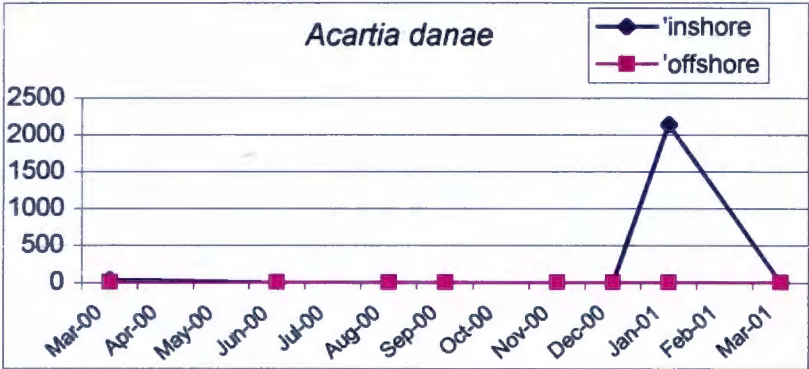


Fig. 2.19s Change in abundance of *Acartia danae*

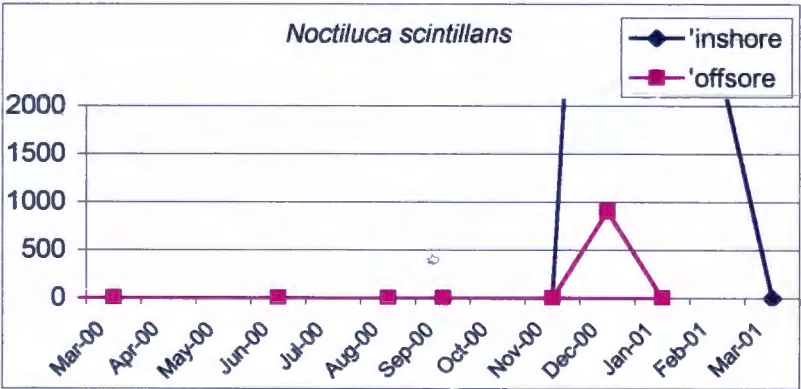


Fig. 2.19t Change in abundance of *Noctiluca scintillans*

The larvaceans (Fig 2.19f), mostly *Oikopleura* sp., are characteristic of shallow water; they were present in high numbers from September until May in the bay, but in low numbers in the channel from September to March. The t-test results (Table 2.2) confirmed that larvaceans were more abundant inshore and in the top net ($p < 0.05$)

Chaetognaths (Fig 2.19g) were observed only in summer in the bay, and some oceanic species were present in winter only in the channel. No significant differences were found in the horizontal distribution (Table 2.2) but chaetognaths were significantly more abundant in the top net than the bottom one in Mercury Passage.

The distribution of zoeae of Brachyura (Fig 19h) is typical of crustacean larvae: they appeared in September in high numbers which then decreased dramatically by an order of magnitude, and at the beginning of summer they had completely disappeared from the plankton. They were significantly more abundant in the bay (Table 2.2), and there was no significant difference between catches of the top and bottom nets.

The only jellyfish collected were Hydromedusae (Fig 2.19i), and they were probably all from the genus *Obelia*, although a precise identification was not undertaken. They were more abundant in shallow waters ($p < 0.05$ Table 2.2) though variability was high, and were present all winter and summer, though they disappeared in March. Their first bloom occurred in August, with a smaller peak, in January. They were significantly more abundant in the top net ($p < 0.05$).

Cladocerans occurred abundantly at both sites. Although several species were recorded, only the occurrence of *Podon* sp. (Fig 2.19j), *Evadne nordmanni* (Fig 2.19k) and *Penilia* sp. (Fig 2.19l) are shown here.

E. nordmanni and *Penilia* sp. were both very seasonal, appearing in January and apparently disappearing in March. But whereas *E. nordmanni* was only abundant offshore, *Penilia* sp. occurred inshore in January and offshore in February. *E. nordmanni* was significantly more abundant in the bottom net both inshore and offshore (Table 2.2).

Podon sp. distribution appeared more complex. It was present in low numbers throughout the year in the bay blooming firstly in the channel in September, and this bloom was observed only in November in the bay. By January, it had disappeared from the channel. The t-test results for horizontal distribution were non-significant (Table 2.2) but *Podon* sp. were more abundant in the top net than the bottom one ($p < 0.05$).

Calanus australis distribution is shown in Fig 2.19m. As an oceanic species, it was interesting to observe *Calanus australis* in abundance at both sites throughout the year apart from July and August. Comparison of inshore/offshore abundance gave a non-significant result ($p > 0.05$, Table 2.2). In September, the number in the channel was three times higher than in the bay, but two months later numbers in the bay rose markedly. Abundance at both sites dropped in December but increased again in parallel from January to March.

Centropages australiensis (Fig 2.19n) was more abundant in the channel ($p < 0.05$, Table 2.2), although it was present for most of the year in the bay in low numbers. The females reached $250\ 100\text{m}^{-3}$ in June, but then fell below 50 and remained low for the rest of the year. The males, on the other hand, increased to less than $50\ 100\text{m}^{-3}$ in June; however they reached 250 in November, then disappeared from the water of both the channel and the bay until March.

Two species of *Labidocera* were recorded in this study: *Labidocera cervi* (Fig 2.19o) and *L. tasmanica* (Fig. 2.19p). *Labidocera* is a neustonic genus with characteristic behaviour. *Labidocera cervi* seems to be an oceanic species, as both males and females were present in greater numbers in the channel (though statistical results were non-significant, Table 2.2). The females appeared first in June, then again in September at the same time as the males. In August, whereas no *Labidocera* were recorded in the channel, they were present in the bay even though their number was quite low. On the other hand, the *Labidocera* juvenile numbers (Fig 2.19q) peaked in August and September only in the bay; then disappeared completely from the bay. However, as their numbers decreased in the bay, they increased in the channel (December, January). This increase coincided with an increase of *Labidocera tasmanica* females offshore (Fig 2.19p). Juvenile *Labidocera* abundance was significantly greater in the bay, whereas abundance of *L. tasmanica* females was significantly greater offshore (Table 2.2).

Numbers of *Temora turbinata* (Fig 2.19r) numbers peaked in March and June at the offshore site, while *Acartia danae* (Fig 2.19s) was a rare species, only occurring in March and January. They both also occurred in the bay, being quite abundant in summer (January), and significantly more abundant than offshore in the case of *T. turbinata* (Table 2.2).

In winter, a relatively less diverse community existed in the bay, consisting of larvaceans, hydromedusae, juveniles of *Labidocera* and *Acartia tranteri*. Outside the bay however, there were large populations of *Calanus australis*, *Centropages australiensis*, *Labidocera cervi*, *Temora turbinata*, and some chaetognaths. They disappeared in August, returning in September-October, when a new cycle would probably begin.

2.3.5 Abundance and diversity

Abundance and diversity of zooplankton communities of the bay and Mercury Passage were compared using a Bray Curtis dissimilarity index and cluster analysis. The results are shown in Fig. 2.20. No distinct clustered groups were identified with more than half of the samples within 50-55% of dissimilarity. Apart from the August 2000 samples, no inshore sample clustered with its offshore counterpart. Although there were no distinctive clusters, the offshore samples demonstrated less dissimilarity than the inshore ones; particularly the summer samples (March and December 2000, and January 2001). The offshore September sample is closer to the March 2000 sample than it is to the inshore September one. The same occurred with the offshore November and June samples; they are more closely related to one another than they are with their inshore pair.

Tree Diagram for 16 Variables
Unweighted pair-group average

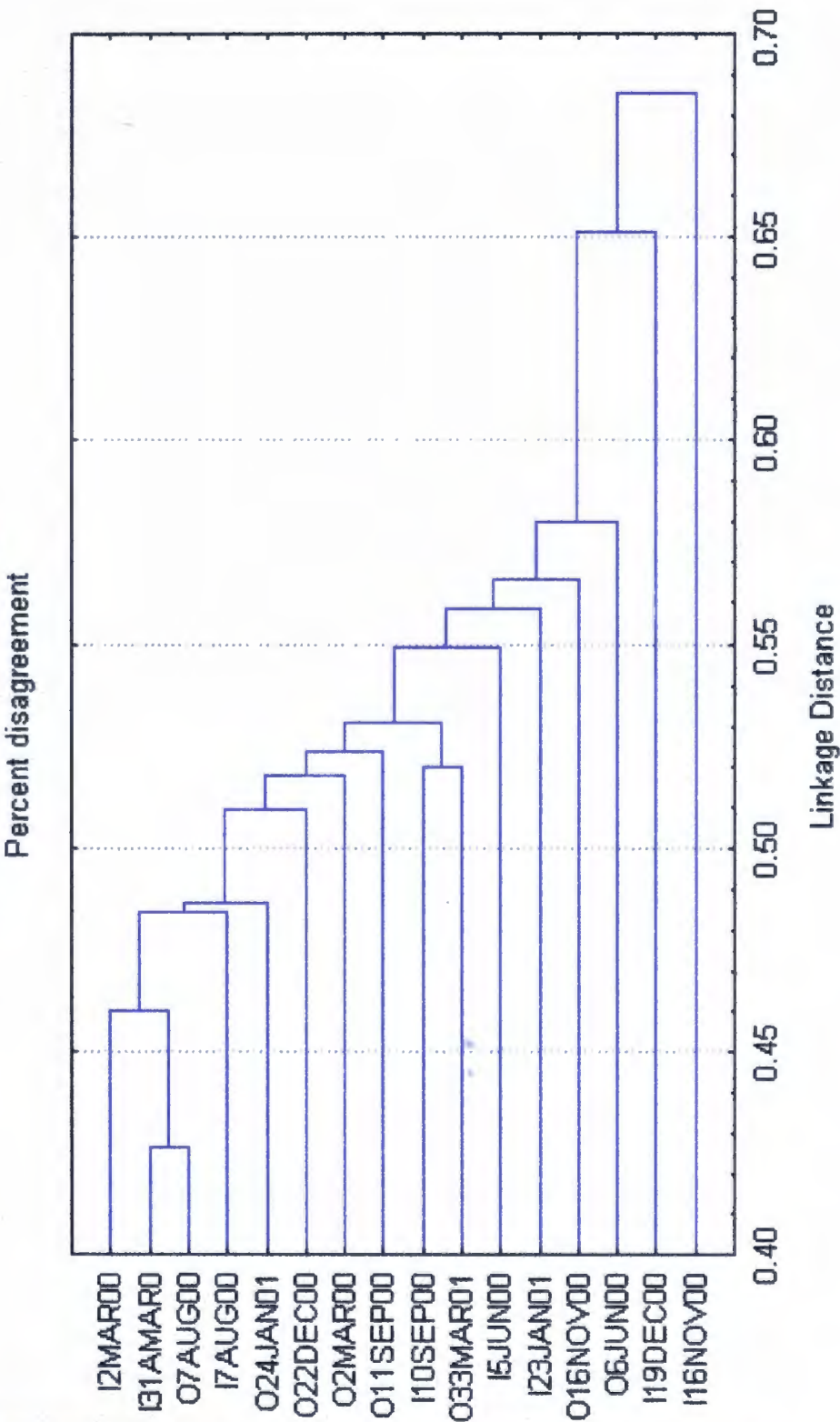


Fig. 2.20 Cluster analysis comparing diversity and abundance of zooplankton communities from Mercury Passage (prefix O) and Okehampton Bay (prefix I). Each sample represents the mean of 2 replicates from each of upper and lower nets.

2.4 Discussion

The years 2000-2001 were considered to be under La Niña conditions (NOAA website <http://www.cdc.noaa.gov/ENSO/enso.current.html#indices>) which would explain the low zooplankton abundance found at the beginning of 2001. Very low abundances of fishes and crustaceans were reported, and Mutton-birds (*Puffinus tenuirostris*), that had returned from their seasonal migration, died of starvation in large numbers on beaches (Skira, 2003).

The present study showed that the zooplankton community composition varied between Okehampton Bay and Mercury Passage although only 1 to 2 km separate the two sites, and there was no salinity, temperature or abrupt bathymetric gradient. Understanding the currents in the area is quite a challenge; the oceanic influence is evident throughout the Mercury Passage and its northern opening corresponds with the northern edge of the bay. At this point the winds are funnelled between cliffs or hills of mainland Tasmania, and Maria island mountain peaks. The island protects the bay from wind coming off the ocean and also from oceanic currents. The bay is quite protected from sea breezes from the south east.

At any given time, none of the zooplankton samples showed the same composition in both sites, apart from August 2000, which was uniformly low in abundance and diversity. The offshore samples appeared to be more closely related than the inshore ones in general, which suggests that the inshore zooplankton community was more heterogeneous.

The biomass was slightly higher in Mercury Passage and this agrees with Suthers and Frank's (1990) findings, i.e. a biomass gradient increasing from inshore to the edge of the shelf. They found a reverse gradient of ctenophore biomass which decreased from inshore to offshore in their samples. This abundance of predators near

the coast could explain the lower biomass of zooplankters. However, this does not seem to be the case for Okehampton Bay; ctenophores were recorded on one occasion in the bay and the surface bloom had disappeared within 12 hours. Although predators were identified in both areas, numbers did not seem likely to limit the zooplanktonic biomass in the bay. Species followed a clear succession and in summer, the changes in the distribution of predator species followed those of the prey distribution, but this phenomenon was similar in both sites. A probable explanation may lie in the characteristics of the Passage: it is quite shallow with a maximum of 30 m depth. It can not be considered as the shelf, but more as an inshore coastal station.

The seasonal variations were quite clear even though the study lasted only 13 months. Most herbivorous species bloomed in September until November, then the predators increased in abundance (i.e. chaetognaths, *Centropages australis* and *Labidocera* sp.) (Bradford, 1999), presumably feeding on the smaller species such as cladocerans, *Acartia tranteri*, *Paracalanus indicus*, and particularly the crustacean larvae. Their populations dropped suddenly between December and January, probably because the availability of food decreased. Some predator species e.g. chaetognaths, increased in abundance again after January and that could be explained by the large bloom of *Noctiluca scintillans* (Fig 2.19f) (Fock and Greve, 2002), reaching almost 100,000 100 m⁻³ at the mouth of the channel in March 2001.

The distribution and abundance of individual taxa showed some interesting features. As described earlier, the bay opens to the Mercury Passage along its whole length. The circulation of the bay depends mostly on tidal currents and the wind's influence, particularly in the case of the neuston. Water penetrates Mercury Passage from the ocean by the channel to the north of the bay. This is shown by the pattern of distribution of some copepod species.

Acartia tranteri was the most abundant copepod inshore, occurring throughout the year though it was rare in autumn. Jillett's (1971) study of the zooplankton in New Zealand waters, showed a different seasonality. *Acartia clausii* (that might be *Acartia tranteri*: species description corrected by Bradford, 1999), was present from June to August only; its presence along our coasts appeared to last longer.

It is worth highlighting the occurrence of *Acartia danae* and *Temora turbinata* since both are characteristic of sub-tropical waters (Bradford-Grieve, 1999) and have been described as being indicators of the sub-tropical influence on the east coast of Tasmania. *Temora turbinata* is a typical subtropical to tropical species recorded all over the world (in Phosphorescent Bay, Puerto Rico by Rios-Jara (1998), found inshore and offshore of the West African coast by Bainbridge (1972), and in inshore waters of Jamaica and Barbados by Moore and Sandes (1976)). *Acartia danae* is described as a surface dweller of warm waters (Wilson 1950, Farran 1948, Rose 1933, 1929), although it was occasionally found in the Mediterranean Sea by Champalbert (1969) and always in deep water in winter. This contradiction should be noted because it contrasts with all others records in the literature.

A. danae and *T. turbinata* first appeared in the Passage then appeared in the bay several months later. This suggests that the retention time of the water in the bay could be as much as 3 months. However, this mixing is between two locations separated by only one or two km with no clear boundary. The zooplankton community compositions at the two sites are not markedly different according to the cluster analysis, however some species showed a clear ability to maintain themselves in one or the other site.

Studies of spatial variation in zooplankton distribution have been uneven and relatively sparse throughout the world. On the other hand, vertical migrations are quite well understood. It was assumed for a long time that, since zooplankters were passive

drifters, their distribution would be the result of physical factors such as the currents, temperature, salinity and the type and amount of nutrients available. Now described as “active drifters” (Wiafe and Frid, 1996), these organisms are capable of active migration, particularly vertical, to avoid predation, seek food or better living conditions, and even to keep their position in the water column during incoming or outgoing tides (Hills, 1991; Manuel and O’Dor, 1997). Moreover, Gibbons et al. (1999) showed that the composition of zooplankton assemblages could not be entirely due to physical factors “but that, under certain circumstances, a more subtle interplay between the biological and physical environment may result in strong changes in assemblage composition”.

The most interesting study on inshore spatial variation in zooplankton communities was undertaken by Archambault et al. in 1998; they studied different types of embayments from large open bays to semi-enclosed bays, with a straight line of coast as a standard site. They investigated the ratio of holoplankton to meroplankton in the different situations, and found that the more enclosed the embayment, the higher the larval retention. They also found that, in most cases, the zooplankton abundance was higher inside the embayment than outside, except for the two largest embayments. This trend is supported by the present results though the results were not significant (Table 2.1). But they did not obtain any embayment size effect on zooplankton abundance. The present site showed a particularly important feature: the presence of Maria Island. It shields Okehampton Bay from most of the prevailing winds and open ocean currents. This is certainly different from the largest embayments studied by Archambault et al. (1998). It also might explain why the meroplankton is still very important in the bay. Moreover, the present study showed that, even though mixing effectively exists between the Mercury Passage and Okehampton Bay, particularly

since the channel supplies the water of the bay, some zooplanktonic taxa are able to maintain their spatial position whether it is in the bay (*Oikopleura sp.*) or outside it (*Centropages sp.* or *Labidocera sp.*). The mechanism is unknown. In the case of the larvaceans, it can be suggested that the organisms are quite unable to maintain their position and are simply washed away and might not survive high turbulence. Also larvaceans like *Oikopleura sp.* are quite specific to shallow waters, are phytoplankton feeders (Fenaux, 1976), and probably become easy prey for all copepod predators, chaetognaths, ctenophores, and hydromedusae (Ohtsuka and Kubo 1991; Ohtsuka and Onbé 1989; Alldredge 1976).

But it is not clear why offshore predatory species, such as *Centropages* and *Labidocera*, are clearly absent in the bay. Food as a limiting factor, as proposed by Kimmerer (1993), does not seem to be applicable in this case as the prey availability in the Passage was not higher than in the bay at that time.

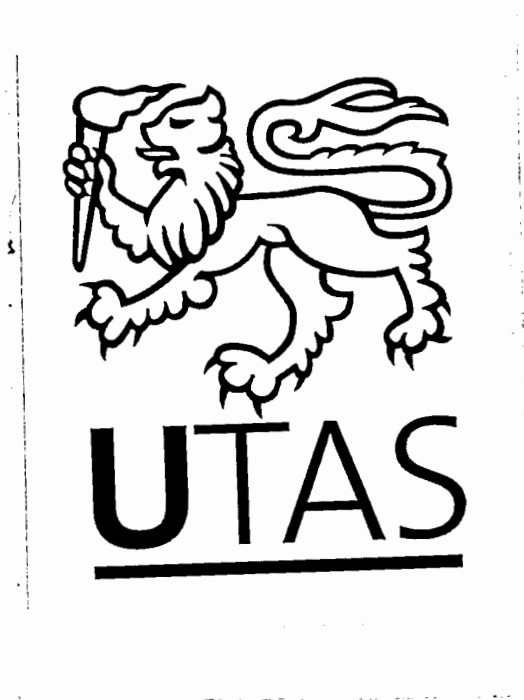
Distribution and abundance of *Calanus australis* in the present study agreed quite closely with results reported by Taw and Ritz (1979). I found two peaks of abundance at the offshore station i.e. March and June, and two peaks inshore in November and March. Taw and Ritz (1979) also described two peaks at coastal stations off south east Tasmania in 1971-72 i.e. Oct-Dec and Mar. Jillett (1971) described *Calanus australis* as a shelf dweller plentiful at the 100 m contour but rarer close inshore in New Zealand coastal waters. Our results clearly differ since *Calanus australis* was as abundant at the inshore site in shallow water as it was at the offshore site.

The bloom of *Noctiluca scintillans* in summer could explain the late summer increase of *Calanus australis* (Petipa, 1960; Porumb 1992). *Noctiluca scintillans* feeds on a wide spectrum from diatoms to copepods and fish eggs, but is itself fed on by

adult copepods (Lehto et al. 1998). This could also explain the low abundance of *Calanus* in December and January. It may be an example of reciprocal predation where one eats the eggs and is eaten by the adults of the same species. The bloom of *Noctiluca* was interesting because of its extent. It lasted for several months and may have had a serious influence on the neustonic composition because it accumulated at the surface; it concentrated in the first 5-10 cm and formed a slimy soup. It is likely that the competition for space was high at this time, and that the low abundance of copepods and other zooplanktonic organisms was directly linked to its presence. Neustonic species could simply not reach the surface and *Noctiluca* probably interfered at every level of the food web. The microbial loop was disturbed by its presence, as it forms part of the prey spectrum of the dinoflagellate (Elbrachter and Qi, 1998).

Kimmerer and McKinnon (1987a) showed that *Paracalanus indicus* was less abundant in a semi-enclosed bay in Victoria (Westernport bay) than outside and suggested that this was due to a high predation pressure in the bay. However, *Acartia tranteri*, the most abundant species in their study, had developed a strategy of vertical migration to avoid predation, and maintained its population in the bay by this means (Kimmerer and McKinnon, 1987a). On the other hand, *Paracalanus indicus* did not show any tendency to develop such a strategy and became the prevalent prey. In the present study, *Paracalanus indicus* was more abundant in the bay, as described earlier. Okehampton Bay conditions may be more favourable than those of Westernport bay; and predation pressure may be less strong allowing the growth of other smaller species. It should also be noted that the abundant presence of *Oikopleura* sp. is an important source of nutrition for many organisms, particularly small ones like *Oithona* sp. These copepods have the ability to enter larvacean housings and feed from inside.

The frequent renewal of housings by the larvaceans provides an abundant food source for detritus feeders in the bay.



3 Ecology and behaviour of two neustonic copepods, *Pontella novaezelandiae* and *Labidocera cervi*

3.1 Introduction

Neuston was defined by Naumann (1917), and later Geitler (1942), as the planktonic organisms living within the first few centimetres of the water column. This group of organisms was enthusiastically studied during the 1970s when it was realised they constituted a distinct community. They occupy an environment variable in salinity (subjected to rainfall, land fresh water supply, but also high evaporation that would concentrate the salinity at the surface), in oxygen, in temperature, but most of all in pressure changes generated by passing waves. However, they exploit a rich flux of organic matter supplied by the microalgae; detritus from the land in the form of degraded plants; and crustacean bodies that have been shown to become less dense after a certain stage of degradation and float at the surface. Moreover, almost every egg floats and constitutes a very large part of the diet of neustonic organisms seasonally (Hardy, 1991).

Most of the neustonic organisms have developed characteristic adaptations to their particular environment and all deserved close study. For example, Tregouboff (1963) found the Cladocera to display a range of adaptations. But it is the subclass of copepods, in particular the pontellid family, that has generated the most interest over the years. They were studied in detail by Champalbert (1971, 1977, 1985) in the Mediterranean Sea, Zaitsev (1968) in the North Sea, Fleminger (1975) in the Gulf of Mexico, and also Itoh (1970) in the Japan Sea and the North Pacific. Some data exist for the South African coasts

but little else. In our region, Grice and Gibson (1975, 1977) reported some observations and experiments on *Labidocera aestivae* and *Pontella media* from New Zealand coastal waters. To my knowledge, there have been no studies on Australian neuston so far though they have been reported to occur along the entire Australian coastline. Pontellidae is a family of neustonic copepods distributed worldwide, but it has been studied mostly in tropical to temperate waters, never cooler waters. Neuston have been found in oceanic waters to neritic waters and even mangroves with each species having its own tolerance range of temperature and salinity. Neustonic organisms are often considered to be good indicators of the water body and also of the water quality.

Pontella novaezelandiae was recorded for the first time off New Zealand coasts by Farran (1929), and it has been recorded occasionally in the same area since. This species has been recorded occasionally in Sydney Harbour (McKinnon, pers comm). The report below is the first record for this species off the Tasmanian coast where it was found regularly but always in low numbers. Farran's (1929) description of *P. novaezelandiae* was redefined by Bradford-Grieve (1999), and my own observations and drawings are based on Bradford-Grieve's description.

A synthesis of all records of *Pontella novaezelandiae* is presented here in an attempt to describe the biogeography of the species. The drawings from individuals sampled on the Tasmanian coasts showed some differences from Bradford-Grieve's ones and a comparison appeared necessary. Probably because of its rarity, few data are available on the life cycle of this copepod; one of the goals of this study is to define the life cycle of *Pontella novaezelandiae* as far as possible.

Two species of *Labidocera* have been recorded in Tasmanian waters: *Labidocera tasmanica* (Taw, 1975) and *Labidocera cervi* (Kråmer, 1895). *L. tasmanica* was identified by Taw as a common and relatively abundant species which does not seem to be the case anymore. Bradford-Grieve (1999) confirmed the specimens found in New Zealand waters as *Labidocera cervi*, but the species described in Australian waters (Greenwood, 1979) seems not to conform to Kråmer's original description. It is possible that the Australian specimens belong to a new undescribed species. For those reasons, a closer study was conducted on *Labidocera* spp from Tasmanian coastal waters.

Vertical migrations are common amongst planktonic organisms, but the diel pattern varies among the pontellids and other neustonic groups. An in vitro experiment was undertaken to investigate the diel movements of *Labidocera cervi* (numbers of *P. novaezelandiae* were insufficient for this purpose).

3.2 Material and Methods

3.2.1 Field procedure.

Zooplankton samples were collected at two sites: the Mercury Channel and Okehampton Bay (Fig. 2.1) approximately bi-monthly from March 2000 until June 2001 (see Table 3.1). A simple WP2 net (UNESCO, 1968) with 250 μ m mesh and 50 cm diameter, was used for the first two months. Then a surface double net was designed so that the neustonic community of the area could be effectively separated from the rest of the plankton. The apertures of this net were 100 cm wide by 10 cm high for the top net, and 100cm wide by

20cm high for the bottom one. The length for both nets was 150 cm and the mesh was 300 μm (see Fig 3.1.).

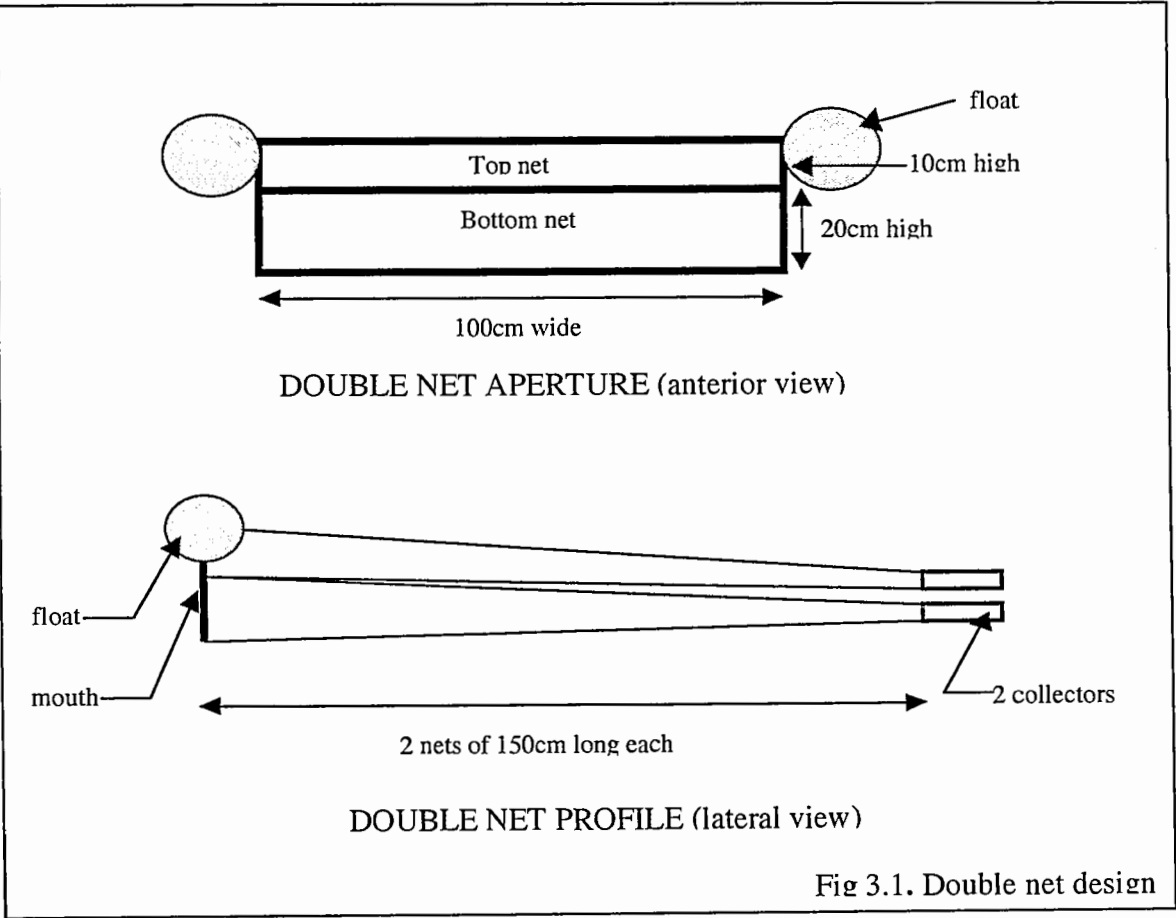


Fig 3.1. Double net design

To sample, the net was towed at the surface on a 15 m cable and at a speed of 1 m.s⁻¹. To maintain the net horizontal, floats were fixed on each side of the aperture and the sampling was mostly made when sea conditions were calm. A calibrated flowmeter (General Oceanics) fixed in the middle of the bottom net was used to estimate volume of water filtered. Details of dates and weather conditions during sampling are given in Appendix Table A3.1.

3.2.2 Laboratory procedure

The samples were preserved as soon as possible in 5% formalin. They were later transferred to 70% alcohol for sorting. The whole sample was examined and all the *Pontella novaezelandiae* and *Labidocera* spp. were counted, sexed and staged using a dissecting microscope.

3.2.3 Laboratory experiments.

All the *Labidocera cervi* (regardless of stages), from collections made in July 2001 or April 2002, were carefully separated from the rest of the catch and placed in an aquarium with clean seawater from the collection site. They were left overnight to become acclimated to the temperature of the room, (13°C, close to ambient, 35 ppt), with an identical light/dark cycle to ambient (10:14 L:D). After 12 h, the *L. cervi* were transferred to a cylindrical perspex tank 1.4 metre high and 50 cm diameter, in clean, filtered seawater; approximately 21 individuals were used in the April experiment and 70 in July. The only light source was an overhead fluorescent tube since the room had no windows. The tank was marked at 10 cm intervals vertically. Approximately every 3 hours for the duration of the experiment, the number of individuals occupying the different depth layers (0-10 cm, 10-20, etc.) were counted. All copepods were dead after 49 h in the April experiment. The July experiment was terminated when all copepods were removed from the tank by carefully sieving them from the top 20 cm, the next 30 cm and the bottom 50 cm. Catches from these strata were examined under a microscope and recorded as male, female or juvenile.

3. 3 Results

Pontella novaezelandiae

The species described by Farran (1929), is very easily identified, being unlike any other species of copepod.

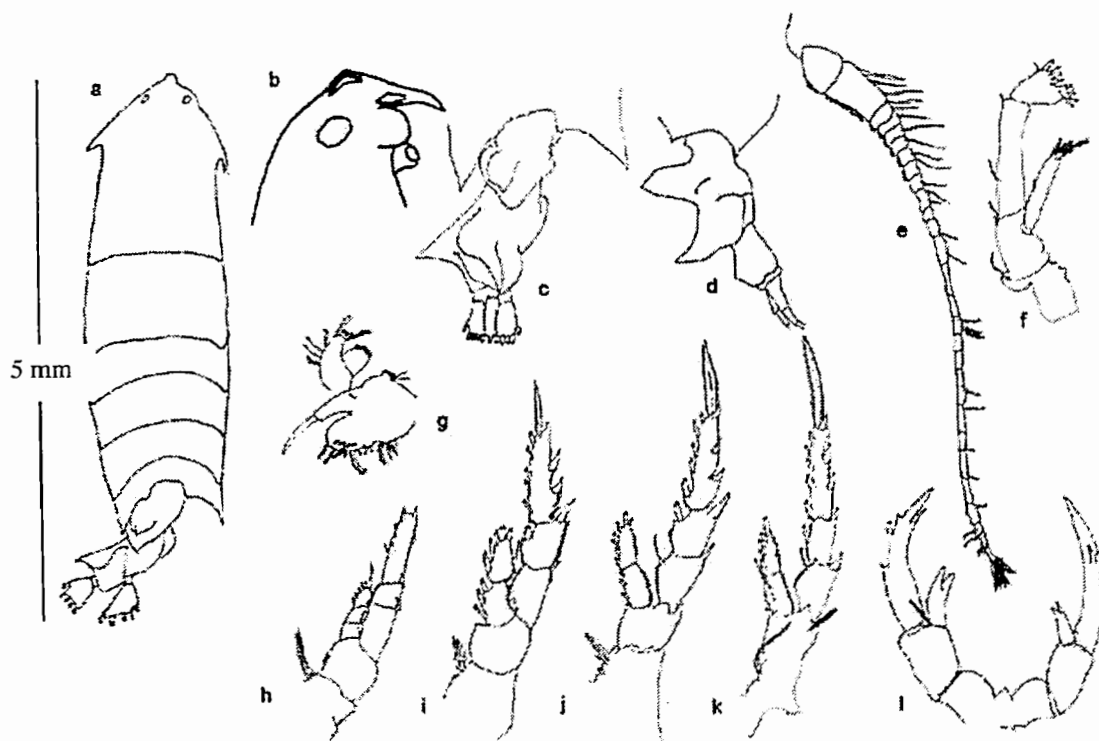


Fig. 3.2. *Pontella novaezelandiae*. Female. a) dorsal view, b) head and rostrum lateral view, c) urosome dorsal view, d) urosome lateral view, e) left antenna 1, f) left antenna 2, g) mandible, h) leg 1, i) leg 2, j) leg 3, k) leg 4, l) leg 5.

Female : (Figs 3.2, 3.3) head with lateral hooks and separated from pedigerous segment 1; with one pair of dorsal cuticular lenses, slight indication of a rostral lens.

Pedigerous segments 4 and 5 separate, usually with pointed lobes extending posteriorly,

Urosome 3-segmented, genital segment covered by a genital operculum and 2 dorsal processes (anterior one blunt and directed dorsally, posterior one tapering to a point and overlapping urosome segment 2), without seminal receptacle. Caudal rami symmetrical.

Antenna 1 24-segmented. Antenna 2 basipods 1 and 2 separate with 1 and 2 setae, respectively; endopod much larger than the exopod,

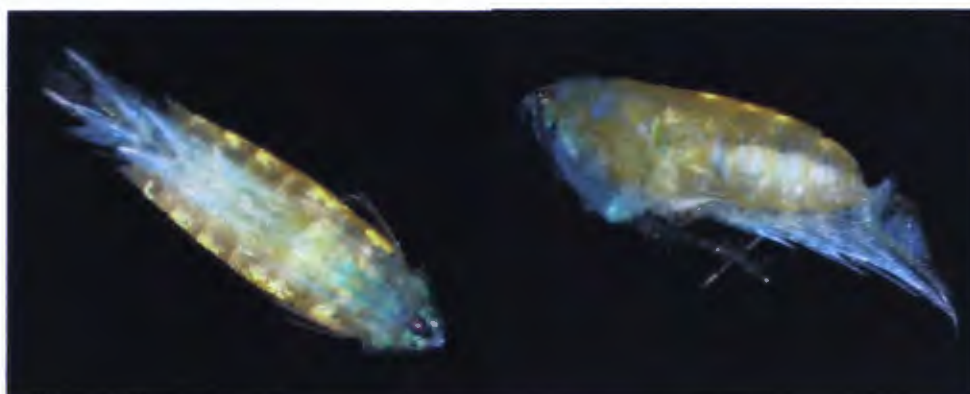
Mandibular blade with 7 pointed teeth, basipod 2 with 4 setae, exopod 5-segmented with 1, 1, 1, 1, 2 setae and endopod 2-segmented with 3 and 6 setae of similar size.

Maxilla 1 with 8-10 spines and inner lobe 2 as long as inner lobe 1 with 3 setae, proximal endopod segment fused to basipod 2, exopod relatively well developed with 9 setae, outer lobe 2 with 1 seta, outer lobe 1 with 7-8 setae. Maxilla 2 with long, strong setae, lobes 1-5 with 4, 3, 3, 3, 2 setae, endopod setation 1, 1, 2, 2.

Maxilliped 7-segmented with basipod 1 large with inner border lobed and basipod 2 and endopod short.

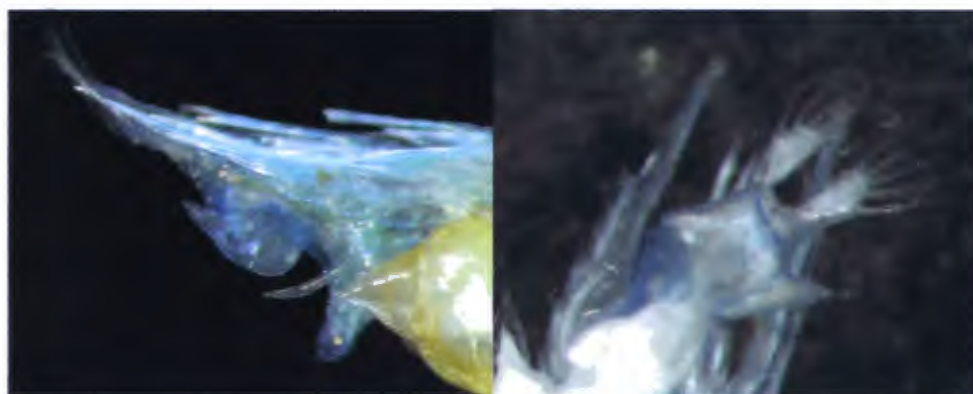
Exopods of swimming legs 1-4: 3-segmented. Endopod of leg 1 3-segmented, and that of legs 2, 3 and 4, 2-segmented.

Female leg 5 not natatory, biramous, each ramus is 1-segmented, not quite symmetrical.



Female, ventral view.

Female, lateral view.



Female telson, side view.

Female telson, ventral view.

Fig. 3.3 Female *Pontella novaehollandiae*

Leg 5 asymmetrical. Right leg palm of chela with a long, slender, proximal thumb and bifid projection arising from its base, left leg with a 1-segmented exopod with a long outer spine arising near its base, a small distal outer spine and 2 terminal spines slightly modified. (description from Farran 1929 and Bradford-Grieve 1999).

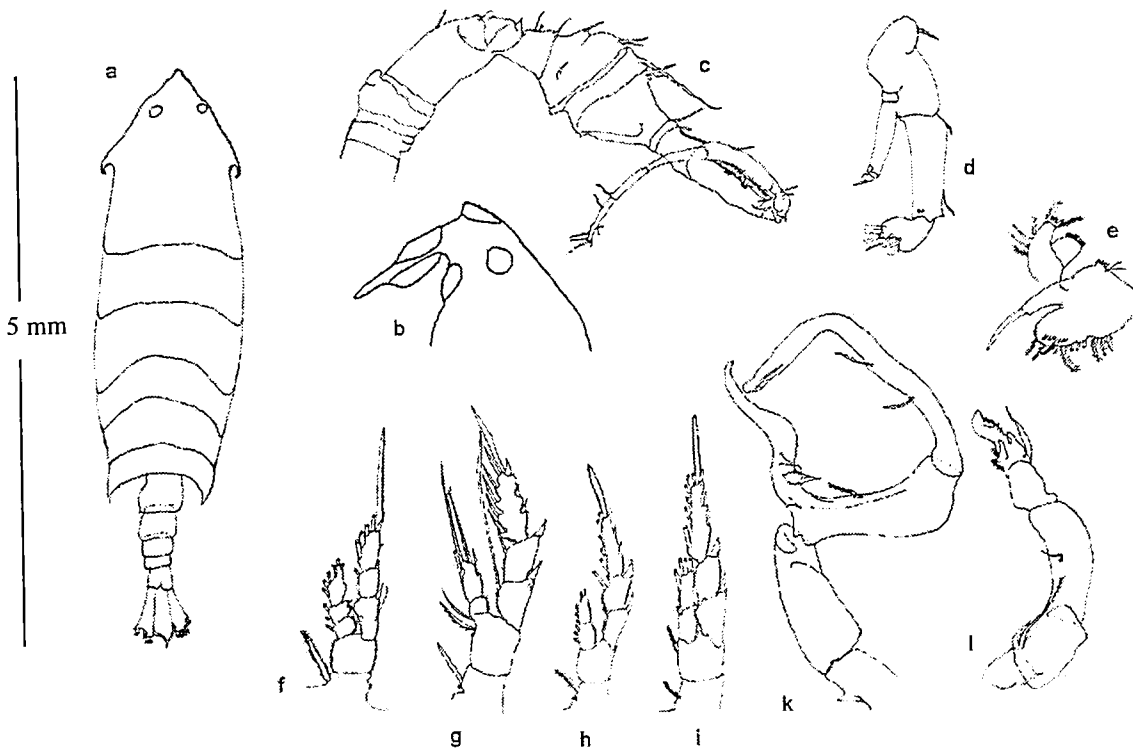


Fig.3.4. *Pontella novaezelandiae*. Male. a) dorsal view, b) head and rostrum lateral view, c) right antenna 1, d) left antenna 2, e) mandible, f) leg 1, g) leg 2, h) leg 3, i) leg 4, j) right leg 5, k) left leg 5.

Male: (Figs. 3.4, 3.5.) as in the female definitions with the following additional characteristics.

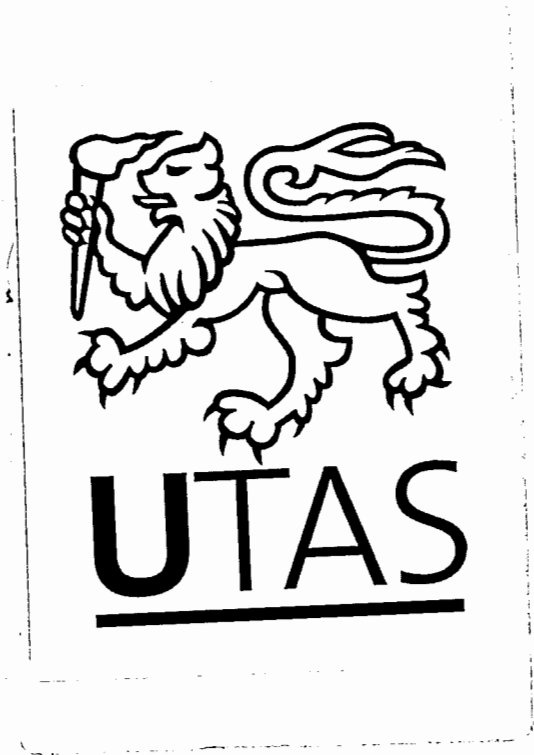
Head terminates in a small crest ending in a blunt tooth, rostrum with a well-developed lens.

Antenna 1 prehensile on right, middle section swollen.

Mouthparts identical to those of female.

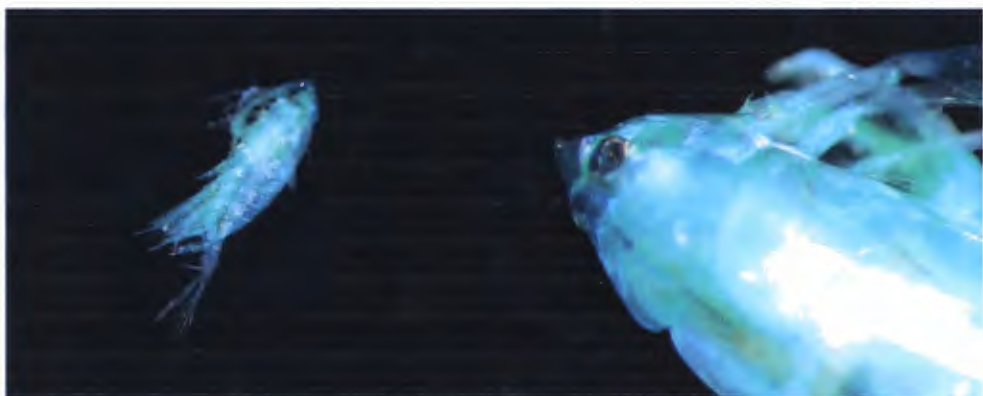
From the different drawings and comparison with Farran's (1945) description, there is no doubt that it is the same species. Apart from some fine anatomical details of the 5th legs and the abdomen, the present drawings are identical with those presented by Bradford-

Grieve (1999) (Figs.3.2 and.3.4). The different parts of the urosome of the male from Tasmanian waters differ in shape and width from the New Zealand specimens.





Male, ventral view.



Male, lateral view.

Male head,
dorsal view.



Male, 5th leg.

Juvenile, lateral view.

Fig. 3.5 Male and juvenile *Pontella novaezelandiae*

3.3.1 Identification of juveniles.

Some juveniles of different stages were recorded. Table 3.1 summarizes some of the characters used to age the copepodites collected during this study.

Table 3.1 *Pontella novaezelandiae*: comparative study of 5 morphological characteristics of copepodite 3 to adult stage (determined from Tasmanian specimens). F= female; M= male.

Characters observed	Copepodite 3	Copepodite 4	Copepodite 5	Adult
Blue body and 3 red dorsal dots	yes	Yes	Yes	Yes
Head with lateral hooks and 1 pair of dorsal lenses	Yes	Yes	Yes	Yes
Size (from the top of the head to the end of the furca)	2-3mm	4mm	4.5-5mm M ? F	>5mm M <5.1mm F
Leg 5	no	Partly developed	yes	Yes
Processes on urosome (M)	no	No	no	Yes

The identification of the species should be straightforward from copepodite stage 3 and maybe earlier (no younger specimens were found). To age a specimen, a closer study of the size, leg 5 and the urosome would be necessary.

3.3.2 Distribution records

Since its discovery in 1910, *Pontella novaezelandiae* has been recorded occasionally but always in the same area: off the North Island, New Zealand, more generally between 30°-40°S. Previous distribution records presented by Farran (1929) are reproduced as Appendix Table A3.2. The species has been recorded from Sydney Harbour on a few occasions during the last 30 years (McKinnon, pers comm) and in Bass Strait in 1979 (Noone, 1979). Details of samples captured in Mercury Passage during 2000-2001 are given in Appendix Table A3.3.

3.3.3 Ecology

Pontella novaezelandiae is a neustonic species, only found in surface samples (up to 5cm depth) during day and night. No specimen was collected in the lower net in the present study. Pontellidae usually live in close association with the film at the sea surface (Champalbert, 1985 and Ohtsuka, 1985); some species even have a special attachment structure which allows the copepods to stay attached to the surface film (Ianora et al., 1992). It was not possible in the present study to identify such a structure on *Pontella novaezelandiae*. It was noted by Champalbert (1979) that most pontellids are bright blue on both back and abdomen. This can be considered as camouflage since individuals become invisible from above to predators such as seabirds. However, they would be clearly visible

from below as black silhouettes against the blue sky and become a target for fish predators. Their ability to jump off the water to avoid such predators is one way of countering this threat, but at high energetic cost.

Pontella novaehollandiae has been found frequently in coastal waters (New Zealand coasts or Tasmanian coasts). In the present study, it was sampled in the Mercury passage but never in Okehampton Bay. This might imply either that it avoids shallow waters or that it is incapable of maintaining itself in such shallow bays. Unfortunately, as it is such a rare species, its absence in the bay might just be due to the slim chance of sampling it.

3.3.4 Study of *Labidocera cervi*

Species identification

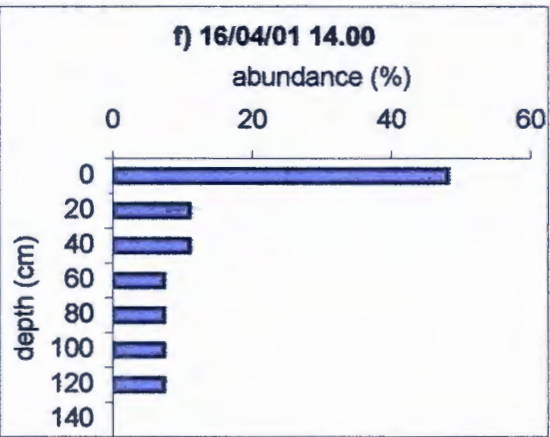
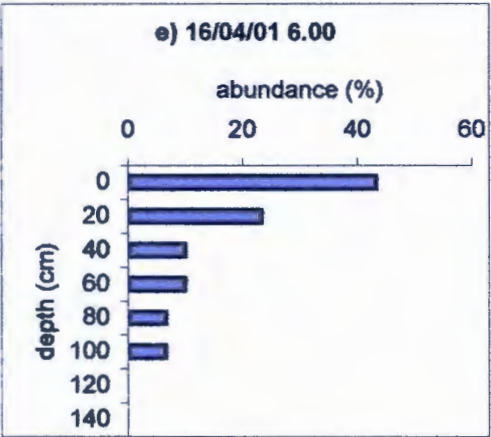
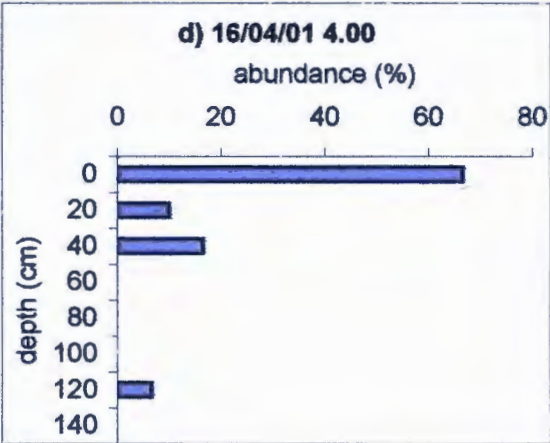
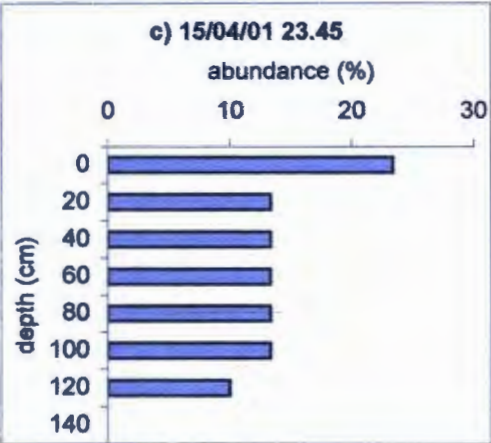
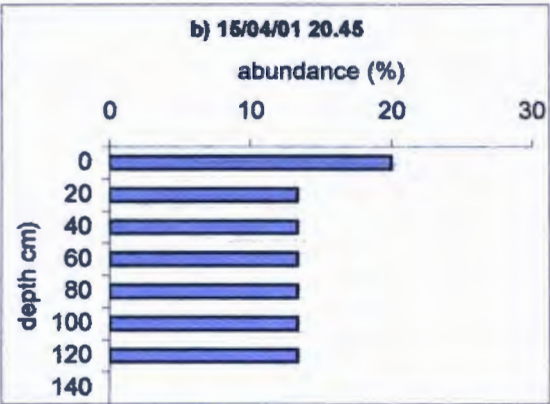
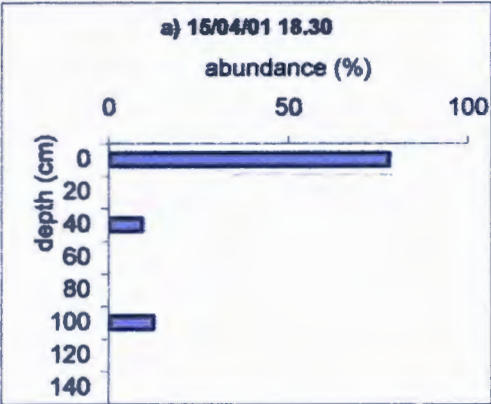
Taw (1975) found *Labidocera tasmanica* in abundance, compared to *Labidocera cervi*. However, the present study revealed quite the opposite: the copepod identified by Taw as *Labidocera cervi* was found commonly throughout the year, particularly the juvenile stages, but *Labidocera tasmanica* was not so abundant. This could be a problem of identification. I used Nyan Taw's drawings and descriptions for both species and the differences between them were quite clear under the microscope. Thus there could have been a genuine reversal of dominance over the intervening time period.

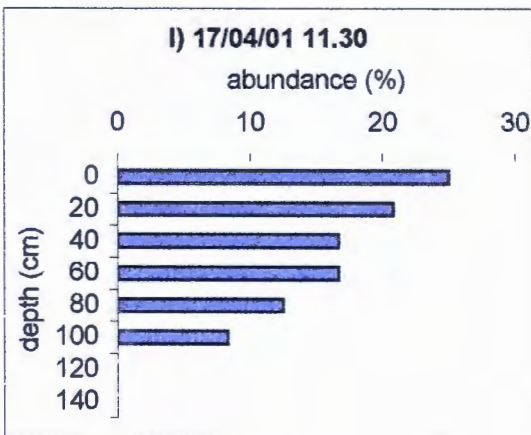
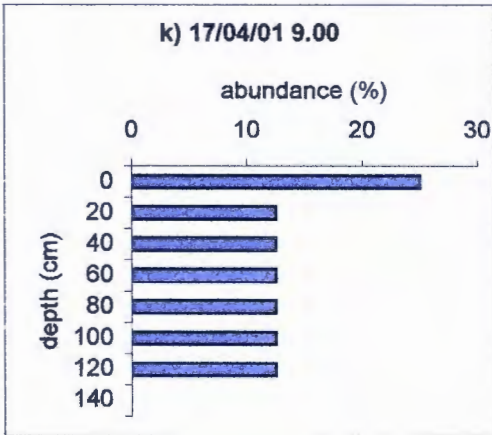
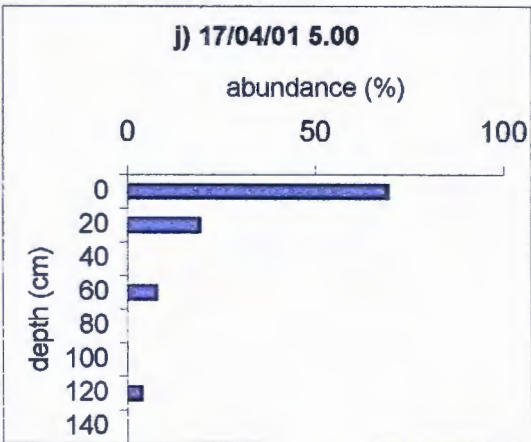
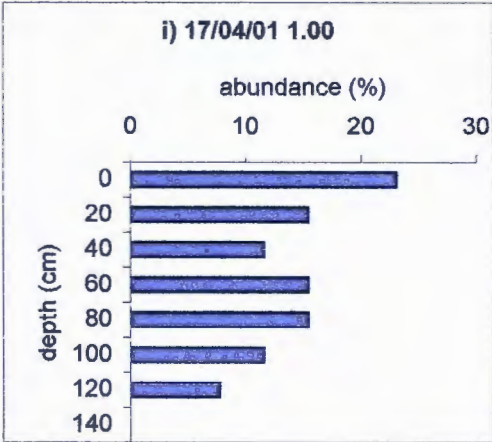
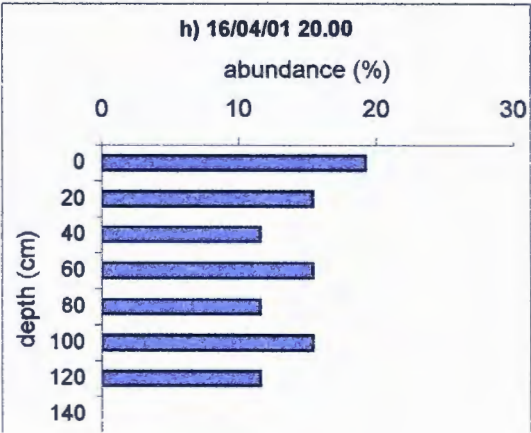
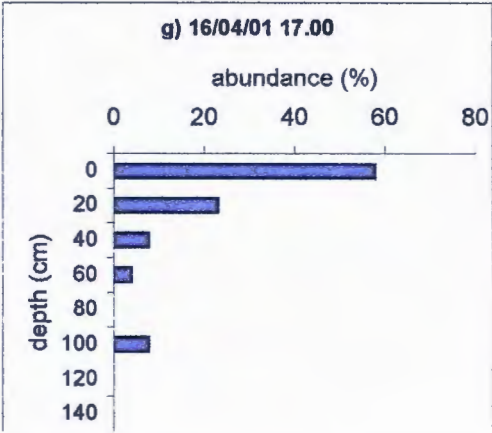
3.3.5 Results of in vitro experiments on diel vertical migration.

Some patterns are apparent from the experiment in April illustrated in Fig. 3.6. This experiment contained only adult copepods. When the copepods were first introduced into the tank they clustered at the surface, later spreading throughout the column and remaining

spread throughout the first night (15th). At 04.00 up to 68% had concentrated in the upper 20 cm. From 06.00 until 17.00 between 45% and 55% remained in the upper 20 cm while the remainder were spread through the column. Individuals remained evenly spread through the column over the second night but again concentrated near the surface close to dawn (05.00). They spread through the column next day (17th). Again a high proportion clustered close to the surface (>50%) near dusk (17.20), and remained close to the surface for most of the following night. By the evening of the 18th April, many copepods had died so the experiment was terminated.

Results of the July experiment diverged from this pattern. That particular sample was characterised by a high proportion of juveniles, and it appeared that their behaviour differed from that of the adults (Fig. 3.7). A high proportion of copepods (between 50% and 60%) concentrated near the surface for much of the first night and first day. By the second night (18th) they were more evenly spread through the water column (around 30% near surface). At the end of the July experiment, the top 20 cm of the water column was occupied only by juveniles and a few females. In the next 30 cm there were again juveniles and a few females. In the bottom 50 cm were only adults, mostly males.





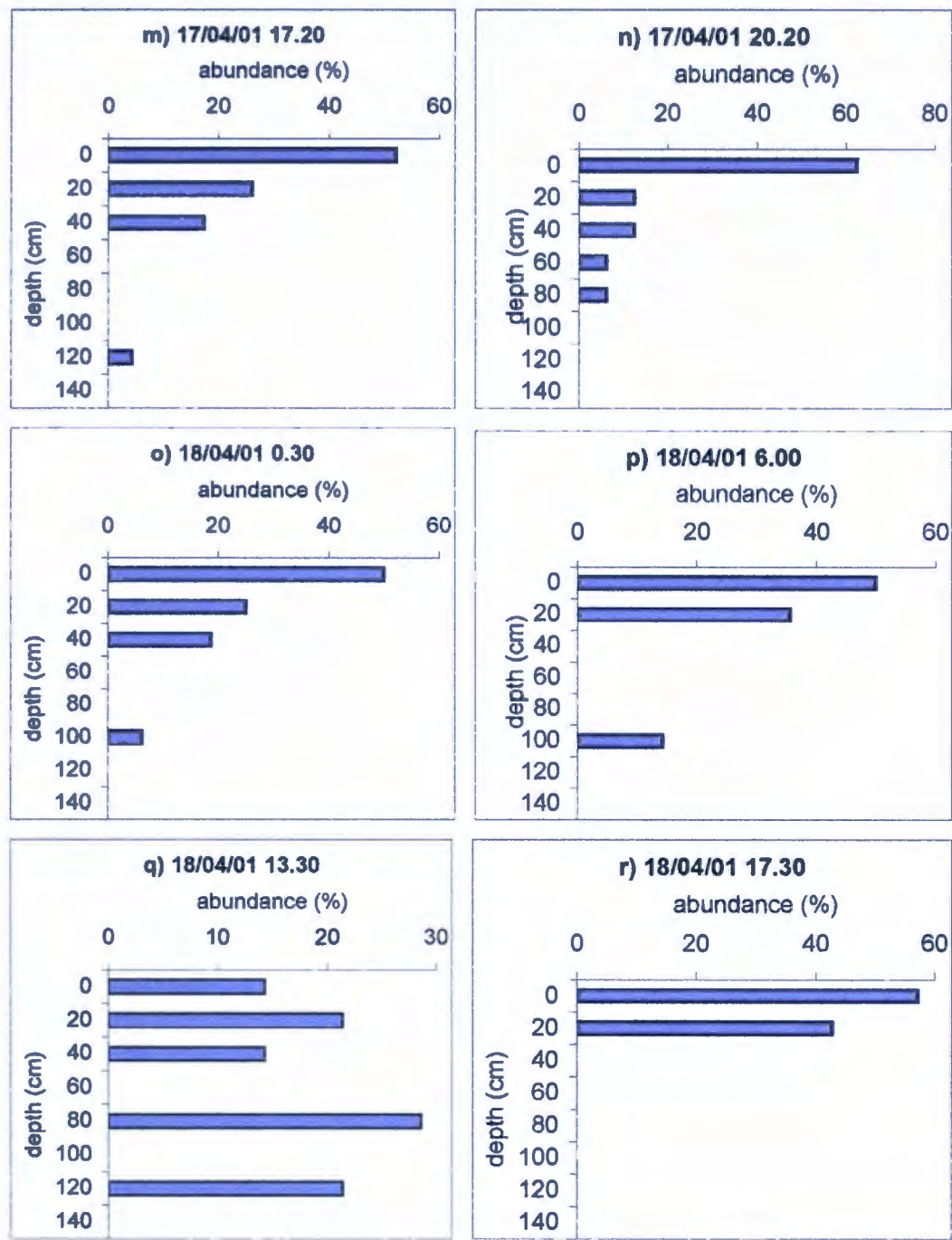
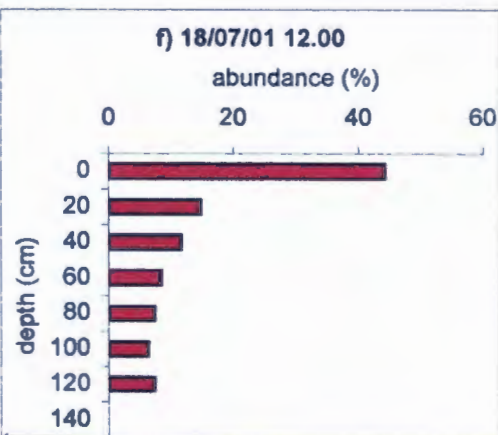
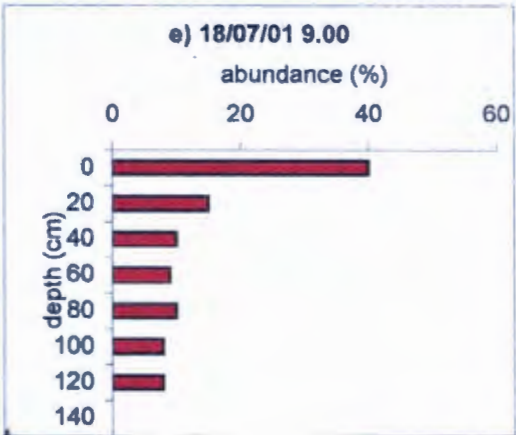
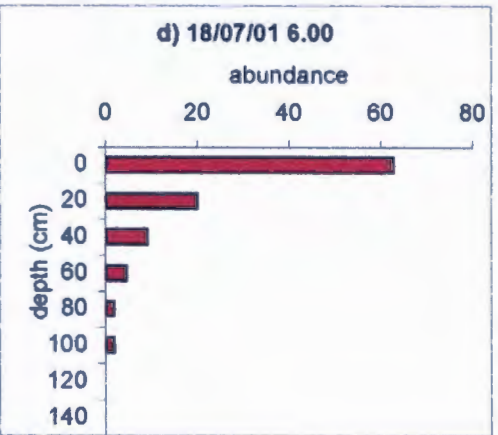
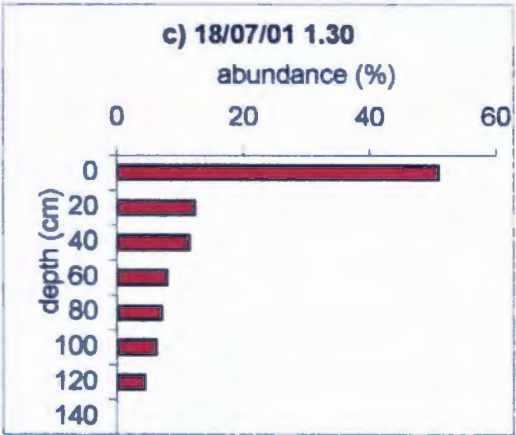
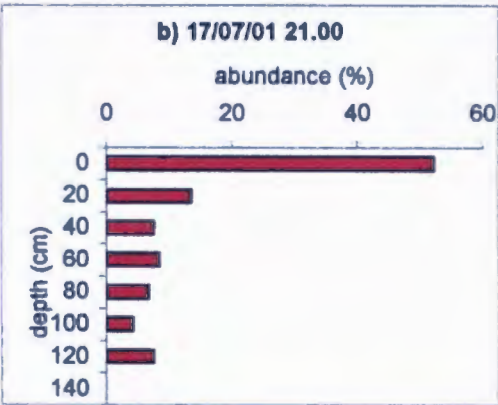
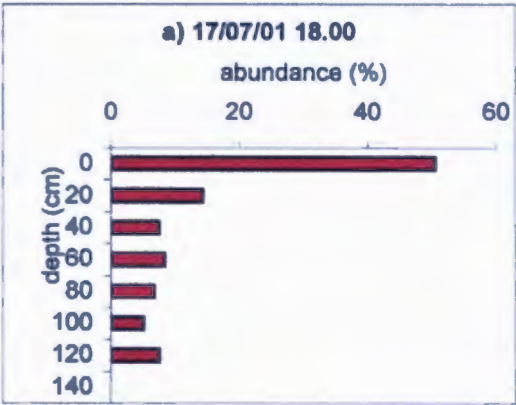


Fig. 3.6 Results of tank experiment to investigate vertical distribution of adult *Labidocera cervi*. Experiment started in the evening of 15/4/01, and ended in the evening of 18/4/01. Sequence of graphs runs horizontally from top left to bottom right.



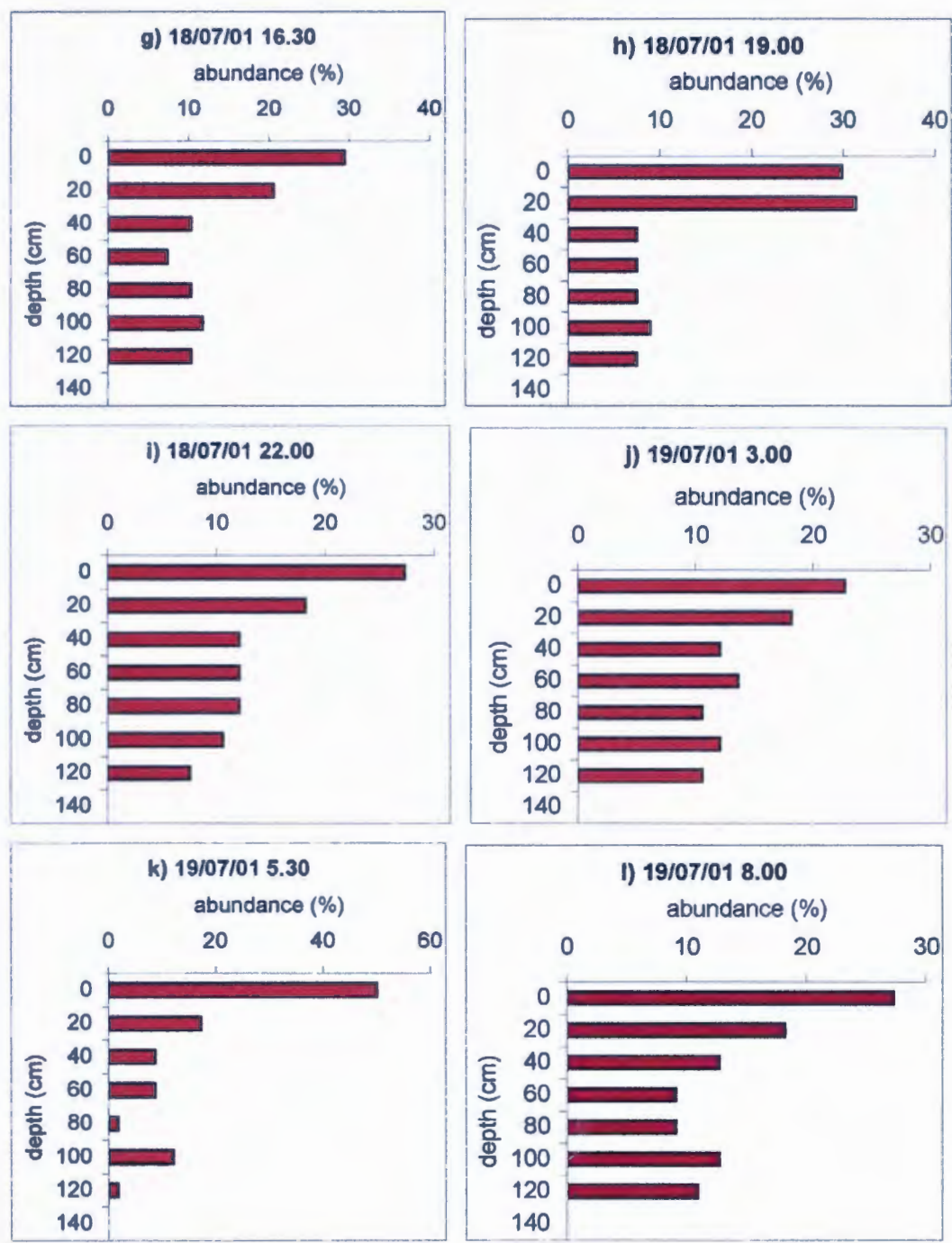


Fig. 3.7 Results of tank experiment to investigate vertical distribution of adult and juvenile *Labidocera cervi*. Experiment started in the evening of 17/7/01, and ended in the morning of 19/7/01. Sequence of graphs runs horizontally from top left to bottom right.

3.4 Discussion

Pontella novaezealandiae was recorded for the first time on the east coast of Tasmania in March 2000. Past records of this copepod have been limited to the North Island of New Zealand always in coastal waters and in low numbers. Of course most studies undertaken off New Zealand coasts did not concentrate on the neustonic community, which could explain why records of *P. novaezealandiae* are so sparse. But *P. novaezealandiae* was also recorded in Bass Strait in the 1970s (Noone, 1979) and in the 1980s, on a few occasions and in very low numbers (1-2 individuals) (McKinnon, pers comm). This rarity might simply be a result of the method of sampling. Unless neuston are specifically targeted, *P. novaezealandiae* could easily be missed. Nyan Taw sampled regularly over a wide area off the east coast of Tasmania and over a period of 2 years. Even though he was sampling using oblique tows, he never recorded *P. novaezealandiae*. This strongly suggests that it was absent. In contrast, during the current study, the copepod was found regularly throughout the year (mainly in summer), always in low numbers, although only one station was sampled for 13 months. If it had been present in the early 70s, Nyan Taw would have had a high probability of capturing it. From previous records, it seems that the copepod was more abundant in offshore waters, which Nyan Taw sampled intensively. These arguments point strongly to changes having occurred in the interval between the two studies. The appearance of *P. novaezealandiae* might be only one of the consequences of such change. The genus *Pontella* has been described as having preference for warm waters. There has been a gradual warming of surface waters off the Tasmanian east coast during the last 40 years (see chapter 4) and this may have ameliorated conditions sufficiently for

the species to survive here. Alternatively its presence might simply be a consequence of the strong La Niña conditions, which prevailed throughout the study.

In Tasmanian waters, the copepodite stages only appeared during March, which may indicate that the species breeds at the end of the summer, beginning of autumn. Only adult stages were recorded throughout the year. The New Zealand data show a different pattern. Farran (1929) sampled in July and August 1911: he seemed to find more specimens at night, and in reasonable numbers (42). In Tasmania, no *Pontella* were found in the night samples. Specimens captured off New Zealand after 1961 were more abundant during the summer and autumn (January and May) than winter, with no significant difference between day and night (Bradford-Grieve pers. comm.).

It seems that *Pontella novaezelandiae* reproduces during summer and survives through the whole year; adults can be caught occasionally at any time of year. Pontellidae release their eggs in the sea where they develop through naupliar and copepodite stages until metamorphosing to the adult. Some species of Pontellidae tend to produce resting eggs (Uye et al., 1984; Lindley, 1990). These possess a second external envelope of variable thickness, sometimes ornamented with granules or spines, and they are very resistant. They can stay on the seabed for several months and, responding to a change of environmental conditions (water temperature, salinity, photoperiod?), they hatch and produce a new cohort of individuals. Even though the mortality rate of these “diapausing eggs” is high, there are enough organisms released to maintain a population throughout the year. So it is possible that the life history of *Pontella novaezelandiae* is similar to that of some of its relatives in that it produces resting eggs in late summer-autumn. This could explain the maintenance of the population (albeit at a low level) the whole year.

The feeding habit of a copepod can be deduced by examining its mouthparts, particularly maxilla 1 and 2 and the mandible (Omori and Ikeda, 1984). According to this, *Pontella novaezelandiae* would be carnivorous (see Fig 2.2 and 2.4 j, k and l), as are all Pontellidae; but some authors have shown that some species from the genus *Pontella* and *Labidocera* are omnivorous. Diatoms and dinoflagellates were found in their stomachs as well as fragments of small copepods and cladocerans. It appears that, though they have mouthparts modified for carnivory and preferentially take animal prey, they are able to feed on microalgae and other particles as well.

Taw (1975) found *Labidocera tasmanica* to be much more abundant than *L. cervi* in his study off eastern Tasmania in the 1970s. This is the reverse of what I found in the present study. If *L. cervi* is the same as the species found by Greenwood and Othman (1979) and discussed by Bradford as *Labidocera spp.*, then maybe its influence is more important nowadays than it was in the 1970s, perhaps because of the increasing influence of the East Australian Current off the Tasmanian east coast.

Vertical migration of neustonic copepods, particularly *Pontella* and *Labidocera*, has been suggested by some authors (e.g. Champalbert, 1977; Zaitsev, 1968), to be of a different nature to that of other copepods. Most planktonic components swim toward the surface at night and swim to greater depths during the day, so they can feed during the night time and avoid visual predators during the day time. Neustonic species use the surface as visual protection (camouflage) as their bodies are blue from carotenoid pigments. This gives them protection from aerial predators; and they have developed the ability to jump off the water surface to escape from pelagic predators (as much as 10cm, Zaitsev, 1968; Ianora et al., 1992). The first few cm of the water column have been proven to harbour a degraded

mixture of plants and decomposed animals, but also a very efficient bacterial cycle (Zaitsev, 1968; Champalbert, 1971;1977; Hardy, 1991). Seasonally, egg production is a rich nutrient supply, as most eggs of planktonic and pelagic species float to facilitate wide dispersal.

Champalbert (1985) showed that *Labidocera* adults feed twice a day, at dusk and shortly after midnight. My study did not allow me to corroborate this result. But it appeared from my results that females and juveniles had a preference for the first 40 cm of the water column at all times. Juveniles in particular, may have stayed within the first 20cm all day and night. Male adults migrated deeper in the column at night, possibly for hunting purposes. In a previous study, it was observed that in two out of eight pontellid species (one was a species of *Labidocera*), females and males had different vertical migration patterns (Matsuo and Marumo 1982). Females spent most of the daytime in the upper layers while males only entered the upper layers for a few hours at night. Also Champalbert (1975, 1976) showed that sexes of three species of pontellids , *Anomalocera patersoni*, *Pontella mediterranea* and *Labidocera wollastoni*, responded differently to changes in hydrostatic pressure.

As stated earlier, many zooplanktonic species migrate to the surface or near surface at night, which may exacerbate spatial competition for neustonic species. Consequently this might lead to neustonic species extending their distribution deeper into the water column until dawn, when they again become the dominant organisms of the surface layer.

4 Changes in coastal zooplanktonic communities of south east Tasmania over a 30 year period

4.1 Introduction

Zooplankton respond rapidly to environmental cycles and community changes can affect the whole food web downstream. Some zooplankters are so specific to certain water bodies they are considered as indicators of those water bodies (Taw, 1975; Nagasawa, 1991). A change in the zooplanktonic community could signal a change of the water, and variation in the circulation pattern. Such a change can be due to the seasonal cycle, but also to climatic events such as El Niño or La Niña (Dessier and Donguy, 1987, Hidalgo and Escribano, 2001, Lavaniegos-Espejo and Lara-Lara, 1990, Palomares-Garcia and Gomez-Gutierrez, 1996) and even as an indicator of longer term climatic changes (Lindley and Batten, 2002).

This is why a long term monitoring scheme in a specific area can provide important information about climatic cycles and their effects on the biological components of the system (Hays et al., 1996). Such surveys have been in continuous operation in the North Sea since 1931 with the utilisation of the continuous plankton recorder (CPR)(Hardy, 1936), and they have been a success (Lindley and Batten, 2002, Hays et al., 1996). They provided important information on the planktonic structure, good estimates of interannual variations and showed the emergence of patterns in these variations. The same type of survey has begun in the Southern Ocean (Hosie pers comm.); unfortunately none have been undertaken in the South Pacific. Zooplankton data earlier than the 1980s for Australian coastal waters is very sparse. Fortunately a study of the zooplankton of the south east coast of Tasmania was undertaken by Nyan Taw in 1971-1973 (Taw, 1975), so these data provided me with an opportunity to compare datasets separated by 30 years, and the chance to observe any change in the species composition that would imply some temporal change of the sea water along the east coast of Tasmania.

4.2 Materials and Methods

4.2.1 Methodology for 1971-72 data: Field procedure

The samples were collected by the then Sea Fisheries Division, based at Taroona, south east Tasmania, from the vessel "Penghana". The stations were situated on the east coast of Tasmania, between latitudes $42^{\circ} 10'$, $43^{\circ} 20'S$ and longitudes $148^{\circ} 00'$, $149^{\circ} 20'E$ (Fig. 4.1). From the whole dataset, only three stations were used for this analysis; the coastal ones (about 0.75 km from shore), are situated off Schouten Island (E12), Maria Island (E8) and Tasman Island (E1). Over a period of 22 months from 1971-1973, there were 10 cruises, during which 89 stations were operated.

A standard plankton net with a mouth area of 1.0 m^2 and a mesh size $330\mu\text{m}$, was used in collecting all samples. Oblique tows lasting 5 min were conducted with 50 m of wire released. The oblique tows were made by lowering the net with a required length of cable released while the vessel was stationary. A few minutes were allowed to have the net reach the required depth. The vessel was then moved forward at a speed of about 2 m.s^{-1} as soon as the net reached the required depth and at the same time a winch was used to pull the net up very slowly. This method of sampling was used to minimise the effect of diel vertical migration of zooplankton. Samples were preserved in approximately 5% formalin immediately after each collection.

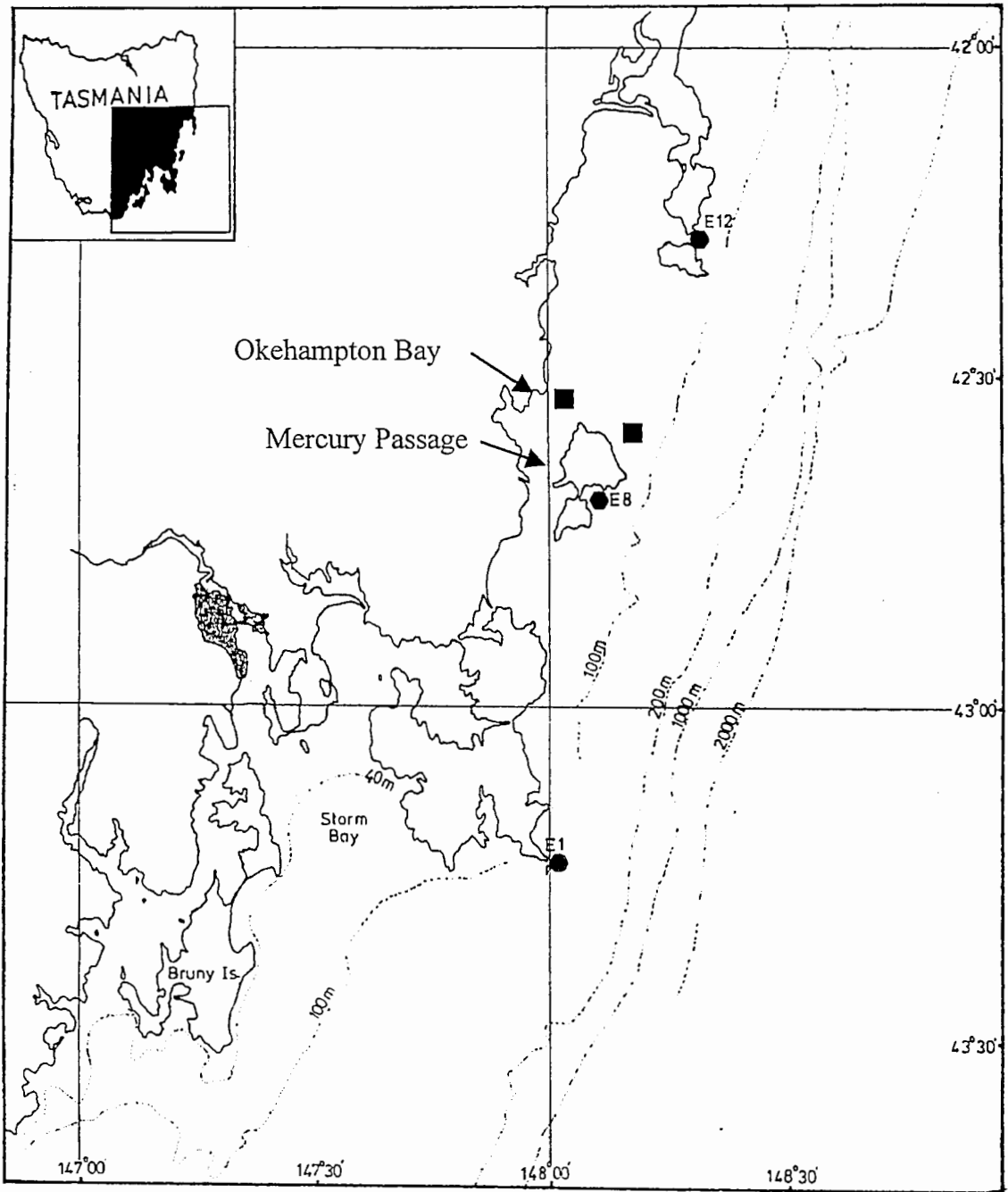


Fig. 4.1 Map of coastal sampling sites (modified from Taw, 1975). ● 1971-73 stations, ■ 2000-01 station (also designated BNMP for May 2002 samples; see text). Station BNMI was also used for May 2002 samples

Surface water temperature was recorded by the vessel's continuous thermograph (Negretti and Zambra) during Taw's study.

Laboratory procedure: sub-sampling

The sub-sampling was carried out using a Modified Whirling apparatus (Kott, 1953), which produces ten sub-samples. Before sub-sampling, all large organisms such as salps, ctenophores, euphausiids, etc., were removed. The whole sample was examined and the rare and less abundant species were counted. For the abundant species, for example *Acartia clausi* (now identified as *A. tranteri*), and *Paracalanus parvus* (now identified as *P. indicus*), in the coastal waters and *Neocalanus tonsus* and *Clausocalanus ingens*, usually one tenth of the sample by volume was counted and the number for the whole sample was estimated. To decide what fraction of the sample should be counted, about one tenth or one twenty-fifth of the sample by volume, depending on the size of the sample, was extracted using a Stempel pipette and counted and the total number estimated. If the number exceeded 100 and was less than 10000 in the whole sample, one tenth of the sample was counted. If the number exceeded 10000, one twenty-fifth of the sample was counted. Counting was done by using a modified counting disc and apparatus set up as described by Nyan Taw (1975). Only copepods, chaetognaths, salps and adults euphausiids were identified.

4.2.2 Methodology applied in 2000-01

For the 2000-01 methodology (sites, sampling and sorting) see previous chapter. As only copepods, chaetognaths and salps were counted in Taw's (1975)) data set, the matrices were reduced to these 3 taxa and the present data set contained no adult euphausiids.

Long term temperature and salinity data recorded at the Maria Island monitoring station (42° 36' S, 148° 14' E) were obtained from CSIRO Division of Marine Research.

4.2.3 Compatibility of the 2 methodologies

Comparison of two different studies with different goals based on different methodologies would only be valid if certain conditions are satisfied. These are:

1. In order to validly include all 3 coastal stations from 1971-73, no spatial differences in zooplankton communities should exist along the south east coast of Tasmania.
2. Small differences in mesh size did not influence the results.
3. Samples collected using oblique and horizontal hauls during daytime were not significantly different.
4. Samples collected in 2001 using Taw's (1975) methods should cluster with 2001 samples and not those collected in 1971-3.

Spatial differences

A cluster analysis using a Bray-Curtis dissimilarity index was used firstly to establish whether there were any major differences in community structure between Taw's (1975) stations E1, E8 and E12.

To estimate the importance of the difference in methodology, the two methods were tested at the same time and the same location in May 2002. Note that Taw's (1975) station E8 was sometimes at the location shown in Fig.4.1 and sometimes at the location labelled BNMI ie. E148° 09'15", S42° 34'7".

Mesh size

For this comparison, both nets had 1.0 m² aperture but Nyan Taw's had a 330µm mesh whereas mine was 300µm. This difference can be readily discounted as the major

variation in organisms captured would be in the abundance of very small zooplankters e.g. early copepodites, echinoderm larvae, bivalve larvae and radiolarians. The last 2 taxa were ignored in Nyan Taw's study, and the copepodites were ignored in both.

Oblique vs horizontal tows

Also while I studied the surface epipelagic zooplankton during my main sampling program, and therefore towed the net horizontally, Nyan Taw used oblique tows from 50 m to the surface. This could have led to serious abundance and diversity differences. In May 2000, paired oblique tows were made with a 330 μm mesh net on the East side of Maria Island (station BNMI) and in the Mercury Passage (station BNMP) at midday, also at the same time, duplicate tows of a 300 μm mesh net sampling horizontally at the surface were made. The results obtained were compared using a contingency table and a Chi Square test. The null hypothesis was that there was no difference in community structure revealed using the two methods. Then the data were added to the whole data set, firstly for 2000-01, then for 1971-73, and a cluster analysis was conducted using the Bray-Curtis dissimilarity index to determine their relationship.

4.2.4 Data analysis

By sampling site matrices, expressed as density values of number of individuals 100 m^{-3} , species were analysed using cluster analysis. Sampling sites were first compared to define areas with similar species composition (q-type analysis). Multivariate analyses were carried out using STATISTICA (StatSoft Inc.).

Prior to the comparison of sampling sites, data were transformed using the $\log_{10}(X+1)$ function to reduce the bias of very high abundance species and to give more

weighting to species likely to have been undersampled, e.g. smaller copepods and cladocerans. Cluster analysis was carried out using the Bray-Curtis dissimilarity index (UPGMA). The Bray-Curtis index was chosen because of its ability to deal with matrices with a high component of zero data entries, i.e. it will not be influenced by joint absences (Field et al. 1982). The whole dataset was also subjected to an MDS analysis (PRIMER). Prior to this analysis the data were fourth root transformed.

4.3 Results and statistical analysis

4.3.1 Analysis of the 1971-73 coastal data

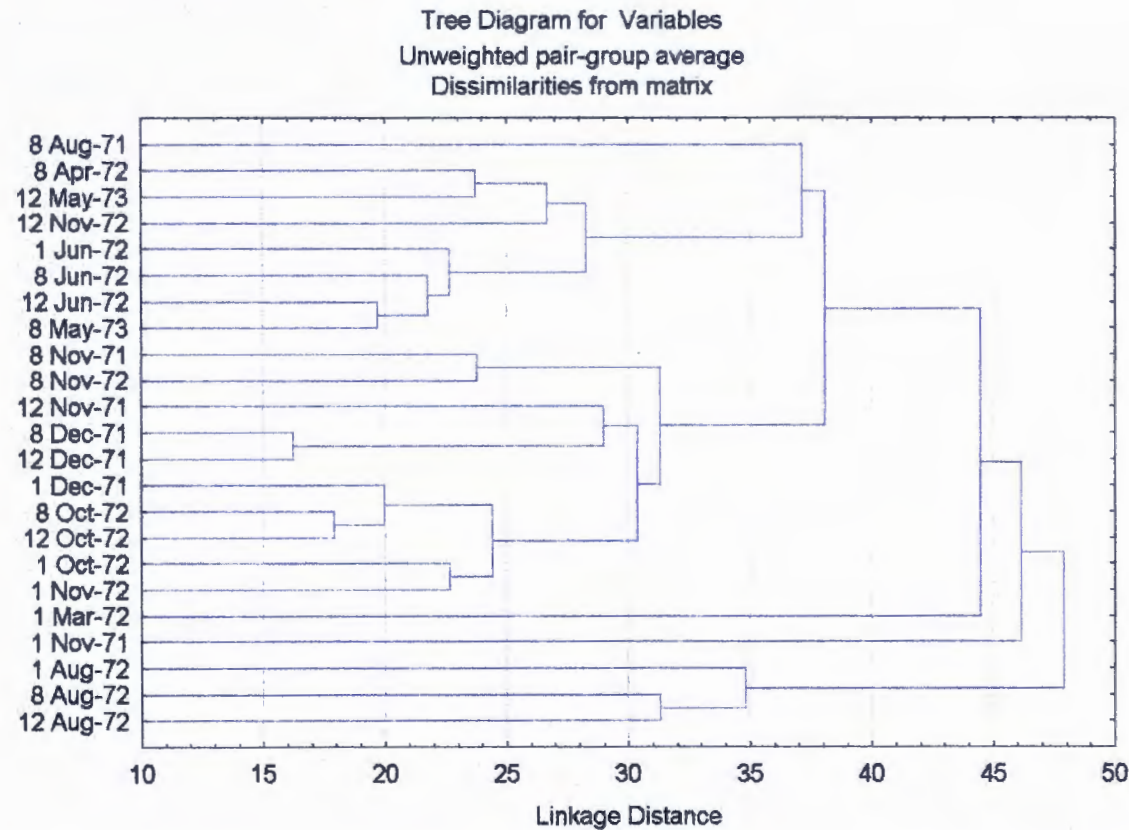


Fig. 4.2 Cluster diagram of stations sampled during 1971-73. 1,8, 12 represent stations off Schouten Island, Maria island and Tasman Island, respectively (see Fig. 4.1), sampled by Taw (1975).

Only the stations corresponding to the sites E1, E8 and E12 were taken into consideration for the present purpose as they are considered as coastal (<200 m)(Taw, 1975). Using these data, a cluster analysis was performed to investigate any changes in the community structure along the coast (Fig. 4.2). The null hypothesis tested was that there was no difference among the samples. Any significant difference between stations would indicate a spatial differentiation, and any significant difference among the samples by months would indicate a temporal differentiation.

The maximum dissimilarity was 47%, so in general, this is a homogeneous group. From the Cluster analysis (Fig. 4.2), we can distinguish 5 groups. Group 1 is composed of the 3 stations for June 72, the 2 stations for May 73, April 72, August 71 and E12 for November 72. We can consider it as the winter group 71 (1 station only), 72 (except August) and 73. Group 2 consists of E8 for November 71, E1 and E8 of November 72, December 71, and October 72; this group can be considered as summer 71 (except 1 station in November) and 72 (except one station in November). Group 3 contains only one station: E1 for March 72. Group 4 also contains only 1 station: E1 for November 71. Finally group 5 is composed of the stations for August 72. The cluster analysis shows grouping of stations and months. The differences among stations within a month are less important than the differences between months (all stations involved), so the 3 stations E1, E8 and E12 are quite similar in abundance and diversity. For example, in August 72, the 3 stations are linked with more than 65% similarity, in December 71 with 70% and even 75% in June 72. Two particular exceptions appeared in the cluster diagram: the first one happened in November 71 where station E1 is separated from E8 and E12. In this case, E1 was characterised by a very low abundance and diversity. The second one also happened in November, but of 1972, where station E12 clustered with Group 1, a winter group. E1 is the most southern station, and Taw

(1975) reported that the subtropical convergence occurred close to the Tasmanian coast and reached as far as Tasman Island in summer. This would explain the characteristic winter community of station E1. But overall, the analysis shows that the zooplanktonic community is similar along the south east coast of Tasmania. Furthermore it gives us some confidence that the site to the north of Maria Island (as in the 2000-01 sampling period) is comparable with the 3 coastal sites sampled by Nyan Taw from 1971 to 1973. This is especially so because some of Taw's sampling was carried out at the location of BNMI (his station E8, see above).

4.3.2 Comparison of the methodologies

The Chi square test showed that the differences between samples obtained using the two methods in May 2002 are highly significant ($p < 0.05$). The Chi square calculated for comparison between samples collected in the mouth of the Mercury Passage was 224; that for the samples from the East coast of Maria Island was 883.9 both for 18 degrees of freedom. The null hypothesis is strongly rejected. The two methods are different and further statistical analysis is not warranted. However, those data were added to the previous cluster analysis (of the two data sets) and they separated out as shown in Fig. 4.3. Although the samples BNMI (Maria Island site, 70s collection method) and BNMP (Mercury Passage site, 01 collection method) were collected in the same month and at the same time of day, they showed a dissimilarity of 58% with the 1971-73 dataset. On the other hand they clustered more closely with the samples obtained using a horizontal tow (current method) in May 2002. Moreover, when the same data are added to the cluster analysis of the 2000-2001 dataset (Fig. 4.4) they appear to fit in the middle of the diagram, and are linked with the rest of the data set,

with a dissimilarity of 46%, particularly samples MAO5 and 6 (June 2000) and MAO7 (August 2000).

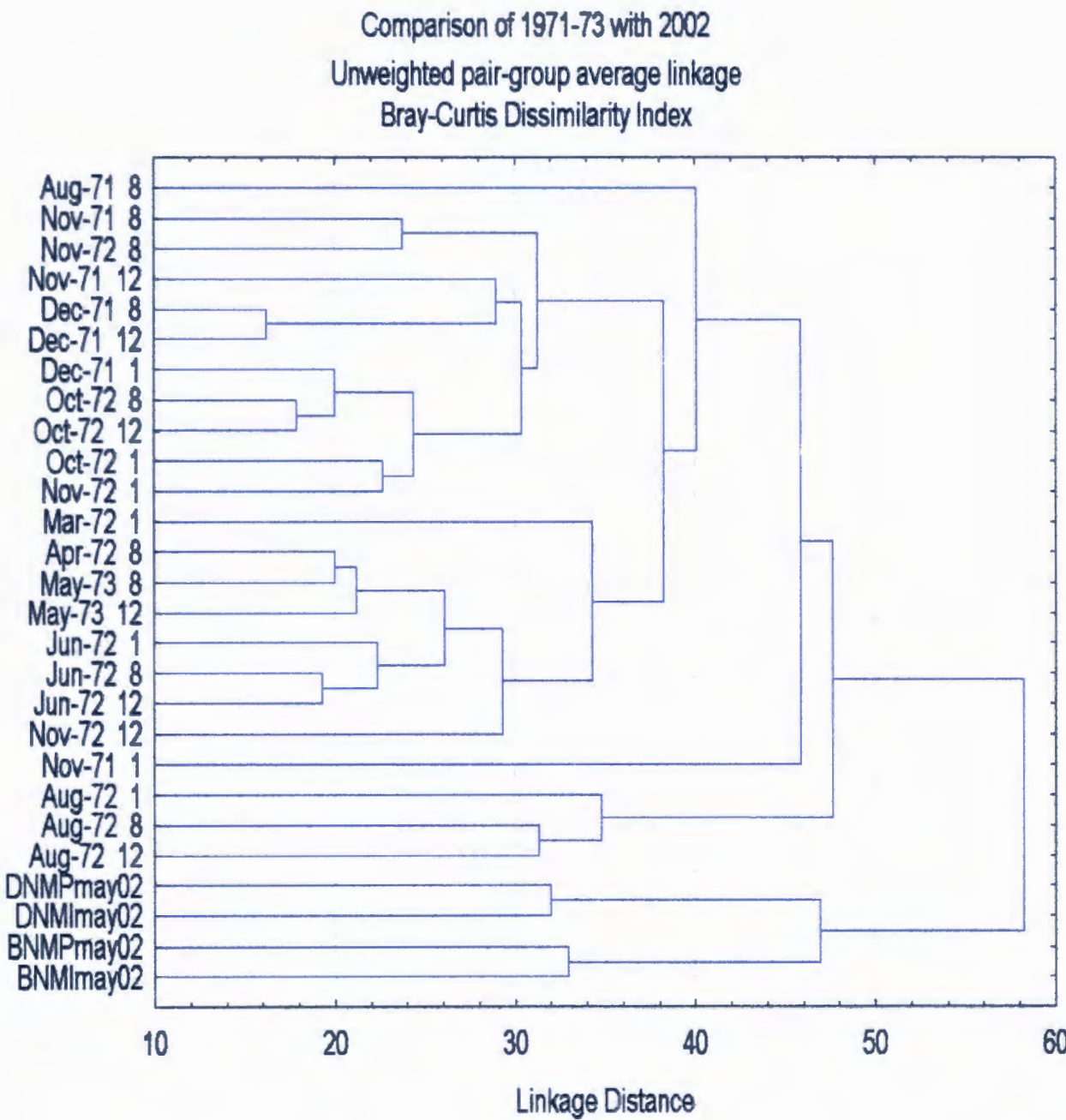


Fig. 4.3 Cluster analysis diagram using a Bray Curtis dissimilarity index. 1, 8, 12 represent the 3 stations (Schouten Island, Maria Island and Tasman Island), DN : method used for 2000-01 data set, BN : method used for 1971-73 data set, MP : Mercury Passage, MI : east coast of Maria Island.

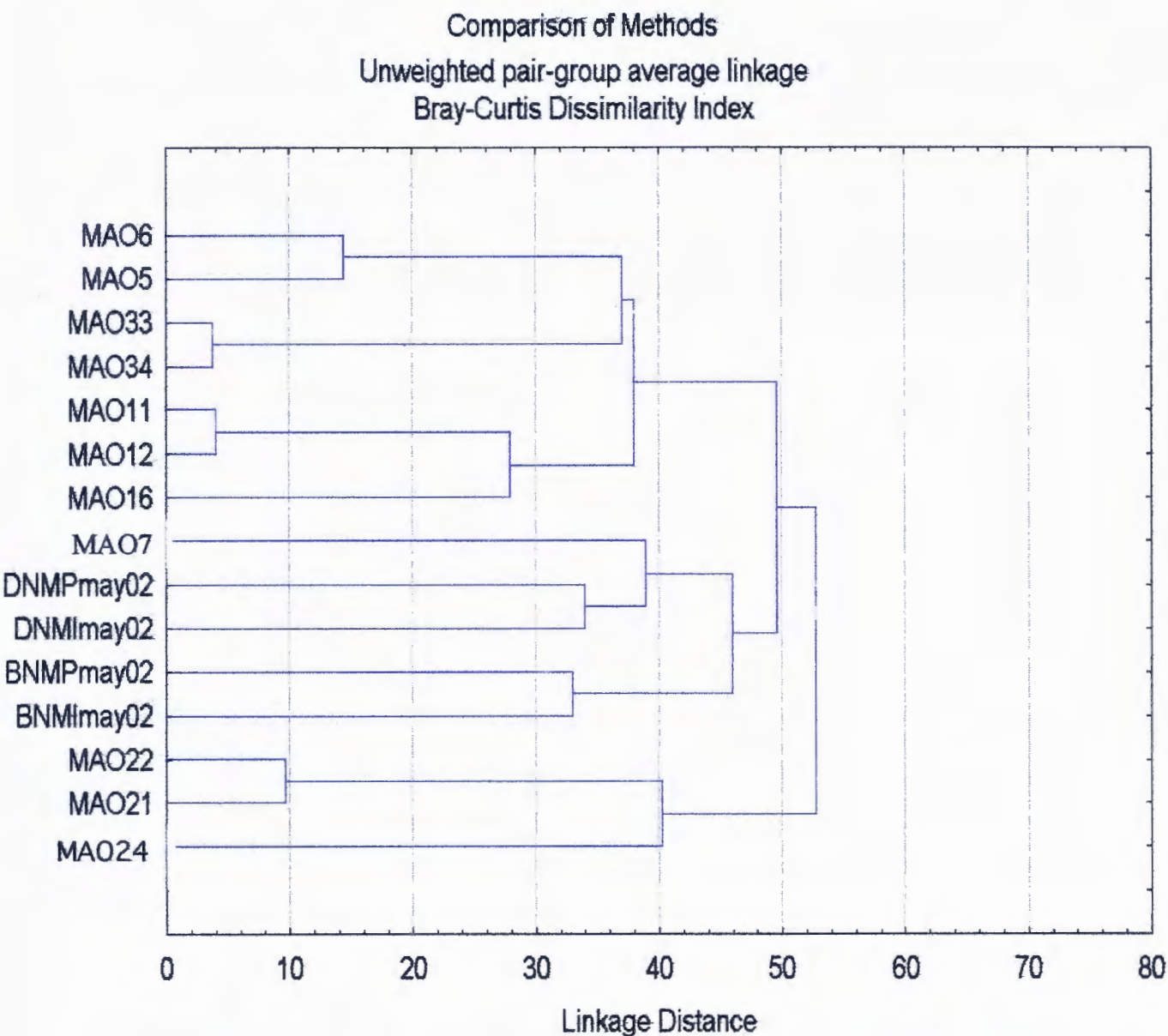


Fig.4.4 Cluster analysis diagram using a Bray Curtis dissimilarity index for the 2000-01 data set. MAO : mouth of the Mercury Passage , DN : method used for 2000-01 data set, BN : method used for 1971-73 data set, MP : Mercury Passage, MI : east coast of Maria Island.

Comparison of 1971-73 and 2000-01 Surveys
Unweighted pair-group average linkage
Bray-Curtis Dissimilarity Index

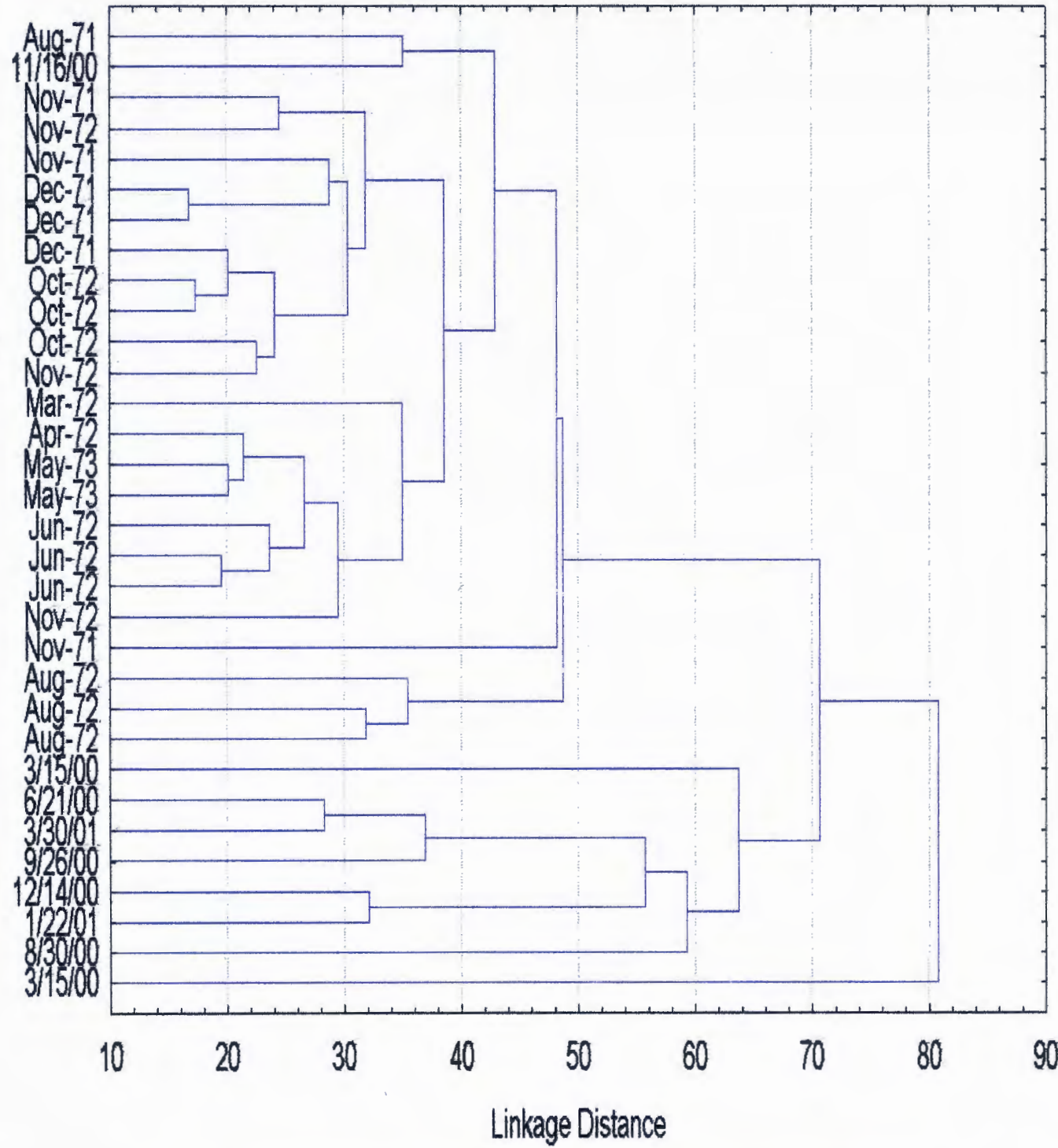


Fig. 4.5. Cluster analysis diagram of a Bray Curtis dissimilarity index. The dataset includes the 3 stations of 1971-73 and the 2000-01 stations.

4.3.3 Comparison 1971-73 and 2000-01 data sets

The cluster analysis diagram is as shown in Fig. 4.5. The 2000-01 data are clearly separated from the 1971-73 ones with more than 70% of dissimilarity. One exception to this, the sample MAO16 (November 2000) linked with an index of similarity of 65% with August 1971. Both those samples were characterised by a very low abundance and diversity.

The MDS analysis (Fig. 4.6) shows the 2000-01 data clearly separate from the 1971-73 data. Also it is clear that the May 2002 samples group separately from both the 2000-01 data and the 1971-73 data. The January 2001 outlier had very low species richness and abundance. The reasons for this difference are not clear.

4.3.4 Comparison of species composition

Table 4.1 Species composition for 1971-73 and 2000-01 datasets, ordered by decreasing abundance (* means that the species is oceanic, green means coastal, blue means cold water indicator, and red warm water indicator. This classification is based on data in Bradford-Grieve et al. 1999).

1971-73 dataset	2000-01 dataset
<i>Paracalanus parvus</i>	<i>Acartia tranteri</i>
<i>Neocalanus tonsus cop.V</i>	
<i>Calanus australis</i>	<i>Paracalanus parvus</i>
<i>Acartia clausi</i>	<i>Ctenocalanus vanus f.</i>
<i>Centropages australiensis</i>	<i>Calanus australis</i>
<i>Clausocalanus ingens*</i>	<i>Temora turbinata</i>
<i>Ctenocalanus vanus</i>	<i>Salpa fusiformis</i>
<i>Acartia danae</i>	<i>Calanus minor</i>
<i>Chaetognaths</i>	Larvae Euphausiaceae
<i>Calanoides carinatus</i>	<i>Oithona sp.</i>
<i>Mecynocera clausi*</i>	<i>Labidocera tasmanica female</i>
<i>Neocalanus tonsus ad.</i>	<i>Centropages australiensis male</i>
<i>Centropages bradyi</i>	<i>Euterpina acutifrons</i>
<i>Calocalanus tenuis*</i>	<i>Ctenocalanus vanus male</i>
<i>Nyctiphanes australis</i>	<i>Labidocera cervi female</i>
<i>Calanus minor</i>	<i>Centropages australiensis female</i>
<i>Pleuromamma gracilis*</i>	<i>Clausocalanus ingens*</i>
<i>Mesocalanus tenuicornis</i>	<i>Chaetognathes</i>
<i>Oncaea venusta</i>	<i>Labidocera cervi male</i>
<i>Calocalanus styliremis</i>	<i>Labidocera sp juvenile</i>
<i>Heterorhabdus papilliger</i>	<i>copepodits calanus australis</i>
<i>Labidocera tasmanica</i>	<i>Oithona tenuis</i>
<i>Lucicutia flavicornis*</i>	<i>Oncea sp.</i>
<i>Oncaea media</i>	<i>Labidocera tasmanica male</i>
<i>Pleuromamma abdominalis*</i>	<i>Eucalanus crassus female</i>
<i>Eucalanus elongatus*</i>	<i>Pontella novaezealandiae</i>
<i>Calocalanus contractus</i>	<i>Acartia danae</i>
<i>Thysanoessa gregaria</i>	<i>Clausocalanus arcuicornis</i>
<i>Rhincalanus nasutus</i>	<i>Clausocalanus jobei f.</i>
	<i>Centropages bradyi</i>

<i>Candacia bipinnata</i>	<i>Gladioferens inermis</i>
<i>Salpa fusiformis</i>	<i>Eucalanus crassus male</i>
<i>Pyrosoma atlanticum atlanticum</i>	<i>Calocalanus pavo</i>
<i>Neocalanus robustior</i>	<i>Clausocalanus brevipes f.</i>
<i>Undeuchaeta plumosa</i>	<i>Eucalanus attenuatus female</i>
<i>Euchirella rostrata</i>	<i>Neocalanus tonsus f.</i>
<i>Eucalanus longiceps</i>	
<i>Eucalanus crassus</i>	
<i>Iasis zonaria</i>	
<i>Eucalanus attenuatus</i>	
<i>Clausocalanus laticeps</i>	
<i>Ihlea magalhanica</i>	
<i>Leptocalanus plumulosus*</i>	
<i>Calocalanus pavo</i>	
<i>Euchirella rostromagna</i>	
<i>Nematoscelis megalops</i>	

There seems to be a greater diversity in Taw's (1975) samples (Table 4.1): 38 taxa listed against 32 in 2000-01. But species composition differs between data sets. Nineteen species are present in both data sets, and most of those are coastal such as *Acartia tranteri* (identified as *A. clausi* by Taw), *Paracalanus indicus* (identified as *P. parvus* by Taw), *Clausocalanus* and *Ctenocalanus spp.*

Table 4.2 Species composition ordered by decreasing abundance for May 1973 and May 2002 samples both collected using oblique tows at the same station. (legend as in Table 4.1). Note *P. parvus* and *A. clausi* identified as *P. indicus* and *A. tranteri* in 2002.

May 1973	No ind/100 m ³	May 2002	No ind/100 m ³
<i>Paracalanus parvus</i>	13832	<i>Acartia tranteri</i>	7004
<i>Calanus australis</i>	1246	<i>Paracalanus parvus*</i>	2107
<i>Chaetognaths</i>	910	<i>Clausocalanus ingens</i>	421
<i>Acartia clausi*</i>	784	<i>Oithona sp.</i>	199
<i>Mecynocera clausi</i>	448	<i>Acartia danae</i>	152
<i>Clausocalanus ingens</i>	434	<i>Ctenocalanus vanus</i>	140
<i>Centropages bradyi</i>	266	<i>Clausocalanus laticeps</i>	140
<i>Ctenocalanus vanus</i>	196	<i>Oncea sp.</i>	69
<i>Centropages australiensis</i>	154	<i>Chaetognathes</i>	41
<i>Mesocalanus tenuicornis</i>	112	<i>Mecynocera clausi</i>	27

<i>Calanus minor</i>	22	<i>Eucalanus crassus</i>	23
<i>Acartia danae</i>	17	<i>Temora turbinata</i>	18
<i>Rhincalanus nasutus</i>	13	<i>Lucifer hansenii</i>	13
<i>Calocalanus tenuis</i>	6	<i>Doliolum sp</i>	4
<i>Neocalanus robustior</i>	3	<i>Centropages</i>	4
<i>Oncaea media</i>	3	<i>Labidocera cervi male</i>	4
<i>Oncaea venusta</i>	3	<i>Pontella sp</i>	4
<i>Candacia bipinnata</i>	2	<i>Euterpina acutifrons</i>	4
<i>Eucalanus attenuatus</i>	1		
<i>Eucalanus elongatus*</i>	1		
<i>Pleuromamma abdominalis*</i>	1		
<i>Pleuromamma gracilis*</i>	1		

The main differences apparent in Table 4.2 are the dominance of *P. parvus (indicus)* in 1973, compared to *A. tranteri (clausi)* in 2002. Of the relatively common species, *Clausocalanus laticeps* and *Oithona sp.* were present in 2002 but not represented in 1973. In contrast, *Calanus australis* and *Mecynocera clausi* were present in 1973 but not captured in May 2002.

4.3.5 Temperature and salinity changes during the last 50 years

At the Maria Island station monitored by the oceanographers of CSIRO since 1946, profiles of temperature, salinity, oxygen, and nutrient concentrations are measured every two months and monitoring is continuing. Data were collected at 0, 20 and 50 m depth successively until 1956, then the 10, 30, 40 and 100 m were added to the scheme. The direct measure at 0m showed too much variability, and tended to confuse the results rather than clarify them. For this reason and, in accordance with Harris et al. (1987) who made the first comparison at this station, the values at 20 m depth were compared with the ones at 10 m, and considered as the SST. The differences between these two depths were used to define any small temporal stratification of the upper water column. For the same reasons, Rochford (1981) used the temperature at 5 m depth as SST values and only in winter, because of possible temporary stratification

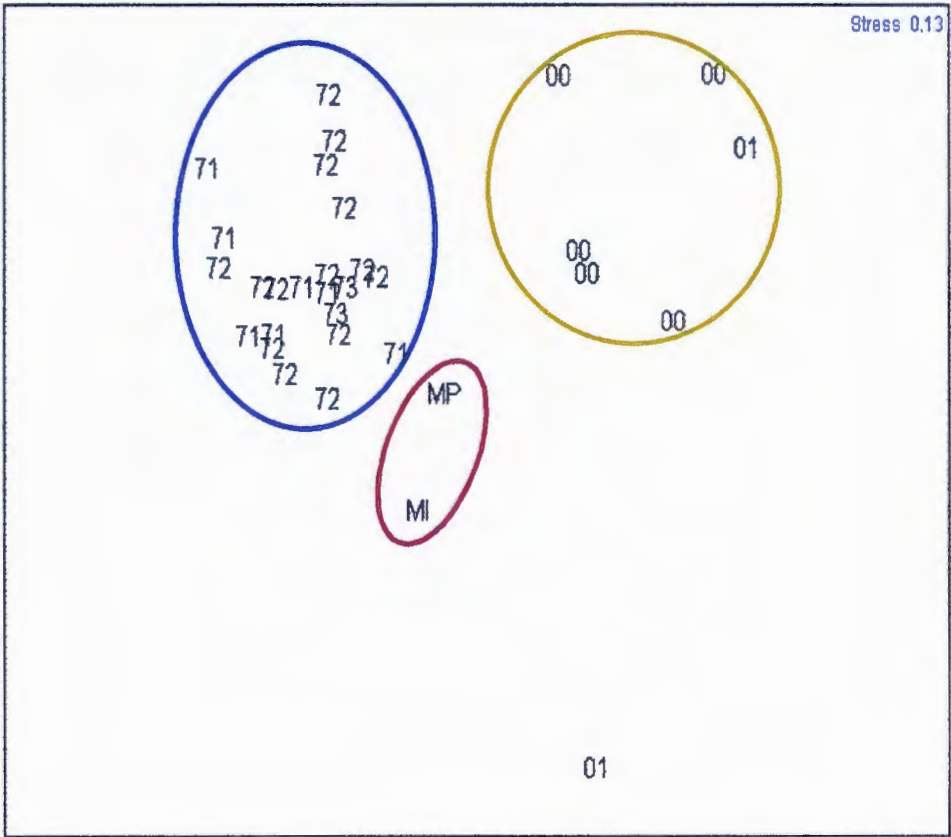


Fig. 4.6. MDS plots of 1971-73 data (blue), 2000-01 data (yellow) and May 2002 data collected in the same manner as the 1971-73 data (red). The outlier from 2001 is from January.

of the upper water column in summer. In 1991, Hsieh and Hamon used the temperature values at 50 m to define their model of ENSO cycles in South East Australian waters, but they did not define it as SST. In the present study, the values at 10 and 20 m did not show any difference in winter, and could have been used interchangeably. However, the values in summer were higher at 10 m than 20 m by 1-2 degree Celsius, but the trend showed the same pattern.

Only temperature and salinity changes were compared for the present purposes. Temperature and salinity time series were analysed separately, and also the relationship between temperature and salinity that is often considered as a good way to characterise a water body.

4.3.6 Trends in the summer maximum temperature

Two kinds of SST graph are presented. Fig 4.6a, b, shows the result of a 5 year and 10 year running average for summer maximum and winter minimum, respectively. The 5 year running average, smoothed the small interannual variabilities, but kept cyclic patterns, for example the presence of ENSO events. The 10 year running average obscured the cyclic events of a few years, but revealed the long term changes, or trends.

The salinity plots (Fig. 4.6c) showed a considerable variability in the 5 year running mean, and they did not reveal any clear pattern, but if the data are averaged over a 10 year run, a clear rising pattern is obtained. A linear regression was fitted and had an r^2 value = 0.75, a result quite respectable for this type of data, that is often subject to considerable variability. Over the same period, the salinity has risen from 35.2‰ to 35.38‰ in 50 years. The surface and subsurface salinity plots seemed to follow the same pattern.

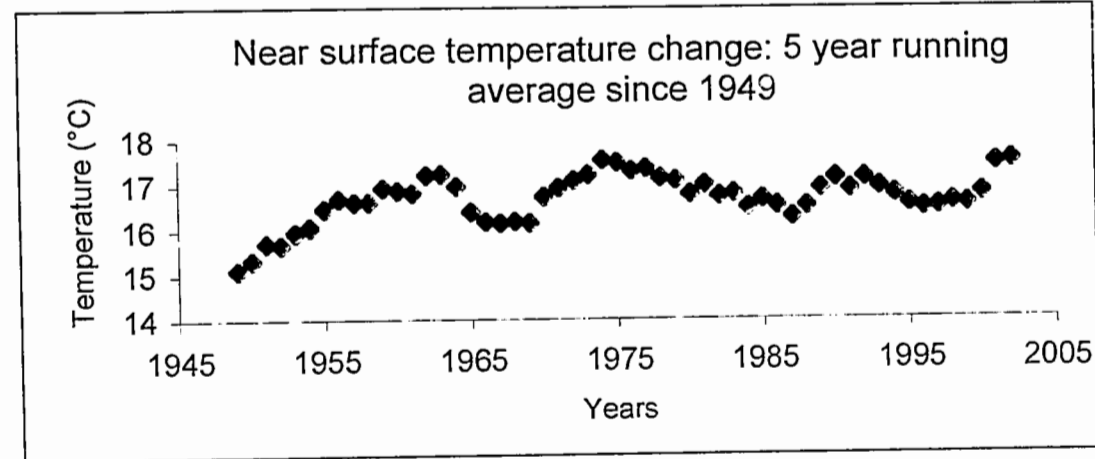
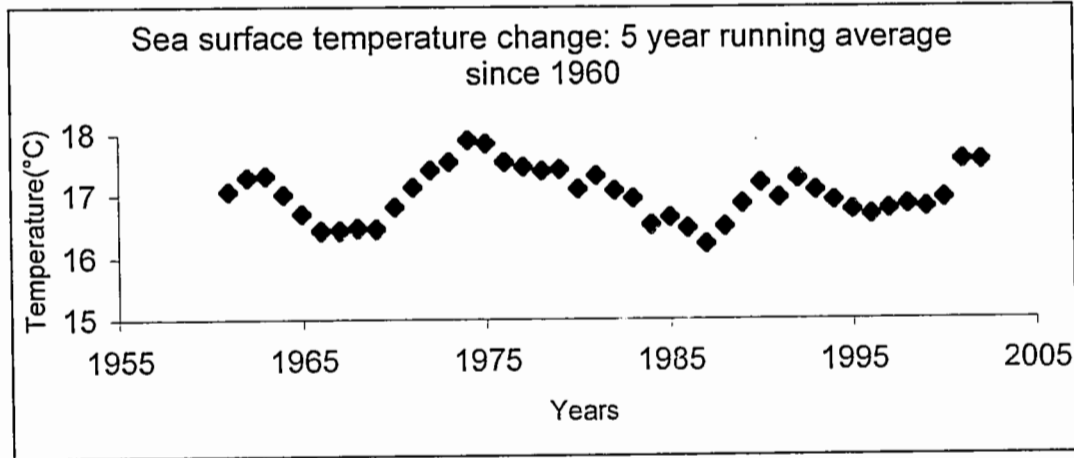
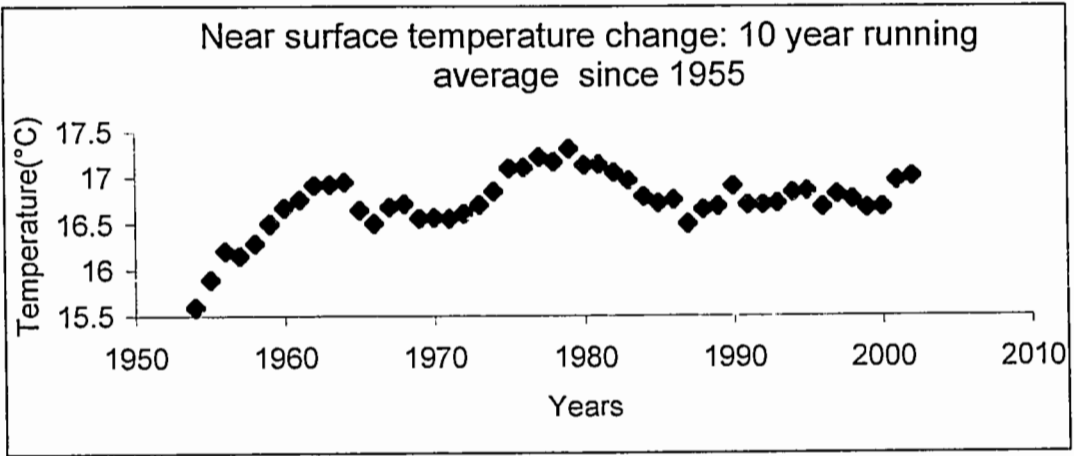
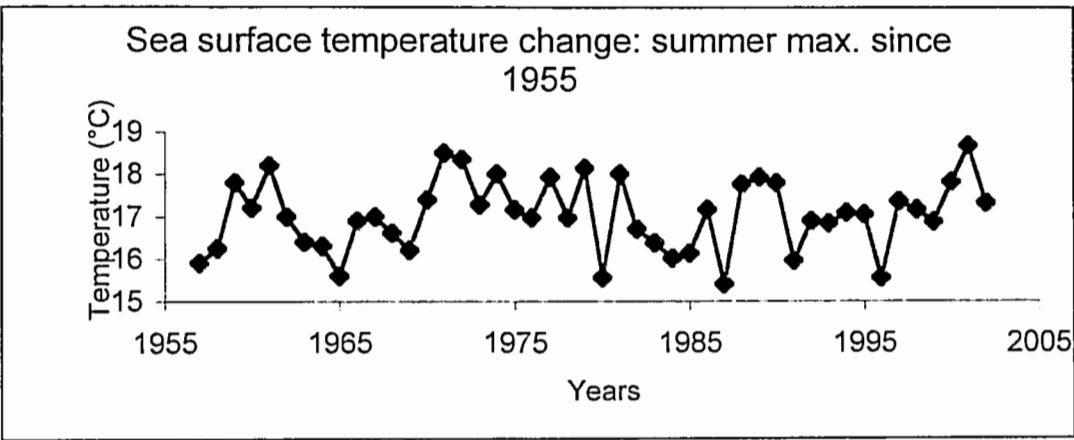


Fig. 4.6a SST changes recorded at the Maria Island monitoring station.

b

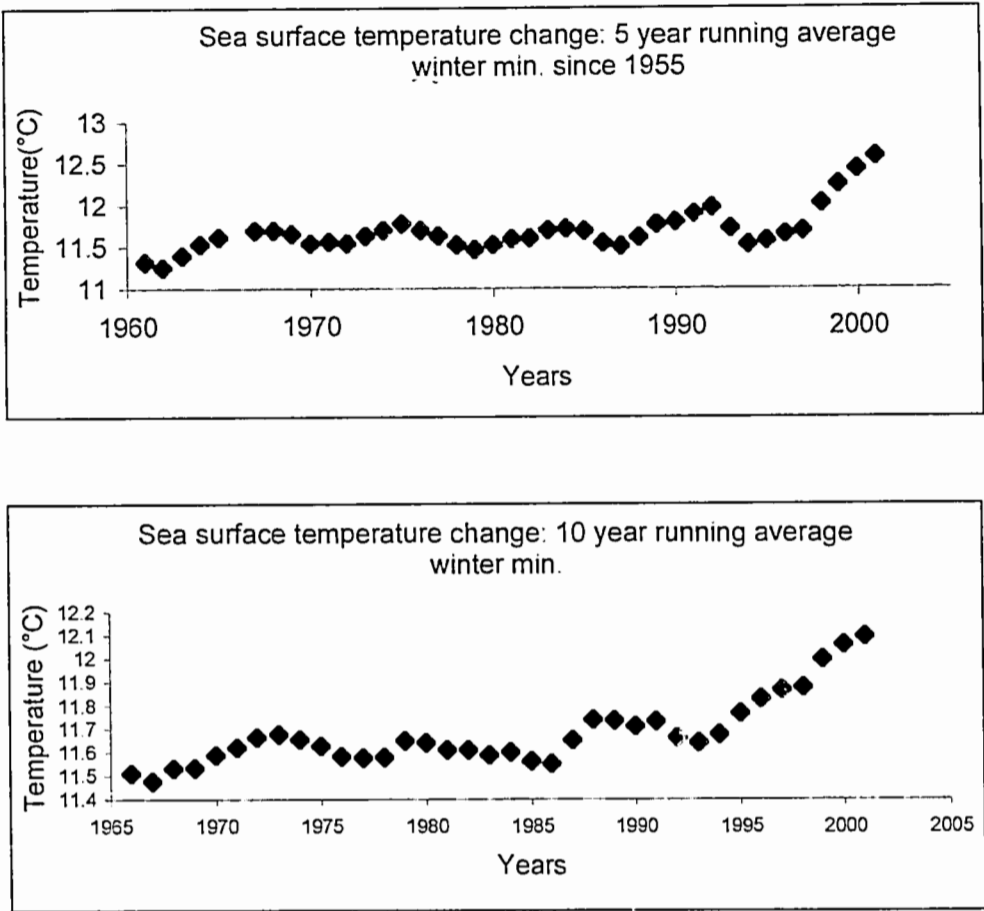


Fig. 4.6b Surface temperature changes recorded at the Maria Island monitoring station. Winter minimum as 5 and 10 year running averages.

c

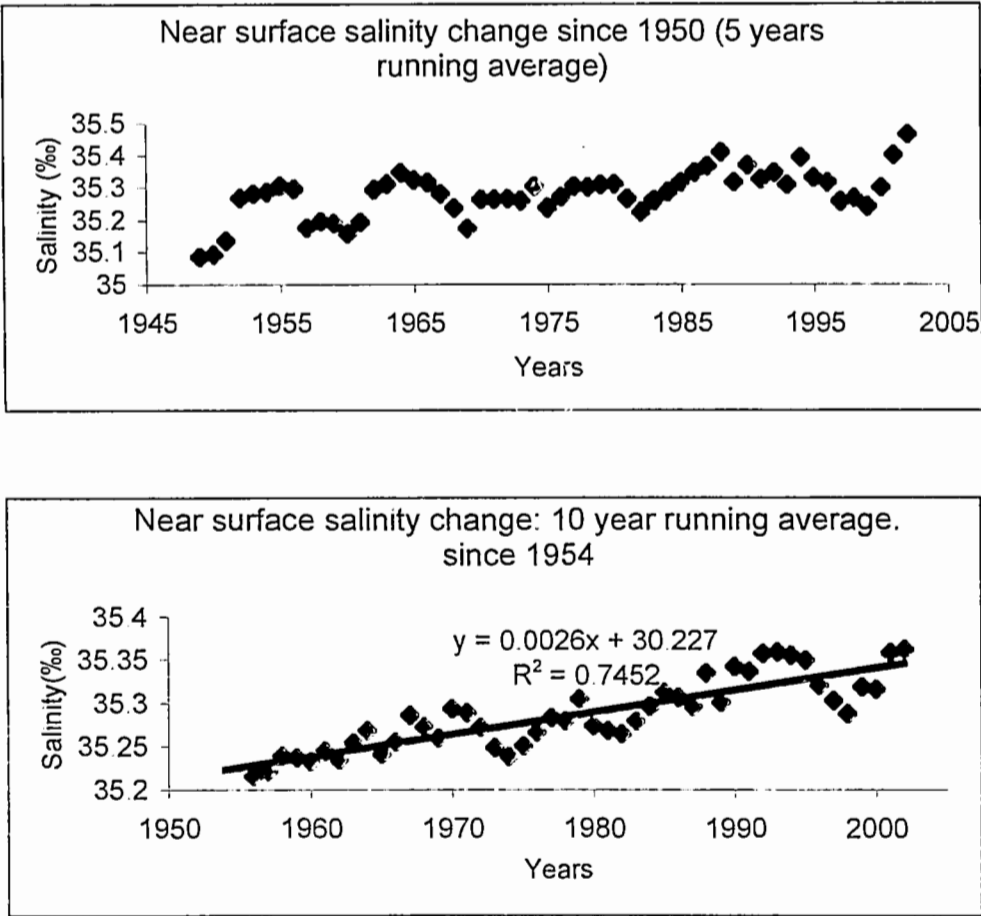


Fig. 4.6c Surface and subsurface salinity changes recorded at the Maria Island monitoring station. 5 and 10 year running averages

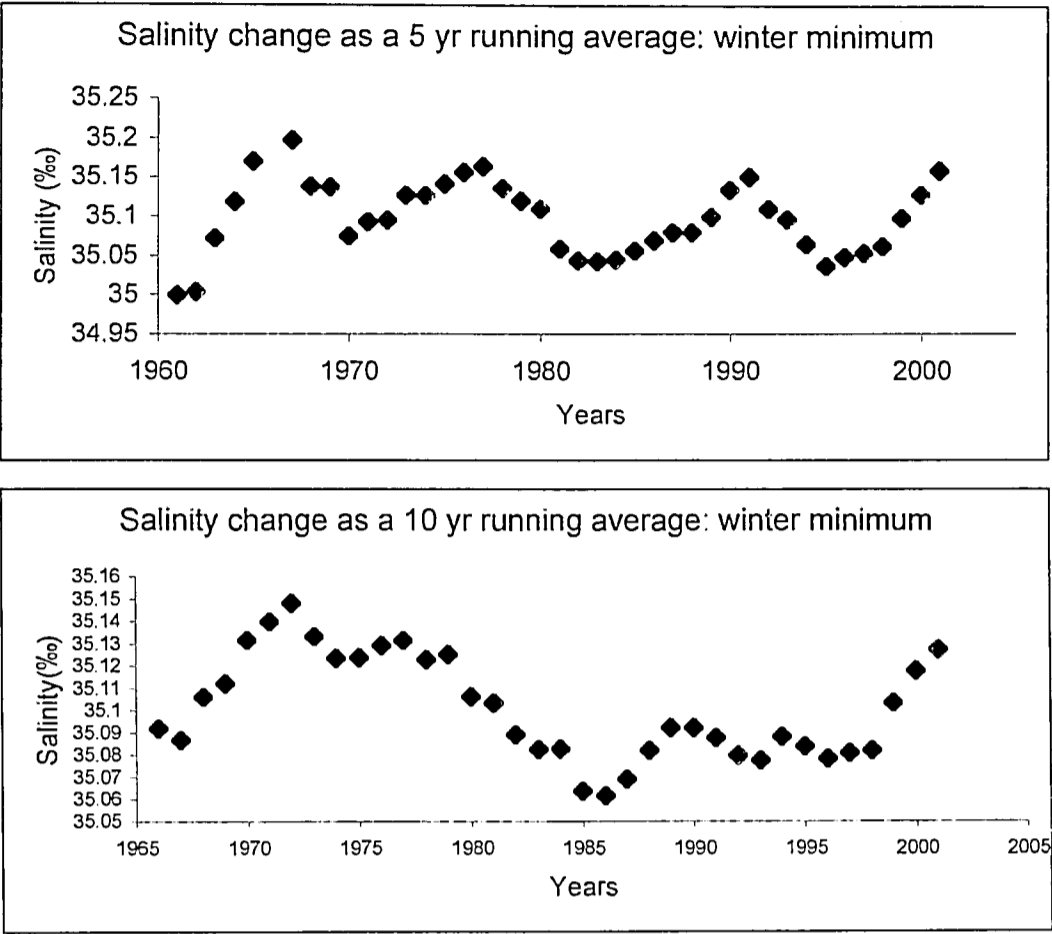


Fig. 4.6d Surface salinity changes recorded at the Maria Island monitoring station: winter minimum as 5 and 10 year running averages.

4.3.7 Seasonal interannual variations

Five year running means of surface temperature values for each season are shown in Fig. 4.6e. For the summer plots, there appeared to be 3 cycles, each of them covering a period of 12-13 years, and 4 peaks of maximum temperature were observed, the last one occurring during the year 2001 - 2002. Maximum summer temperature clearly increased with time. In 1963-1964, it was 15.8°C; in 1974-1976, it was 16.15°C; whereas, in 1990-1993, it was 16.6°C and finally in 2002, the mean maximum SST in summer was 16.65°C and we might expect it to increase again in 2002-2003. The summer minimums were not as clear as the maximum peaks, in particular, during the second cycle lasting from 1973 to 1986 however, they were all situated between 15.0 and 15.2 °C.

The autumn plots show a similar pattern to the summer ones but the curves were smoother, and the cycles less clear. The temperature ranged between 14.7 and 16°C, and the maximum was observed between 1973 and 1980. The lowest minimum temperatures (14.7°C) occurred in 1967-1969, 1987 and 1999. The winter and spring plots appeared to follow the same pattern. A slight increase occurred from 1960 until 1967, then a decrease during three years; the temperature then started to increase again in 1971 until 1975 and decreased after that. It reached a plateau in 1980 until 1987 for the spring graph, whereas it continued to decrease in winter during the same period. Subsequently temperature increased for the next 5 years followed by a steep fall from 1991 until 1994, and then increased again until 2002. The drop is of less importance in winter (13.0 to 12.4°C) than in spring (from 13.15 to 11.65°C).

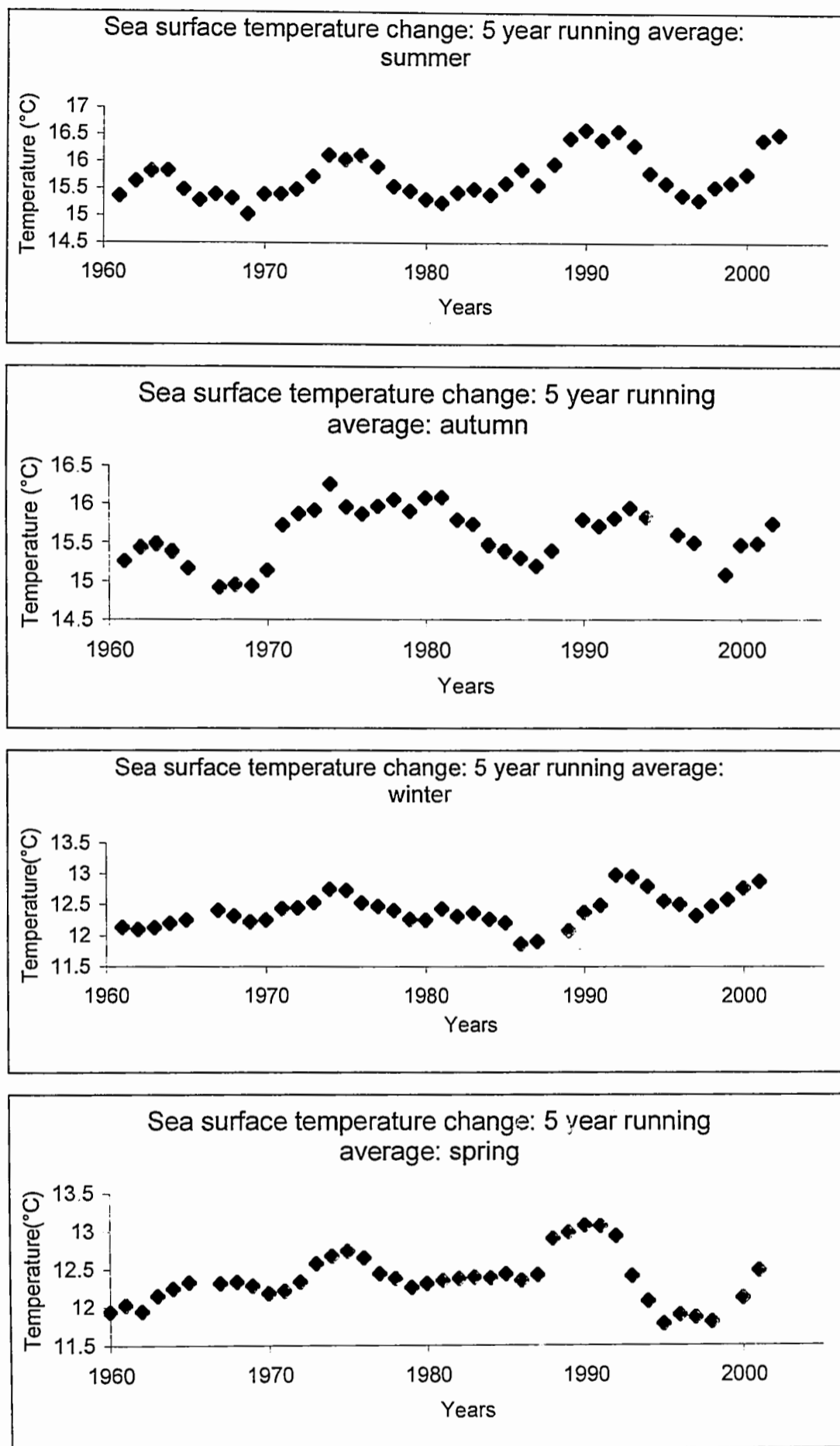


Fig. 4.6e SST changes in each season as 5 year running averages recorded at the Maria Island monitoring station.

The seasonal variation in salinity over time was also studied. The results (Fig. 4.6f) followed the same pattern as the maximum summer and minimum winter temperature analysis. A salinity peak was reached in summer 1967 and marked the beginning of the downward salinity influence, until 1985. Then clearly the salinity has continued to increase since and, in 2002, reached a maximum never previously attained in this database.

In autumn, the salinity followed a similar increase that reached its maximum in 1995, then seemed to drop and finally reached a plateau in 2000. But the continuous augmentation started right from the beginning of this survey in 1965.

On the other hand, spring and winter followed quite an opposite pattern. There was a small increase from 1965 until 1974, it fell continuously until 1985, then seemed to increase again in spring whereas the pattern is less clear in winter.

The salinity of the surface clearly has increased since the beginning of this survey; at least within the first 20 metres. The trend is less evident for temperature, and even if the current SST (2000-2002) were the highest measured within the period of survey, it still showed cyclic patterns of 11-12 years, and the current period of study was on a peak of such a cycle whereas the years 1972-73 were on the rising slope of the cycle.

It is worth noting that in 1993, a lag seemed to occur in the winter and spring mean SST, and it coincided with the beginning of the rising slope of the winter minimum.

It is also interesting to note the decrease in temperature in 1993 and 1996 for the same graphs (winter and spring means), whereas on the winter minimum one, the curve rose but with a lower slope than after 1996, when the winter and spring means both showed a rise.

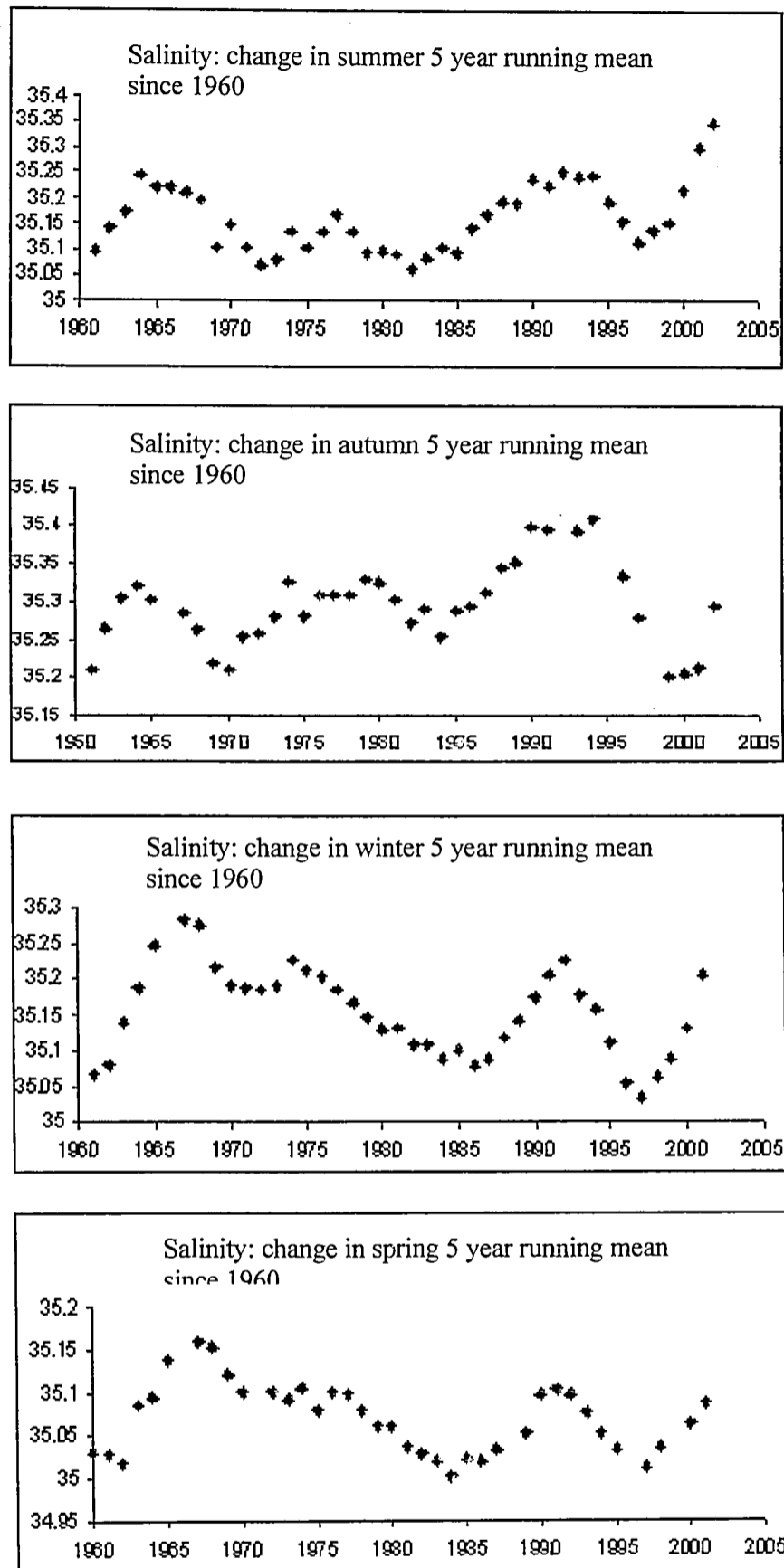


Fig. 4.6f Seasonal salinity changes recorded at the Maria Island monitoring station.

4.4 Discussion

It is acknowledged that the highest zooplankton biomass in the water column lies in the first 10 m below the surface. As a consequence, the surface planktonic and neustonic biomass constitutes a very low proportion of the whole water column. For this reason a quantitative comparison between the two data sets at our disposal is not valid; the 2000-01 surface samples would be much smaller than the 1971-73 ones (50 m to the surface).

Qualitative differences between the two zooplankton datasets can not be explained only by differences in the methodologies as the samples collected in May 2002, using techniques identical to those used in 1971-3, clustered with the data set of 2000-01 with less than 46% dissimilarity. Neither can they be explained by spatial difference as it was shown that the zooplanktonic community was similar along the southern part of the east coast of Tasmania. It has to be accepted that the two zooplanktonic communities of 1971-73 and 2000-2001 are genuinely distinct, and that this distinction occurred over the intervening period. Whether this differentiation is due to interannual variability, or these two sets are at different stages of a cyclic pattern, or lastly whether they represent stages of a long term trend is a matter for discussion.

The communities were different both in terms of species composition and relative abundance. In the 1970s, the zooplankton had more subantarctic oceanic species, which were all absent in the 2000-01 samples. If we examine the frequency of appearance of some warmer water species, it is apparent that it increased from 1970s samples to current ones. For example, *Temora turbinata* was occasionally found in small numbers in 1971-73, but it occurred more often and in proportionally greater numbers in 2000-02. Bradford (1977) demonstrated clearly the subtropical affinities of *Temora turbinata*, and showed that its presence would be an indication of the influence

of the east Australian current. The same increasing concentration occurred for *Calanus minor* and *Acartia danae*. Those two species are usually found in association with *Temora turbinata*.

The change from dominance of *Paracalanus* in the 1973 to dominance by *Acartia* in 2002, could be due to a greater neritic influence in the region in 2002 (Trinast 1975, Kimmerer and McKinnon 1987a, Swadling and Bayly 1997). As mentioned earlier, zooplankton communities have often been used as indicators of climatic change. It seems reasonable to suggest that this change in the zooplankton of the East coast of Tasmania is due to a climatic change in the region.

Taw's data were collected over 2.5 years and this should have smoothed some of the interannual variability. The present study was conducted over 13 months and, though it accommodated a complete seasonal cycle, it was not long enough to define interannual pattern. However, some known events, such as the ENSO events, are clearly identified. The years 2000 and 2001 were strongly under the La Niña influence which could have explained the presence of warmer water species as La Niña is characterised, in the eastern Australian coastal environments, by warm, low nutrient, low salinity waters (Harris et al. 1987, 1991, Hsieh and Hamon, 1991). But 1971 was a La Niña event, as was the beginning of 1972; then there was a period of transition and El Niño started in 1973, according to the NOAA data base (Fig. 4.7 and see <http://www.cdc.noaa.gov/ENSO/enso.current.html#indices>). Taw's sampling stopped in April 1973, so most of his sampling period was under La Niña conditions or in a transition phase. In consequence, it did not seem that the 30 year temporal differences in the zooplanktonic community could be due to a succession of El Niño – La Niña conditions. Other factors must be responsible.

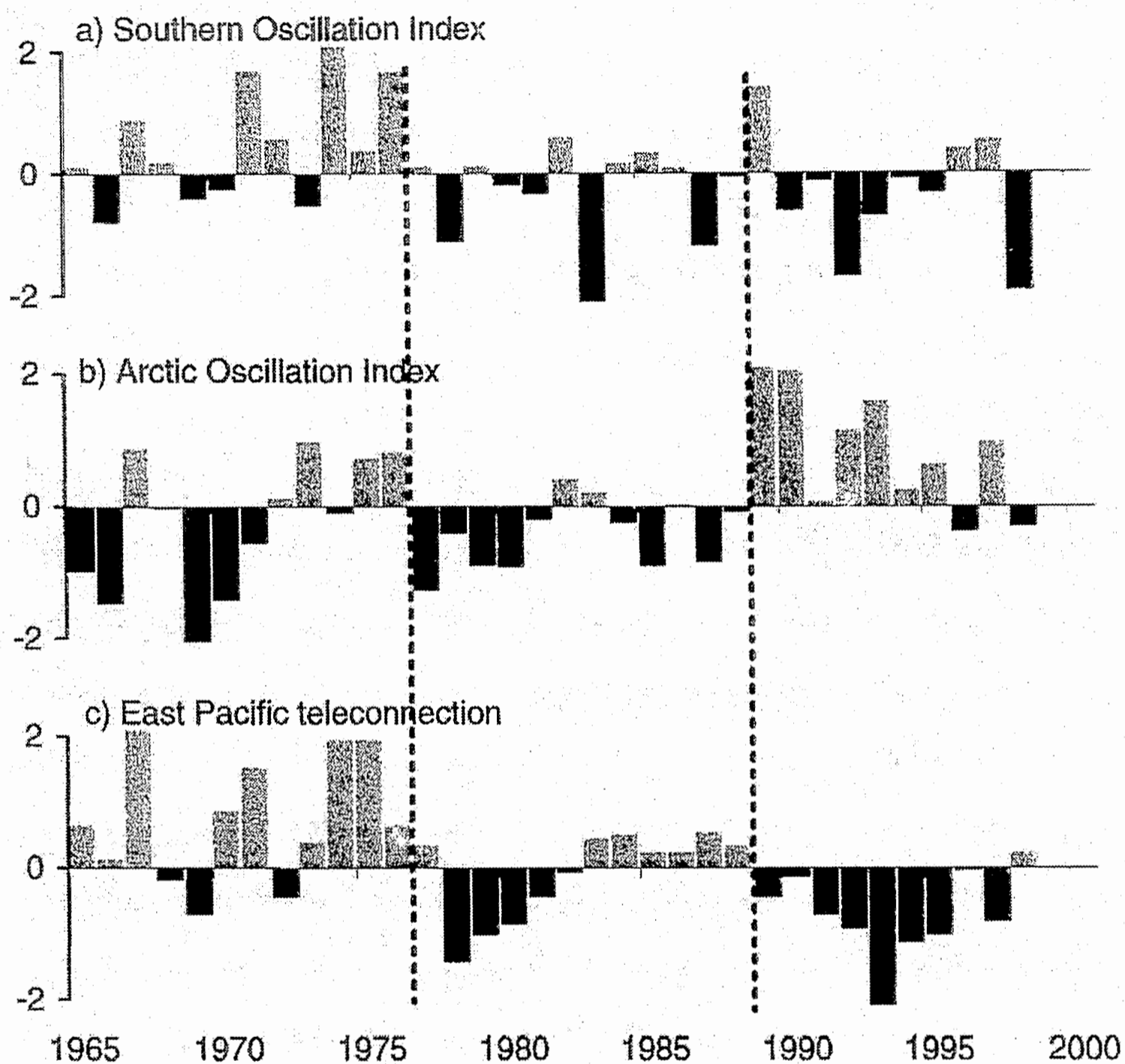


Fig. 4.7 Southern Oscillation Index (NOAA) from 1965 to 2000. Positive indicates a La Niña year, negative an El Niño year (from Hare and Mantua, 2000).

The Antarctic Polar Wave cycle has been a subject of intense discussion amongst marine and climate scientists (White and Peterson 1996). This event has a complete cycle of 8 years, with 2 years of cold waters alternating with 2 years of warm waters. The signal is not systematic and might or might not be felt in the Tasman Sea,

and so, as far as this study is concerned, the east coast of Tasmania. The observation of such a signal has been quite recent and no data are available before the 1990 unfortunately. So it is impossible to know the position of the wave during the years of Taw 's (1975) study. Also the signal seems to be strongly linked with the ENSO event and, by coincidence, the effects of both signals might combine or alternatively, might cancel each other. It is because of such complex interactions that the polar wave signal is so controversial. For this reason it will not be considered further until more evidence becomes available.

Other signals similar to ENSO ones were reported by Yuan Zhang et al. (1997) and it appeared that quite a few cyclical patterns have been demonstrated in the last decade. In a compilation of time series data from 1965 to 1999, from the North Pacific and the Bering Sea, Hare and Mantua (2000), described the existence of two regime shifts in the last 40 years. The first occurred in 1976-77 and the second in 1988-89. They used 100 indices both physical and biological (Fig. 4.8), and evaluated the extent of the variation using Principal Components Analysis. These two regime shifts were identified as specific to the North Pacific, but no similar work has previously been done in the South Pacific. There is evidence of changes in the pattern of zooplanktonic productivity over time (Mackas and Tsuda, 1999). They report shifts and not cycles because the different components tested did not return to the preceding pattern, but revealed a new pattern each time. Yuan Zhang et al. (1997) proposed another shift in 1942-3 in the North Pacific.

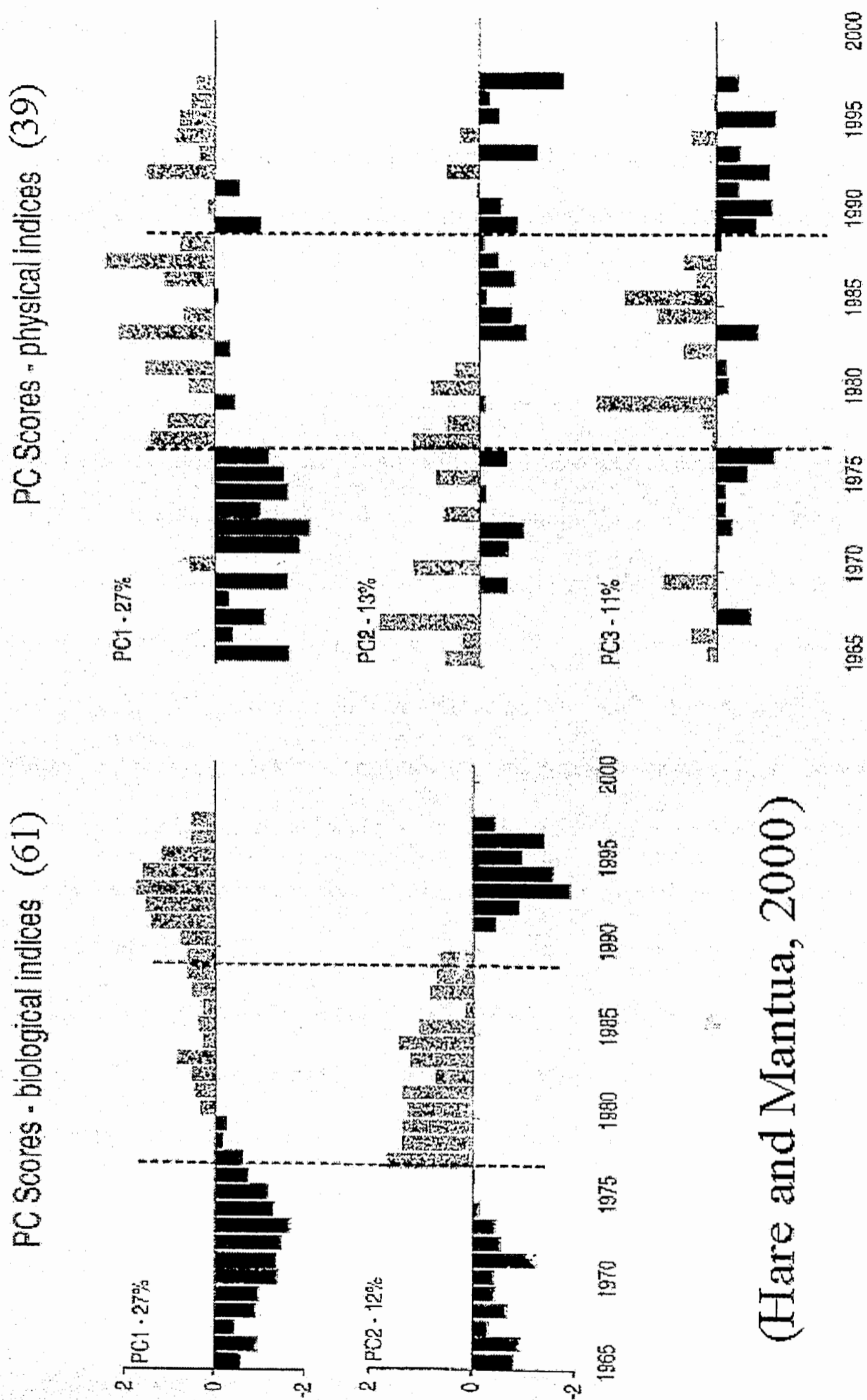


Fig. 4.8 Principal Component Analysis scores of 61 biological indices and 39 physical indices. (from Hare and Mantua, 2000)

Lindley (2002) undertook a study of the changes in zooplankton communities in four areas of the North Sea since 1958 using the CPR. He observed an increase of abundance and diversity of plankton indicating Atlantic influence on the shelf of Britain but a decline of residents associated with cooler water. He interpreted these results to be a consequence of a warming of the seawater and the evidence of a long term climatic change.

From the Maria Island T-S data, three distinct trends are apparent. Newell (1973), defined 4 types of waters at the surface in summer: i) coastal waters with high temperature (15-16.5°C) and low salinity (<35.1‰), also high concentration in oxygen and low in nitrates; ii) subtropical surface waters with high temperature (15-16.8°C) and high salinity (35.10-35.26‰); iii) subtropical waters which Rochford (1960) identified as of western origins with low temperatures (12-14°C) and high salinity (35.10-35.25‰); iv) sometimes he also observed the intrusion of a 3rd water type; i.e. a subantarctic intrusion with low salinity and low temperature. This latter type was the result of the Subtropical convergence in the region of the westerly wind belt covering an area between 43° and 50°S (Deacon, 1937).

In winter, Newell (1973) defined only two distinct water bodies: near surface well mixed, subtropical water with a salinity greater than 35.20‰ and a temperature between 11.8-12.2°C, found mostly onshore, and subantarctic waters with low salinity (< 35.10‰ and low temperature (11 to 11.8°C). The origin of the subtropical water in winter seems well established as being the East Australian current reaching south east Tasmania and often extending south of the State (Newell 1973). Newell used bottle drifters to observe the current off the South East coast of Tasmania. He observed currents from North, and North West in winter and from the south in summer, with

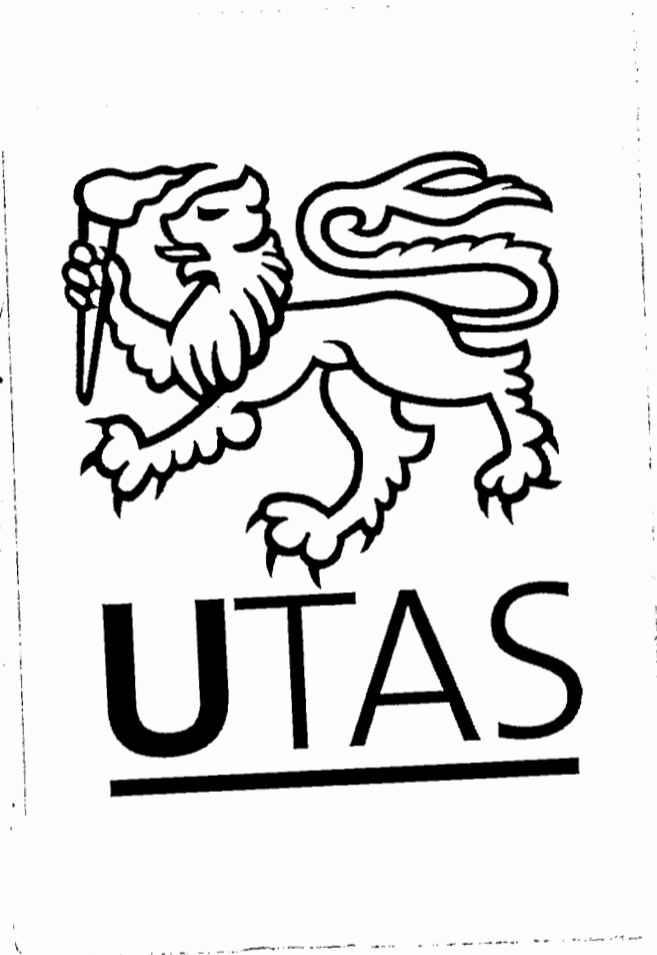
some eastern coastal drift currents in the south until they meet the subtropical surface water offshore.

The SST, generally accepted as an indicator of climatic changes, showed a general warming coupled with an increase in salinity along the east coast of Tasmania. These characteristics would indicate the increasing influence of the East Australian current along the coasts in autumn and winter and because the current extends further south along the coasts, it would take it longer to retreat north, and this would result in a decreasing influence of the subantarctic waters. The East Australian current and the ENSO events are more or less ruled by the westerly wind belt (Williams, 1987), and this Zonal Westerly Wind follows a cyclic pattern (Harris et al., 1988) of 11 years. But it has also been suggested that this belt has moved about 5° further south during the last 50 years (S. Rintoul, pers. comm.); which would result in the East Australian Current penetrating further south in the Tasman Sea, and thus along the east coast of Tasmania, bringing warmer and saltier waters to the area.

Cresswell (2000) has shown that the Zeehan current, off the western coast of Tasmania can extend around the south of the island and move north along the south east coast, where it meets the East Australian Current. This creates a barrier to the subantarctic waters. This is also supported by the fact that no aggregations of adult *Nyctiphanes australis* have been seen along the south east Tasmanian coast for several years (Young et al. 1993). These swarms are characteristic of nutrient enriched water (Harris et al. 1991). Most zooplankters typical of cold waters have also been rare over the same period.

It is suggested that the change in the zooplankton community observed in the present study is an indicator of a climatic change of the same amplitude as the one described by Hare and Mantua (2000). This means a major change has occurred in the

South East Pacific in the last 30 years. This change could have been sudden as there was a distinct shift in SST and salinity over the different seasons in 1985. In addition there was a continuous increase in the influence of the east Australian current, as the salinity in summer and the SST in winter clearly show.



5 General Discussion

The original aim of this project was to compare the zooplankton community from a nearshore embayment with that of an adjacent offshore site. Also to examine the neustonic communities. The two communities were not significantly distinct. However, some taxa showed a clear pattern of residence in the bay, while others were only found offshore. Moreover, some taxa changed their habitat depending on stage of the life cycle (e.g. *Labidocera* sp). The question of limited replicates (2) could explain the statistical results; the characteristic patchy distribution of zooplankton is well known and is always a source of problems in such studies. An increased number of replicates might have reduced the differences due to the patchiness. But it needs to be noted that this issue has been encountered by many other researchers in the past.

How can some taxa maintain their position in one or the other area of study? I have shown that there is no physical barrier: kelp forest, salinity, bathymetry or temperature gradient. The only factors responsible for the water movements in the bay are the tides and the wind. The tidal cycle of 6-12 h does not explain the presence of a species for several months in the bay and not in the adjacent coastal water. Another category of factors might be responsible for these results, i.e. biological factors such as predation, competition, and selective tidal stream transport. Appendicularians are likely prey for *Centropages*, *Labidocera* and other predatory copepods in the Mercury Passage; this could perhaps explain the low abundance of appendicularians there. Appendicularians were abundant in the bay while the larger copepods were absent, perhaps because the latter were selectively predated by fish.

Vertical migration of some species during their life cycle and throughout the year could be another important factor. The bay is shallow and the seabed is mostly composed of bare sand; by migrating deeper perhaps they find a refuge from predators like birds or fishes

Studies on neustonic communities are sparse and geographically dispersed e.g. Champalbert (1971) in the French Mediterranean area and Zaitsev (1968) in Northern and Baltic Sea. Neuston represents a component of the zooplankton that is fully adapted to the upper few centimetres of the sea. These organisms have a variety of special adaptations i.e. transparent or colourful exoskeletons for protection from predation, the ability to jump out of the water to avoid predatory attack, the ability to attach to the surface film by means of microscopic hairs, and exploitation of food sources which are heavily reliant on the microbial loop. These conditions can last all year but are dependent on the stability of the sea surface. After a storm, it is not known how long such a system takes to restabilise although it appears to be resilient (Hardy, 1991). In vitro studies would be of great interest to understand the stability of the neustonic ecosystem.

The biogeography and the life cycle of *Pontella noveaezelandiae* and *Labidocera cervi* have scarcely been studied. They deserve closer attention both as part of the neuston, but also as possible water mass indicators as are many other members of the Pontellidae.

A temporal comparison between zooplankton datasets separated by a long time interval is a difficult task. It needs comparable sampling and analytical methods, and also confidence in taxonomic identification, particularly if the sample themselves are no

longer available. But there is always the risk of confusing interannual variability with longer oceanographic or climatic cycles.

A time series is preferable and would give more reliable results. Unfortunately such time series of zooplankton collections are rare and if one wishes to study the temporal variations in an area, one has to make some compromises. It has been the case for the present study. The two datasets analysed in chapter 4 are separated by thirty years and showed clear differences that were apparently not due to spatial or sampling methodological differences. A time series of SST and salinity showed strong trends of warming and of steadily increasing salinity. Warm, saline water is characteristic of the East Australian Current, which implies a greater influence of this current in the studied area over time. This has been confirmed by some oceanographers and is linked to the southerly migration of the westerly wind belt. Cresswell (2000) observed the presence of the Zeehan current and its influence on the south west coast of Tasmania. The combined effect of these two southerly flowing currents has had a major impact on the Tasmanian coasts and on the marine fauna including zooplankton. This is a sign of climate change. More data are needed before we can conclude whether such changes are part of a long term climatic cycle, or whether they are a manifestation of a global warming trend. Zooplanktonic and neustonic communities are good indicators of climatic cycles because they have short generation times and therefore respond rapidly to change, and because they are believed to be largely controlled by bottom up forces, they are unaffected by large changes in predator abundance.

The present study has highlighted a climate change in the area, but to understand its importance, its characteristics and its effects, further study on the Tasmanian east

coast is needed, over a longer period, using a consistent sampling technique. The establishment of a CPR survey in the area, similar to that presently operating in the Southern Ocean by the Australian Antarctic Division, but using ships of opportunity, is a possibility. Sorting and identification is the most time consuming and expensive part of the process. Resources could be optimised by limiting analysis to holoplankton, particularly copepods, salps, chaetognaths and euphausiids. Many of these organisms are good indicators of specific water bodies so changes in their relative abundances can give a rapid assessment of the impact of changes in oceanic circulation.

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Table A3.1. Dates, times and weather conditions for the monthly samples collected (2000-2001) in Mercury Passage, SE Tasmania

date	Time	Weather	Miscellaneous
15.03.00	11.45am	Mostly fine, windy	
15.03.00	3.15pm	Windy	
24.04.00	3.45pm	Fine	
24.04.00	4.45pm	Fine	
21.06.00	11.35am	Fine	
21.06.00	11.50am	Fine	
21.06.00	12.00pm	Fine	
30.08.00	10.45am	Overcast	1 st sample with doublenet
30.08.00	11.15am	Overcast	
30.08.00	11.33am	Overcast	
26.09.00	2.15pm	Overcast	
26.09.00	2.30pm	Overcast	
26.09.00	7.30pm	Overcast	Night time
26.09.00	7.45pm	Overcast	
16.11.00	8.16pm	Fine	Night time
16.11.00	8.25pm	Fine	
16.11.00	8.35pm	Fine	

17.11.00	6.05am	Fine	Dawn
17.11.00	6.14am	Fine	
17.11.00	6.25am	Fine	
14.12.00	12.30pm	Fine	
14.12.00	12.45pm	Fine	
14.12.00	1.00pm	Fine	
14.12.00	1.15pm	Fine	
22.01.01	12.25pm	Fine	
22.01.01	12.40	Fine	
22.01.01	12.55	Fine	
07.03.01			Sample not valid
30.03.01	10.25am	Fine	
30.03.01	10.40am	Fine	
30.03.01	10.55am	Fine	
30.03.01	11.05am	Fine	
12.04.01	6.00pm	Fine	Dusk
12.04.01	6.15pm	Fine	
13.04.01	5.30am	Fine	Dawn
13.04.01	5.45am	Fine	
13.04.01	6.30pm	Fine	Dusk
13.04.01	6.40pm	Fine	
14.04.01	5.45am	Fine	Dawn

14.04.01	5.55am	Fine	
16.05.01	11.00am	Fine	
16.05.01	11.10am	Fine	
16.05.01	11.25am	Fine	

Table A3.2 Previous records of *Pontella novaezelandiae* (Farran, 1929)

Station no	Location	Date	Time	Depth of collection	No. individuals recorded
89		25/07/1911	20.00-22.00	surface	42
93		28/07/1911	21.00-4.00	surface	4
100		4/08/1911	13.00-14.00	surface	3
107		4/08/1911	20.00-5.30	surface	1
108		5/08/1911	12.00-16.00	surface	3
109		5/08/1911	20.00-8.00	3m	16
110		6/08/1911	21.00-4.00	surface	6
112		6/08/1911	12.00-16.00	3m	3
127		25/08/1911	21.00-5.00	surface	1
C628	39 13'S 171 54'E	25/05/61	14.45-17.16	surface	1female 8males
N718	39 21.7'S 177 52.9'E	5/09/76	15.30-15.52	0-20m	1male
AUZ81	33 09'S	23/07/62	17.07-17.57	0-100m?	1female

	176 06'E				1male
AUZ82	33 09'S 176 06'E	23/07/62	19.03-19.45	90-100?	2males
J1/57/72	36 21'S 173 54'E	12/01/72	20.30-21.00	surface	5females 6males

Table A3.3. *Pontella novaezelandiae*: Records from Mercury Channel, Tasmania for the season 2000-2001.

March 2000 (5 ind 100m⁻³)

- 2 copepodite III
 - no 5th leg,
 - no asymmetrical antennule,
 - length 1: 2mm and length 2: 3mm.
- 1 copepodite IV female
 - 5th leg present but incomplete
 - symmetrical antennule
 - length: 4mm.
- 1 copepodite V female (sexually immature)
 - 5th leg present but no abdominal process
 - symmetrical antennule
 - length : 4mm.
- 6 adult females

- 5th leg present + abdominal processes (sexually mature)
- symmetrical antennule
- length: 5.1mm
- 2 adult males
 - 5th leg characteristic (like a pincer)
 - asymmetrical antennule, clasping right antennule
 - length : 4.9mm

June 2000 (1 individual found in 100m)

- 1 female adult mature (5mm)

December 2000 (1 individual in 100m)

- 1 male adult (4.9mm)

March 2001 (1 individual in 100 m)

- 1 copepodite III (no 5th leg, symmetrical antennule, 4mm)

