BALLAST WATER AS A DISPERSAL VECTOR FOR NON-INDIGENOUS MARINE ANIMALS

A REPORT TO THE FISHING INDUSTRY RESEARCH COMMITTEE

BY

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March, 1982.

ABSTRACT

Ships' ballast water was sampled on 28 occasions in four ports between November, 1976, and October, 1978.

A 100 μ plankton net was hand hauled vertically 5 times in each tank. Eight non indigenous species were obtained: 6 copepods, 1 mysid and 1 amphipod. A further 14 species of copepod and 4 non-copepod taxa were found which have an Indopacific distribution. Twenty one copepods and twenty noncopepods could not be identified to species level which meant their zoogeographic affinities were undeterminable. The role of factors such as amount of water imported, hull position, port of loading, voyage duration, mid ocean exchange, pumping survival and salinity and temperature shock was briefly examined.

Sediments in the bottom of ballast water tanks were examined on 9 occasions. Eight non indigenous species, 8 cosmopolitan species and twenty seven other taxa were found indicating a new potential vector for the dissemination of aquatic biota.

No evidence was obtained to indicate successful colonisation had taken place via either ballast water or ballast mud. However, because the identification and distribution of indigenous fauna are so poorly known it is equally impossible to conclude that successful colonisation has not taken place. The need to protect local species from predators, competitors and parasites requires that a sterilization policy be adopted. Preliminary estimates of the amount of sodium hypochlorite (liquid) and calcium hypochlorite (solid) required to kill animals in ballast tanks were made.

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I. INTRODUCTION

The increase in international ship traffic since the end of World War II has enhanced the potential for successful introduction of marine organisms into new locations around the world. This in turn has led to concern that the non-indigenous species might prove harmful to established commercial species. In order to come to grips with this situation on a world wide basis Walford and Wicklund (1973) collated information on exotic marine introductions. Among other things they concluded that ships' hulls seemed the most likely vector for sessile organisms but it would appear that the need to keep hulls free of marine growth to reduce fuel costs has reduced the importance of this vector. The grids and pipes of sea inlet valves were suggested as a vector by Naylor (1957 & 1965), Newman (1963) and Walford and Wicklund (1973).

Ballast water was first suggested as a means of introduction by Peters and Panning (1933) after the appearance of the Chinese mitten crab (*Eriocheir sinensis*) in Germany in 1910. This crab became a nuisance throughout Europe because it cut fishnets and collected in eel pots preventing some eels from entering and eating those that did. By 1972 however, the population numbers had diminished and it was no longer considered a nuisance (Working Group 1972).

Other animals apparently transported by ballast water include decapods (Rees and Cattley, 1949; Wolff, 1954; Holthuis, 1955) fish (Brittain *et al*., 1963; Hubbs and Miller, 1965; Dawson 1973; Hoese, 1973) and a mollusc (Dinamani, 1971). Medcof (1975) found living ostracods, crustacean larvae, adult and larval polychaetes and chaetognaths in ballast water of a wood chip carrier at Eden, N.S.W.

Dinamani's investigation (1971) listed ballast water as a possible vector for the introduction of the Japanese oyster *Crassostrea gigas* to New Zealand. Medcof and Wolf (1975) were concerned that the spread of *C. gigas* north along the New South Wales coast might be aided by ballast water discharge; they felt *C. gigas* might outcompete the Sydney rock oyster *Crassostrea commercialis* (*Saccostrea commercialis*).

At least 19 marine species have been introduced to Australia (Table 1). Ballast water may have been the vector by which the molluscs, crustaceans, ascidians, and fish were introduced. No detrimental effects from these introductions have yet been observed.

There is concern, however, that introduced species could be more competitive than, or predatory or parasitic on, local resource species, with serious consequences to the fishing industry. This concern engendered an application to The Fishing Industry Research Committee for funds to investigate the possibility that ballast water from foreign ports discharged in Australian harbours could be a likely means of introducation of non-indigenous marine animals.

This study asked the following initial questions:-

(a) How much ballast water was entering Australian ports each year?

(b) What animals were present in the ballast water, and

(c) Could any of the non-indigenous species be competitive with, or either predatory or parasitic on Australian marine organisms?

(d) Could any animals present in ships' water survive discharge through the normal pumping system?

(e) Were there differences in salinity and temperature between the ballast water and surrounding harbour water?

(f) Was magnitude of the differences in salinity and temperature large enough to affect survival of non-indigenous organisms on discharge?

(g) What method of treatment of ballast water would kill all organisms present but have minimal impact on the local fauna after discharge of the water?

A chance observation made in Eden was that ballast tanks contained appreciable amounts of mud which was shovelled into a bucket and dumped over the ship's side. This led to an additional question: could mud in ballast tanks act as a vector permitting the introduction of a different group of organisms?

These questions are dealt with as appropriate under one of 6 main topics: Amount of ballast water, Faunal studies, Wharf and hull samples, Pumping survival, Salinity and temperature comparison between ballast and harbour waters and Treatment investigations. The methods, results and discussion of each topic are presented together. All topics are interwoven in a section entitled "Overview".

II. AMOUNT OF BALLAST WATER

A. Methods

Upon arrival in Australia large vessels (> 200 tonnes) must file a return with the Customs House of that seaport. One category of the return shows whether the vessel arrived "in cargo or in ballast". Vessels arriving "in ballast" and which called at a single Australian port were considered to be bulk carriers and the amount of water discharged was estimated to be nearly equivalent to the registered net tonnage.

B. Results

Table 2 gives the estimated amount of ballast water discharged annually in each state from 1975/76 to 1977/78. The Australian total showed a progressive increase, as did that of Queensland, New South Wales, Tasmania and the Northern Territory. Western Australia received approximately half the total in each of the three years.

C. Discussion

Crisp (1958) postulated that the greater the frequency and abundance of introduced exotics the greater the likelihood of successful colonisation. As the amount of ballast water received in Australia over past years has increased and as this trend is anticipated to continue, the bulk export of Australian raw materials would seem to enhance the risk of introduction of non-indigenous species. As Western Australia receives approximately half the Australian total it would seem this State is most at risk.

The amount of mud released into Australian waters is far more difficult to estimate than ballast water but its increase can be inferred. Turbidity in foreign parts caused by local weather conditions at the time of ballasting and distance between ballast suction pipes and the harbour bottom are two of a number of variables which determine the amount of fine sediment taken aboard. Weather conditions at sea and exchange at other ports will influence the amount of material which settles and provides habitat in the ship.

There are no treatment facilities for ballast water or mud in Australia. The method of disposal is overboard discharge: ballast water is pumped straight to the harbour or near shore waters and mud is usually cleared by being hauled on to the main deck and then washed overboard, or by being hosed from the ballast tank into the double bottom tanks which are then flushed.

III. FAUNAL STUDIES

A. Methods

1. Plankton: Sampling was carried out quarterly between November, 1976, and October, 1978, in ships berthed at Eden, N.S.W.; Triabunna, Tas.; and Cape Lambert, W.A. Sampling at Gladstone, Qld., was discontinued after November, 1977, for logistic reasons. Eden and Triabunna, both woodchip exporting ports, were chosen as they are in temperate regions. Usually two vessels arrive at each port per month. Cape Lambert and Gladstone, located in the subtropics, generally receive about one vessel per day, and export iron ore and coal respectively. None of the ports are in estuaries. The study was restricted to ships loading ballast water in Japan because of the preponderance of bulk trade to that country and because the taxonomic literature on Japanese marine animals is considerable.

The optimum sampling method was judged to be the procedure which gave maximum species abundance for minimal sampling and processing effort. Trials in a ballast tank indicated 5 hauls with a 100 μ mesh aperture net (1.19 m long, mouth area 0.059 m^2) gave better results than either a 200 μ or 350 μ net. After field sampling had ended, a check was run on the 5 haul/100 μ combination by predicting the maximum number of species expected if sampling had continued indefinately. This was done by fitting a logistic curve using a non linear least squares technique (C.S.I.R.O. subroutine LMM2) and estimating the asymptote.

The central holds of ships at Eden, Triabunna and Cape Lambert were sampled by dropping the net through the open cargo hatch to the bottom of the central ballast tank, and then hauling it to the surface at 0.05 m $sec.^{-1}$ A wing tank of coal ships loading in Gladstone was sampled after removing the manhole cover, and hauling plankton nets as described previously. A dip net was taken to Eden to be used if necessary.

An attempt was made to see if animals from inside the ballast tanks could be found outside the ship after the ballast water was discharged. Five bottom to surface hauls were taken from the wharf alongside ships before, and then after, ballast water discharge. This sampling was abandoned in 1978 because of the lack of time to examine the material so collected.

All plankton samples were fixed in phosphate buffered 4% formaldehyde in seawater in the field. In the laboratory organisms were sorted into major taxonomic groups. Mollusc larvae were stored in 70% ethanol, while all other taxa were stored in phosphate buffered, 4% formaldehyde (pH8.3). The taxa found were identified as far as possible using Barnard (1969), Barnes (1974), Dakin and Colefax (1940), Giesbrecht (1892), Mori (1937) and Ii (1964). Local and overseas taxonomists (see Acknowledgements) confirmed the identification of particularly the indigenous Japanese species. Some taxa were not taken to species level because of apparent cosmopolitan distribution (e.g. Podon). The distribution of species was clarified by consulting C.S.I.R.O. (1954, 1955a, 1955b, 1957a, 1957b, 1957c, 1958, 1959a, 1959b, 1961, 1965), Dakin and Colefax (1940), Sears (1974), Ortmann (personal communication) and Ross (personal communication).

Abundance estimates were made for all ballast water taxa, but the abundance of certain very rare species were counted directly. The mean abundances were ranked in the following classes: rare (0-1.00 m^{-3}) occasional (1.01-10 m^{-3}), common (10.01-100 m^{-3}) and abundant (> 100.01 m^{-3}).

2. Mud: After ballast water had been discharged in Eden, mud samples were taken from ships' holds on six occasions between October, 1977, and November, 1978. Mud samples were also taken from ships in Sydney Harbour between August and November, 1978. One approximately 100 cm^3 sample was obtained from a vessel in Triabunna, and another sample from Cape Lambert, in 1978. The mud and animals were fixed as described above, and the animals identified in the laboratory.

B. Results

1. Sampling Limitations: It is appropriate to discuss three main limitations of this study before presenting the body of results. The inability of ourselves, and local and overseas experts to identify the great range of larval and juvenile forms meant that over half the taxa found could not be identified to species level. This has made analysis difficult, and limited the interpretation of results. Personal contact, via visits, with Japanese taxonomists would have cleared up some of the taxonomic problems encountered.

The lack of a suitable sub-sampling device meant that accurate abundance figures could not be made; therefore abundance categories were used. This prevented numerical comparisons between different seasons, Japanese ports, and voyage times.

The distribution of sampling effort was the third major limitation. It had originally been intended that the study be spread over as wide a range of Australian ports as feasible, hence providing the basis for more specialised and localised research if necessary. The results were sufficient to show that an abundance and considerable diversity of planktonic and benthic taxa are discharged alive into the four harbours chosen via the pumping of ballast water, and/or the dumping of mud, but insufficient samples were taken to determine the full range of species entering; to unequivocably show seasonal effects, the effects of different ports, different voyage times, and different ballast tanks on faunal survival; and the usefulness of mid ocean exchange as a means of reducing the introduction of neritic species. Any alternative approach would have been to sample more frequently in say Eden and Triabunna. Interpretation would have been enhanced if samples for comparison could have been taken in Japanese harbours when ballast tanks were being filled, in the tanks immediately after they were filled, and immediately before and after ballast water was exchanged in mid ocean as well as immediately before the tanks were emptied in Australian harbours.

2. Sampling: Twenty-eight ships were sampled for zooplankton, and nine of these plus three from Sydney harbour had samples of mud from ballast tanks examined for animals (Table 3). The table highlights some of the sampling problems encountered. For example, because vessels do not always return to the same Japanese port from which they departed and because technical staff assisting in Queensland, Tasmania and Western Australia often had other commitments, it was not possible to resample the same ship/port combination on all occeasions. While this would have been the ideal sampling design it was approximated only at Triabunna where a vessel from one port (Ishinomaki) arrived monthly.

3. Plankton Samples: The taxa caught in the plankton hauls are listed in Tables 4 and 5 (for a detailed listing of taxa obtained on each sampling see Appendix A). Six species of copepods, one mysid, and an amphipod are endemic to Japanese waters. A further 14 species of copepod, and four non-copepod taxa have wide distribution in the Indopacific region. The zoogeographic affinities of the remaining 21 copepod and 20 non-copepod taxa not identified to the species level, are uncertain.

All of the 21 copepods not identified to species level were identified to family or genus; Australian species belonging to the same family or genus have not been found to be detrimental to a fin fishery. However, some species of polychaetes and pinnotherids are parasitic or commensal with oysters and mussels both in Japan and Australia. It is therefore possible that some Japanese species may provide a threat to parts of the Australian shellfish industry if they become established in, and prove to be more demanding parasites than existing Australian species. The presence of bivalve veligers also is cause for concern, as these may be veligers of the Japanese oyster (*C. gigas*). While this species occurs rarely in New South Wales, oyster farmers could be further disadvantaged either through regular recruitment from individual discharges or an expansion of the animal's range and abundance.

Table 6 provides a general summary of the numbers of taxa arriving at each port per voyage. Gladstone is obviously depauperate whereas Cape Lambert was highest in total copepods and total taxa. Triabunna had the greatest totals for non-copepods.

The check on the efficiency of hauling a 100 m net 5 times gave varying results. The logistic curve predicted a maximum of 52 taxa at Cape Lambert if sampling had continued indefinitely; 50 taxa (96%) were actually found. At Triabunna and Eden 39 out of 61 (64%) and 39 out of 68 (54%) were counted and predicted respectively. The Eden difference may be caused by avoidance as four copepod species (*Paracalanus parvus*, *Euchaeta concinna*, *Scolethithrix danae*, and *Corycaeus crassiculus*) were taken in the net trials by either the 200 μ or 350 μ nets but not with the 100 μ net. No new non-copepod taxa were taken with the larger nets.

The dip net taken to Eden was used in the full ballast tank on 26th July, 1978, when one juvenile of each of the fish *Theropon jarbus* and *Ptereleotris sp.* was obtained. This vessel was the only one to originate in Yokohama. No other macrofauna were seen or captured during the study.

4. Specific Questions:

4.1 Does position of the ballast tank affect number of fauna in tank ?

Most bulk carriers coming to Australia carry ballast water in double bottom tanks and a central cargo hold. Other bulk carriers (e.g. the coal vessel sampled at Gladstone) do not use a central tank but carry ballast water in wing tanks at the junction of the hull and the upper deck.

This position would seem to make the ballast water susceptible to solar heating; it was therefore hypothesised that there was no significant difference in the number either of all taxa, or taxa identified to species level in hull tanks or wing tanks. The ports used in the comparison were Cape Lambert (hull tanks) and Gladstone (wing tanks), chosen because the voyage times and latitudes (hence sea surface temperatures throughout the voyage) were similar. A 2 X 2 contingency table analysis (the 2 ports vs. all copepods, Table 4 and all non-copepods, Table 5) gave a X^2 value of 4.65; 2 X 2 analysis of identified species gave a value of 4.75. In both cases $P < 0.05$ indicating significantly higher numbers in the hull tanks. The water temperature in the wing tank on the single occasion it was measured was 32°C, and it may be that high temperatures killed off the temperate copepods in the tank without substantially affecting the non-copepod taxa present. We conclude that there is less risk of introduction of exotic species from wing tanks compared to hull tanks.

4.2 Are differences in numbers of taxa due to different ports of loading of ballast water?:-

Ships loaded ballast water in six different broad areas in Japan. These areas (and the ports, see Table 2 - Saizaki could not be located in spite of numerous attempts, even the ship's log was consulted for spelling errors) were Hokkaido (Muroran), North Honshu (Ishinomaki, Sendai), Central Honshu (Chiba, Nagoya, Shimizu, Yokohama), Inland Sea (Fukuyama, Innoshima, Kasado, Kure), West Coast Kyushu (Tobata, Wakamatsu) and East Coast Kyushu (Kushima, Oita). The hypothesis was that there was no difference in the number of total taxa, or taxa identified to species level in ballast water from the six regions.

Contingency table analysis (6 X 2) was again used; no significant differences were found for all taxa ($X^2 = 1.36$, 5df $P > 0.05$) or for taxa identified to species level ($X^2 = 1.82$, 5df $P > 0.05$). Therefore, there do not appear to be differences between the six geographic regions.

4.3 Were there any seasonal differences in the number of taxa in ballast tanks?:-

Most temperate waters exhibit a marked seasonal pattern of abundance and species succession (Woodmansee, 1958, Deevey, 1948).

On the basis (see 4.2) that differences, if any, in faunal structure between Japanese harbours are nominal, and in order to analyse a reasonably large data base, samples taken at Eden and Cape Lambert were combined to test the hypothesis that there was no seasonal difference in number of taxa in ballast tanks.

Samples were compared based on the following northern hemisphere seasonal definitions: winter; December - February: spring; March - May: summer; June - August: and autumn; September - November. Contingency table analysis (4 X 1) for all taxa demonstrated a highly significant difference ($X^2 = 11.61$, $P < 0.01$). When identified copepods combined with identified noncopepods were analysed, no significant difference was determined ($X^2 = 4.15$, $p > 0.05$). A number of other contingency table analyses were then carried out, e.g. all non-copepods, non-copepods identified to species level, and in each case there was no significant difference. On the basis that only one analysis showed a significant difference, we conclude that there do not appear to be seasonal differences in the numbers of taxa arriving.

4.4 Does the number of species in a ballast tank vary with the voyage time?

Increasing voyage time could affect species presence and abundance through food availability. Phytoplankton cannot grow in the absence of light, and would have been quickly grazed to very low levels in 2-4 days, initiating a food chain collapse that should progressively reduce the number of species found in the ballast tanks. In addition, planktonic larvae of benthic animals would have more probability of metamorphosing and settling out with increasing voyage length. It is expected that particle feeding benthic species would survive longest in these conditions.

We tested the hypothesis that the number of taxa present in ballast tanks did not change with increasing time. The alternate hypothesis was that taxa number decreased as voyage time increased. We used samples taken at Cape Lambert to test the hypothesis because external environmental conditions were similar (i.e. no midocean exchange as per Triabunna), and the voyage lengths ranged from 9-17 days (vice an interval of only 4 days at Eden, Table 3).

Regression analysis of taxa number against voyage length for all taxa, all copepods and all non-copepods was performed. The correlation coefficient for combined taxa ($r = -0.740$, $P < 0.05$) was significant, and the slope of the regression line ($y = 40.85 - 2.16x$) was negative showing that the longer the voyage, the fewer the number of taxa that would be present in the tanks. The correlation coefficient for copepods ($r = -0.704$, $P = 0.053$) is almost significant, and the slope of the regression line ($y = 27.09 - 1.53x$) was again negative. The correlation coefficient for non-copepods ($r = -0.504$, $P > 0.05$) is not significant but the slope of the regression line ($y = 13.75 - 0.63x$) was negative. We conclude that there is some evidence that the longer the voyage, the fewer the number of taxa that would be alive and available for introduction into harbours on discharge of ballast water.

4.5 Does mid-ocean ballast water exchange reduce the number of taxa in ballast tanks or the frequency with which they arrive?

On the first sampling visit to Triabunna, ship's crew advised it was regular practice to exchange ballast water in mid-ocean as part of their export licence. This exchange took place while underway in the tropics; about 90% of Japanese water was discarded. Temperature records showing this change were provided by the crew (Figure 1).

Mid-ocean exchange should replace neritic Japanese fauna with a pelagic, Central West Pacific fauna. If this does occur then the number of mid-ocean species and the frequency of their arrival should differ from the neritic species. To test this the Eden data were compared with the Triabunna data; it is unfortunate that the Eden voyages were significantly shorter (Students t test, $P < 0.001$, 19df) than the Triabunna voyages but offered a better approximation than the other two ports.

There were no species found at Triabunna which were unique to the Central West Pacific (Tables 4 and 5). The total number of species and taxa taken at Eden and Triabunna was the same (39) and differences in numbers within these major categories were small (Tables 4 and 5). Differences in the frequency of occurrence were examined using the Bray Curtis dissimilarity measure (Clifford and Stephenson, 1980); the hypothesis being tested was that there was no difference in the similarity index of fauna from exchanged and non exchanged vessels. Values between 0.00 - 0.30 were assumed to show similarity and those between 0.70 - 1.00 dissimilarity. Only species which occurred on more than one occasion were used; single occurrences were considered freak occasions and deleted. The results (Table 7, column 1) indicate dissimilarity between the frequency of occurrence data for all categories of copepods; they were found more frequently at Eden than Triabunna. No such trend appeared for non-copepods. A comparison of Triabunna and Cape Lambert data (column 2) gave a similar trend, whereas Eden and Cape Lambert tended towards similarity in all taxonomic categories.

Interpretation of this result is complicated by the possible effect of voyage duration (see 4.4) particularly as the Triabunna voyages were longer than Eden voyages, but we conclude that mid-ocean exchange may reduce the chance of colonisation by indigenous Japanese copepods by reducing the frequency with which they are introduced. No such conclusion can be made about non-copepods and furthermore, exchange has little effect on mud biota. In addition, and there may be some weather conditions in which mid-ocean exchange might not be carried out for safety reasons; the overall effectiveness of exchange appears doubtful.

5. Mud Samples: Live animals were recovered from mud in the ballast tanks in each of the nine samples taken. Eight indigenous Japanese species, and eight cosmopolitan species were identified from the 43 taxa found (Table 8). One species, *Pinnaxodes mutsuensis*, is commensal with two bivalve species (*Volsella modiolus* and *Crenomytilus grayanus*) in Japanese waters. Sampling of the mud was not quantitative as its importance as a new vector for spreading a different type of animal was not realized until sampling had been concluded. There were insufficient samples collected to analyse the mud samples in the same way as the plankton samples were analysed.

C. Discussion

The results of the Faunal Studies confirm the earlier work of Medcof (1975) that various types of living organisms are in the ballast water tanks of ships arriving in Australia. This previous body of knowledge has been expanded in at least three ways: 1. Species identifications have been made on a number of animals and some are distinctly Japanese. 2. A reproductive potential for some non-native species was implied as adult pairs of non-indigenous copepod (L. bipinnata, Table 4), a non-indigenous mysid (N. japonica, Table 5), and a gravid non-indigenous amphipod (P. c.f. inermis, Table 5), were found. 3. Perhaps most importantly, ballast water mud was found to be another vector for introductions, adding a completely new dimension to the type of animals which can be imported.

The single most difficult problem to overcome with regard to successful colonisations is the extremely limited state of marine taxonomy in Australia. Without a fully described list of indigenous species there can be no confident comparison of what is imported and what is native. Even when an adequate taxonomic record is prepared, a second major problem will be encountered in identifying all the incompletely developed juvenile and larval forms likely to be imported. Thirdly, nominating which, if any, of the species found could pose a threat once introduced into a new environment with a new suite of species is an extremely difficult ecological problem. At the very least the recommendation of Newman (1963, p. 119) "it is inescapable that any introduction will have an effect on established ecosystem and than when an introduction occurs it should be recognised, identified and followed" must be adopted by research institutions and government agencies dealing with the aquatic environment.

IV. WHARF AND HULL SAMPLES

A. Methods

In April, 1977, ramdom portions of the Eden loading wharf were scraped to see if non-indigenous fouling species were present. The samples were preserved as previously noted and returned to the laboratory for identification. In April and July, 1977, divers examined the hulls of two woodchip vessels for the presence of fouling organisms.

B. Results

The fouling organisms collected in April, 1977, from piles at the Eden woodchip wharf did not include any exotic species. The principal organisms collected were the barnacles Tesseropora rosea (Krauss) 1818, Tetraclitella purpurascens (Wood) 1815, and Balanus sp., the mussel Mytilus edulis (Linne) 1758 and tubes of the polychaete worm Galeolaris sp. On the two occasions that hulls were inspected underwater, no fouling organisms were observed.

C. Discussion

Because wharf sampling was so limited we cannot draw firm conclusions as to whether or not exotic species have already colonised Eden waters. In the case of the hull inspections our observations are consistent with the shipping industry's need to minimise vessel operating costs, by keeping hulls clean. More intensive sampling effort would be needed to more accurately assess the presence of exotic colonisers in Eden or other Australian ports.

V. PUMPING SURVIVAL

A. Methods

To determine whether plankton would survive discharge pumping, a pilot study was made using ballast tanks on the FRV "Kapala". The vital stain crystal violet was added to the vessel's 20 m^3 ballast tank to a final concentration of 1 ppm. After five days, the ballast tank was emptied via the vessel's centrifugal pump (capacity 20 $m^3\ hr^{-1}$) while plankton hauls were made outside the ship. These samples were examined to see if live, stained organisms were present. Four experiments were done on the FRV "Kapala" but for logistic reasons it was not attempted on a bulk carrier.

B. Results

Live, stained zooplankton were found in plankton samples taken adjacent to the FRV "Kapala" immediately after the ballast tank had been emptied, thus proving that animals can survive pumping through a relatively small centrifugal pump and associated piping. It is not known if the pumping subsequently affects the viability of the animals compared with umpumped animals; such a question was outside the scope of this preliminary investigation.

No uniquely Japanese animals were found in the few plankton samples examined which had been taken outside the bulk carriers after discharge. This is most probably due to the low abundance of the non-indigenous species in the ballast water and the much higher zooplankton abundances outside the ship. No studies were carried out to see if animals that were present in the ballast tank mud survived their discharge.

C. Discussion

The centrifugal pumps used on bulk carriers are at least 50 times the capacity of "Kapala" (K. Wingate, personal communication) and it could be argued that pumps of such large size have a good killing potential. This question would be best addressed by initiating plankton hauls prior to ballasting and immediately thereafter in the full tank.

In spite of these uncertainties it is common policy on most if not all ballast carriers to empty much of the central and wing tank ballast load via gravity discharge. Entrained species are therefore not subject to any of the rigors of pumping and are more likely to survive discharge, increasing the possibility of colonization.

VI. SALINITY AND TEMPERATURE COMPARISONS

A. Methods

On the first sampling at each port, salinity and temperature measurements were made at 1 m depth intervals from surface to bottom of the ballast tanks, and at the surface and 1 m above the bottom outside the vessel. The tanks were well mixed, and sampling was subsequently done only at the surface and bottom. Routine sampling of vessels was carried out at Eden only: it was discontinued at other ports after the first sampling because of logistic reasons. A daily temperature record from the main ballast tank and ambient air temperatures of ships travelling to Triabunna was made by crew on seven occasions.

B. Results

Surface and bottom readings in Eden ballast water tanks differed marginally (Table 9) and there was little seasonal variation.

Salinity of surface ballast water averaged 2.0 ^{o}/oo less than harbour surface salinity; temperature in ballast tanks averaged 7.9^{o}C greater than the harbour. Maximum salinity and temperature differences were 2.2 ^{o}/oo in winter and spring and 12.8^{o}C in winter.

The highest ballast water temperature reading was made at Gladstone (32.2^{o}C) in the wing tank of a coal carrier. A reading made at Cape Lambert in a central tank (similar latitude) only three weeks later was much lower, 24.5^{o}C.

The temperature data forwarded for Triabunna voyages (Figure 1) showed that regardless of starting temperature a uniform reading of 25^{o}C was generally reached two thirds of the way through the trip.

C. Discussion

The role wing tanks play in reducing species numbers, presumably due to solar effects, has already been discussed and it was pointed out that double bottom tanks on vessels with wing tanks are not susceptible to solar heating.

It has been hypothesised that salinity and/or temperature shock on discharge would act to reduce the likelihood of colonisation. While some of the Japanese harbours (e.g. Shimizu) are susceptible to salinity fluctuations, the geography of most Australian bulk loading ports is such that except for an excessive rainfall interval it is unlikely that salinity will vary from marine conditions. Therefore, the chances of a permanent salinity gradient of such magnitude as to incapacitate imported species is remote.

The critical element in determining shock would therefore seem to be temperature; animals discharged in Tasmania in winter would be presumed to suffer the most. Mid-water surface water temperatures at Triabunna have gone down to at least 9°C (T. Dix personal communication) and would therefore differ by about 16°C from the arrival temperatures measured by ship's crew. In contrast the maximum difference measured at Eden was 12.8°C and the mean difference about 7.5°C. Oceanic zooplankton which perform diurnal vertical migrations often pass through temperature differences in excess of 10°C twice per night (Hansen 1951, Banse 1964) without apparent difficulties. It would seem therefore that if there is a temperature shock it would mostly occur in Tasmania in winter, but the temperature difference may not be lethal.

VII. TREATMENT INVESTIGATIONS

A. Methods

A number of techniques of treating ballast water to kill the biota present were considered in terms of cost, safety, simplicity and effectiveness. Techniques considered unsuitable by these criteria were temperature and/or salinity changes, reduction of dissolved oxygen, ultra sound, ultra violet light, and pumping ballast water to an onshore tank.

In contrast, chemical methods can easily be used by unskilled personnel at sea. Calcium and sodium hypochlorite were selected for static bioassy tests using the glass shrimp *Acetes sibogae australis*, and the juvenile fishes *Girella elevata* Macleay and *Liza argentea* Quoy and Gaimard. Tests were carried out to determine the concentration necessary to give a 100% kill in 24 hour exposure (24-h LC 100). Industry guidelines (B. Copper, pers. comm.) indicate that a concentration of 50 ppm free chlorine is produced with 71 kg. calcium hypochlorite or 400 L sodium hypochlorite per 1000 m^3 water. Replicate solutions varying from 0.5 to 500.0 ppm were made up on this basis in 8 L aquaria. At least 10 shrimp or 5 fish were used and mortality checked for at regular intervals. Chlorine levels in aquaria were not measured.

One low dose ($\simeq$ 0.5 ppm) field trial with calcium hypochlorite was carried out over 5 days in the central ballast tank (13,170 m^3) of the "Alnwick Castle", an ore carrier operating between Port Hedland and Port Kembla. Time limitations did not allow for further field testing.

B. Results

Seven laboratory tests were run with either calcium or sodium hypochlorite (Appendix B) and a minimum starting point concentration of 20 ppm was indicated as the level to effect a complete kill within 24 hours. Figure 2 gives representative toxicity curves for each of the two compounds, and while they appear similar it should be recalled that sodium hypochlorite can be added directly as a liquid and so overcome premixing difficulties. This advantage is somewhat offset by the fact that sodium hypochlorite is a bit more expensive than the calcium compound.

Bearing cost in mind, the field trial aboard "Alnwick Castle" was designed to use as little reagent as possible over a 10 day interval. Live zooplankton were recovered indicating either inadequate mixing or the final concentration was below the lethal level.

C. Discussion

The use of biocide has the advantage of eliminating all risk from ballast water and mud fauna. A biocide also has the advantage of ease of policing. No taxonomic skills would be required of inspectors, a plankton net would be issued to them and replicate hauls made in the central ballast tank to check no living zooplankton were present. While double bottom tanks could not be sampled in this way it may be that certain configurations of the general service pumps would allow a sample to be drawn off, say from the main deck fire mains.

The bioassay results indicate that at a 1981 cost of 25¢/L, treatment of 20,000 tonnes of ballast water (woodchip vessel) at a concentration of 20 ppm sodium hypochlorite would require 3,200 L at a cost of about $800.00. While the cost is not prohibitive the greatest disadvantage seems to be the handling of the large volume of biocide.

In this regard further investigation is needed on the three obvious handling techniques: 1. treat overseas from wharf facilities at the time of ballasting; 2. treat from a shipboard tank of biocide while underway no less than 24 hours before arrival in Australia; 3. treat once moored in Australia. Cost benefit studies on these general techniques and variations (e.g. decrease the treatment time by increasing chlorine concentration) would also indicate whether more than one treatment method was economically viable. In some cases dry ingredients could be shipped (northwestern Western Australia) whereas liquids would be used at ports close to capital cities.

The two chlorine compounds investigated are unlikely to have major residual effects on discharge waters particularly if the application rate is further refined.

VIII. OVERVIEW

Non-indigenous fauna are being discharged into Australian waters via ballast water and mud. Aspects such as position of ballast water tank, voyage duration and mid-ocean exchange appear to influence the numbers of species and frequency of their arrival. Other aspects such as home port, season, pumping survival and salinity and temperature shock do not appear to exert major effects. We were limited to sampling ships once at the end of a voyage, rather than daily throughout the voyage. The number of taxa present at the end of a voyage would be influenced by the number, and abundance of taxa entering the tank at the start of the voyage; a revised sampling programme would assist in eliminating a number of unknown factors arising from this study.

No practical means is available to completely sterilise a vessel; grids and ducts will always provide a mobile habitat. Risk of unwanted introductions can be minimised by ballast water treatment, but there can be no guarantee that ships' masters will consistently treat their water unless required as a part of normal quarantine procedure.

While none of the marine introductions listed (Table 1) can be conclusively linked to ballast water, the amount and frequency with which water is delivered makes it a prime candidate for the successful invasion of an exotic species.

While Crisp (1958) suggested successful colonization was enhanced by frequency and number of animals introduced it must be recalled that at least in the terrestrial context a number of open niches have been disastrously exploited (e.g. rabbits) by the introduction of relatively few individuals. As so few data are available concerning the successful introduction of the species listed in Table 1, it is difficult to assume that high frequencies and abundances are mandatory for a marine introduction. Of the taxa collected in this study the following might be liable to successful colonisation because of the frequency with which they are discharged.

a. Japanese copepods: Calanus sinicus, Corycaeus affinis

b. Undetermined copepods: Microsetella sp., Calanus spp., Family Harpactidae

c. Undetermined non-copepods: polychaetes, gastropods (larvae), bivalves (larvae)

An alternate approach would be to develop and test sophisticated modelling techniques to forecast minimal numbers needed for colonisation, however, this is a complex task. Rather than expend resources on the latter and risk a successful introduction in the meantime, it is felt that treatment of ballast water is required and further research should be directed towards refining a practical methodology.

IX. SUMMARY

1. A substantial and increasing amount of ballast water is being discharged in Australia; as the export of bulk products increases the amount of water imported is expected to increase.

2. The harbours which undergo repetitive discharges such as Cape Lambert and Gladstone would seem most at risk; risk still exists in other ports due to the likelihood of open niches.

3. Eight species of non-indigenous planktonic animals were identified in the ballast water sampled in Australian ports. Eighteen cosmopolitan species were identified. At least forty one taxa could not be identified to species level because of lack of suitable taxonomic keys both in Australia or Japan.

4. The total number of taxa discharged (and the theoretical maxima) in Cape Lambert was 50 (52), in Eden 39 (68) in Triabunna 39 (61). The Gladstone total was 13 but because sampling was discontinued no attempt was made to estimate the maximum.

5. The mean number of taxa per ship (ballast tank) in each port was Cape Lambert 13.13; Eden 12.50; Triabunna 10.63; and Gladstone 3.50.

6. There were significantly fewer copepods (but not non-copepods) in wing ballast tanks compared with hull tanks. This may be due to solar heating of ballast water in wing tanks.

7. In general the composition of the fauna from the six geographical ballasting areas of Japan did not differ.

8. There were no significant seasonal differences in the numbers of species arriving.

9. There is some indication that the length of voyage reduces the number of species of copepods present; no effect of this was seen on non-copepods.

10. With respect to the use of mid-ocean exchange as a management strategy, there was some reduction in the frequency of arrival at Triabunna of copepods but no reduction of other taxa.

11. Two species of fish were obtained with a dip net.

12. Eight non-indigenous species and eight cosmopolitan species were identified in ballast tank mud. Twenty-seven taxa could not be identified to species level.

13. No non-indigenous species colonised wharf piles at Eden. As piles represent only one type of benthic habitat, they are an inadequate basis on which to assess whether non-indigenous species are present.

14. No hull fouling species were found on the two vessels inspected at Eden.

15. Experiments on FRV "Kapala" showed live plankton survive pumping into and discharge from ballast tanks. Extrapolation of these findings to the very much larger pumping systems aboard bulk carriers is uncertain but it seems likely that live animals would survive passive discharge.

16. Salinity differences between ballast water and harbours are probably not large enough to act as a control agent for predominantly euryhaline animals.

17. Temperature differences in excess of 10^{o}C may exist between ballast tanks and some Australian harbours but these differences are not persistent and may not be large enough to cause significant mortality.

18. It was beyond the resources of this study to carry out comprehensive experiments on the cost and effectiveness of a number of possible treatment methods. The advice of water treatment engineers that chlorine would be the cheapest and most effective method of killing ballast water biota was heeded.

19. Laboratory trials indicated a concentration of 20 ppm for either calcium or sodium hypochlorite is effective in killing certain zooplankters. Further field trials and cost benefit studies would be necessary to establish an effective shipboard biocide and the most practical handling techniques.

20. A revised programme to sample plankton in harbour waters before ballasting and ballast tanks regularly during the voyage (especially immediately before and after exchange) would provide a better base on which to answer many of the questions arising from this study.

21. No unequivocal evidence was available to show that any taxa found in either ballast water or mud was competitive or commensal with, or predatory or parastic on, Australian marine organisms. There is a fundamental lack of information about this complex ecological problem and it is beyond the scope of this project to provide this information.

RECOMMENDATIONS

1. That the Fishing Industry Research Committee forward this study to the Standing Committee of Fisheries for the latter's information. Consideration should be given to referral of the study to the Australian Departments of Health and Transport and Bureau of Customs to formally acknowledge the discharge of ballast water as a quarantine issue.
2. That because a policy of mid-ocean exchange has some inherent weakness (there is no evidence at this stage to suggest exchange reduces the number of species in the water column, mud species are not eliminated, and exchange cannot be implemented on every voyage) a policy of elimination by treatment be adopted.

3. The most practical method of treatment appears to be chlorine compounds but further testing should be supported.

XI. ACKNOWLEDGEMENTS

The study was funded by a Fishing Industry Research Trust Account grant. It would not have been possible without the help of the following people:-

Logistics N.S.W.: H. Boudville, P. Coolican, M. Dawson, S. Goodridge, J. Lawler, J.Matthews , C. Medcoff, W. Porritt, G. White, K. Wingate.

Logistics Queensland: M. Dredge.

Logistics Tasmania: T. Dix, O. Miezitis.

Logistics Western Australia: B. Bartley, A. Gouge, P. Wood.

Identifications: L. Holthuis, J. Kudenov, J. Lowry, S. Matoda and staff, K. Muraoka, I. Nakamura and students, M. Pilkington, T. Sakai, S. Siddall.

Treatment: D. Alderman, B. Copper, J. Moyse.

The typing was done by F. Armaghanian, P. Wilson, S. Moore, R. Boyrazian and the figures were drawn by L. Anderson.

Mr. Brian Griffiths of the C.S.I.R.O., Division of Fisheries & Oceanography is specially acknowledged because of his patience, continued interest and critical assistance in the study.

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SPECIES	ORIGIN	NEW LOCATION	REFERENCE
BRYOZOA			
Bugula flabellata Thompson	Atlantic & Mediterranean coasts	N.S.W., S.A.	Allen 1953
Conopeum tubigerum Osburn	West Indies	Qld.	Allen 1953
Schizoporella unicornis Johnston	Japan	Qld., N.S.W., S.A. W.A.	Allen 1953, Wood & Allen, 1958
Watersipora cucullata Busk	unknown	Qld., N.S.W., S.A. W.A.	Allen, 1953 Kormon, 1960
Anguinella palmata van Beneden	Atlantic coasts	N.S.W.	Allen 1953
HYDROZOA			
Bougainvillia ramosa van Beneden	Northern hemisphere	N.S.W.	Briggs 1931; Allen 1953
POLYCHAETA			
Hydroides norvegica Gunnerus	European coasts	Australia generally	Allen 1953; Wood & Allen 1958
MOLLUSCA			
Thecacera pennigera Montagu	United Kingdom	N.S.W.	Allen 1953
Crassostrea gigas (Thunberg)	Japan	N.S.W., Tas., S.A.	Medcof & Wolf 1975
CRUSTACEANA			
Cirripedia			
Balanus improvisus Darwin	northern temperate regions	southern Australia	Bishop 1951
Balanus amphitrite var. denticulata Broch	Suez Canal	Qld.	Bishop 1950;Allen1953
Balanus algicola Pilsbury	South (Southwest?) Africa	N.S.W.	Allen 1953; Walford & Wicklund 1973
Mysidacea			
Neomysis japonica Nakazawa	Japan	N.S.W.	Hutchings, 1982
Decapoda			
Palaemon macrodactylus Rathbun	Japan	S.A.	T. Walker pers. comm., 1977
Carcinides maenas Penn	Europe	Vic.	Fulton & Grant 1901; Allen 1953

Cont..../2

ASCIDIACEA			
Molgula manhattensis (de Kay)	North Atlantic	Qld., Vic.	Kott 1976
Styela clava Herdman	Northwestern Pacific	Vic.	Holmes, 1976
VERTEBRATA			
Pisces			
Acanthogobius flavimanus Temminck & Schlegel	Japan	N.S.W.	Hoese, 1973
Tridentiger trigonocephalus (Gill)	Japan	N.S.W.	Hoese, 1973

Table 1 Summary of Marine Organisms Introduced to Australia.

State	Maximum Tonnage for 1975/1976	Maximum Tonnage for 1976/1977	Maximum Tonnage for 1977/1978
Western Australia	31,721,207	33,067,850	31,753,564
Queensland	10,519,285	12,147,275	12,291,450
New South Wales	7,773,091	8,936,413	10,144,637
Victoria	2,004,546	1,724,935	2,304,100
Tasmania	2,156,215	2,219,771	2,254,279
Northern Territory	1,451,824	1,631,681	1,882,838
South Australia	1,278,764	801,793	1,113,858
Australian Total	56,904,932	60,529,718	61,744,726

Table 2: Maximum tonnage of ships' ballast water introduced per state for 1975/76, 1976/77 and and 1977/78 (includes liners, tramps, tankers) One tonne approximately equals $1m^3$ sea water

Source: Australian Bureau of Statistics, pers.comm.

PORT OF DISCHARGE	SAMPLING DATE	WS	MS	VOYAGE DURATION (d)	POST EXCHANGE INTERVAL (d)	PORT OF ORIGIN	SHIP	EST. BALLAST WATER DISCHARGED (t)	NO. HAULS	TOTAL VOL. FILTERED
TRIABUNNA, TAS.	2.11.76	x		18	10*	ISHINOMAKI	MERIDIAN	25,000	5	5.35
	6. 2.77	x		18	11	CHIBA	"	"	5	2.97
42°30'S	6. 5.77	x		17	10	ISHINOMAKI	"	"	5	5.35
147°55'E	18. 9.77	x		17	10*	"	"	"	5	5.35
	5.11.77	x		19	9	"	"	"	5	5.35
	30. 1.78	x		15	7	"	"	"	5	5.35
	13. 3.78		x	18	10	"	"	"	–	
	29. 5.78	x		18	10	"	"	"	5	3.86
	21. 8.78	x		18	12	"	"	"	5	5.35
				$\bar{x}$ = 17.6	$\bar{x}$ = 9.9					
				SD = 1.13	SD = 1.36					
EDEN, N.S.W.	26. 1.77	x		16		SHIMIZU	EDEN MARU	25,000	10	10.70
	19. 4.77	x		14		"	" "	"	8	8.56
37°04'S	19. 7.77	x		14		"	" "	"	7	7.49
149°55'E	27.10.77	x		17		MURORAN	EMPRESS OF EDEN	24,000	8	8.56
	9.12.77	x		16		"	" " "	"	9	9.63
	15.12.77		x	15		SENDAI	DAIHO MARU	?	–	–
	2. 5.78	x		15		"	NEW INDEPENDENCE	20,000	5	5.35
	8. 5.78		x	16		MURORAN	EDEN MARU	25,000	–	–
	21. 6.78		x	15		SHIMIZU	" "	"	–	–
	26. 7.78	x		14		YOKOHAMA	EMPRESS OF EDEN	24,000	8	8.56
	31.10.78	x		16		MURORAN	" " "	"	5	5.35
	2.11.78		x	16		"	" " "	"	–	–
				$\bar{x}$ = 15.3						
				SD = 0.98						
SYDNEY, N.S.W.	10. 8.78		x	18		FUKUYAMA	SHOHUKU MARU	6,000		
	21. 9.78		x	18		"	" "	"		
	23.11.78		x	18		AMAGASAKI	SHINSHO MARU	15,000		
				$\bar{x}$ = 18.0						
				SD = 0						

CAPE LAMBERT, W.A. 20°35'S 117°10'E (* DAMPIER)	26.11.76	x		10	SAIZAKI	SAMRAT ASHOK	30,000	5	3.71
	1. 3.77	x		12	TOBATA	SHINSHO MARU	54,000	5	1.20
	10. 6.77	x		13	INNOSHIMA	ZUIHO MARU	41,000	5	6.55
	31. 8.77	x		11	FUKUYAMA	KASAGISAN MARU	"	5	6.55
	25.11.77	x		15	NAGOYA	MIFUNESAN MARU	50,000	5	6.55
	11. 4.78	x		9	TOBATA	SEVEN SEAS CONQUEROR	43,000	4	5.24
	14. 6.78	x		12	WAKAMATSU	WAKAZURU MARU	55,000	5	6.55
	26. 9.78	x	x	17	OITA	ARIMASAN MARU	59,000	5	6.55
				$\bar{x}$ = 12.4					
				SD = 2.61					
GLADSTONE, QLD.	11.11.76	x		10	KUSHIMA	ROBERTS BANK	30,000	5	1.20
	24. 2.77	x		13	KASADO	CHIKUZEN MARU	14,000	5	1.05
23°51'S	24. 5.77	x		13	KURE	BALDER TRADER	20,000	5	0.75
151°16'E	16. 8.77	x		12	WAKAMATSU	HORO MARU	?	5	1.25
				$\bar{x}$ = 12.0					
				SD = 1.41					

TABLE 3 Details of ballast water and mud sampling conducted between 2.11.76 and 23.11.78. Voyage duration ≡ time from when ballast water was taken on until time sampled. Post exchange interval ≡ time from when mid ocean exchange commenced until time sampled. *Dampier (one sampling only) located at 20°39'S, 116°43'E. WS equals water sample; MS equals mud sample. * equals assumed interval.

TABLE 4. COPEPODS

	TRIABUNNA f	TRIABUNNA RA	EDEN f	EDEN RA	CAPE LAMBERT f	CAPE LAMBERT RA	GLADSTONE f	GLADSTONE RA
JAPANESE								
Calanus sinicus	1	C	7	C	2	Oc	0	–
Centropages abdominalis	0	–	0	–	1	Oc	0	–
C. yamadi	0	–	0	–	1	C	0	–
Labidocera bipinnata	0	–	1	Oc	1	C	0	–
Pontellopsis tenuicauda	0	–	0	–	1	C	0	–
Corycaeus affinis	1	C	3	Oc	5	A	0	–
Total species	2	–	3	–	6	–	0	–
Multiple occ.	0	–	2	–	2	–	0	–
Abundance – R		0		0		0		0
Oc		0		2		2		0
C		2		1		3		0
A		0		0		1		0
COSMOPOLITAN								
Calanus vulgaris	1	C	0	–	1	C	0	–
Eucalanus attenuatus	0	–	1	C	0	–	1	Oc
Centropages orsini	0	–	0	–	1	Oc	0	–
Temora turbinata	0	–	0	–	3	Oc	0	–
Pseudodiaptomus hickmani	1	C	1	Oc	2	Oc	0	–
Callanopia elliptica	1	C	0	–	1	R	0	–
C. thompsoni	0	–	0	–	1	C	0	–
Acartia clausii	2	A	2	Oc	3	Oc	0	–
Tortanus forcipatus	0	–	0	–	3	C	0	–
Oithona similis	2	A	7	C	5	C	1	Oc
Euterpe acutifrons	2	C	1	C	3	C	0	–
Clytemnestra rostrata	1	C	3	Oc	2	Oc	0	–
Oncaea venusta	1	C	6	C	4	C	0	–
Sapphirina darwini	1	Oc	2	Oc	0	–	0	–
Total species	9	–	8	–	12	–	2	–
Multiple occ.	3	–	5	–	8	–	0	–
Abundance – R		0		0		1		0
Oc		1		4		5		0
C		6		4		6		2
A		2		0		0		0
UNDETERMINED								
Calanus spp.?	1	C	1	Oc	4	C	1	C
Eucalanus sp.	1	C	0	–	0	–	0	–
Mecynocera sp.	2	C	1	Oc	0	–	0	–
Ctenocalanus sp.	1	Oc	0	–	0	–	0	–
Scolecithricella sp.	0	–	0	–	1	Oc	0	–
Calanopia sp.	0	–	0	–	1	R	0	–
Labidocera sp.	0	–	0	–	1	C	0	–
Pontellopsis sp.	0	–	1	Oc	0	–	0	–
Tortanus sp.	0	–	0	–	1	R	0	–
Family Harpactidae	1	C	4	Oc	3	C	0	–
Microsetella ?	0	–	2	C	0	–	0	–
Microsetella sp.	1	C	6	C	4	A	1	C
Oithona sp.	0	–	1	R	1	R	0	–
Oncaea sp.	0	–	1	Oc	0	–	0	–
Corycaeus spp. ?	0	–	0	–	3	C	0	–
Oncaea/corycaeus sp.	1	C	2	C	2	C	0	–
Copilia sp.	0	–	1	Oc	0	–	0	–
Unknown N	0	–	0	–	1	Oc	0	–
" O	0	–	0	–	1	Oc	0	–
" P	0	–	0	–	1	Oc	0	–
" larvae	0	–	0	–	1	C	0	–

Total taxa	7	–	10	–	14	–	2	–
Multiple occ.	1	–	4	–	5	–	0	–
Abundance – R		0		1		3		0
Oc		1		6		4		0
C		6		3		6		2
A		0		0		1		0
ALL CATEGORIES								
Total species	18		21		32		4	
Multiple occ.	4		11		15		0	
Abundance – R		0		1		4		0
– Oc		2		12		11		2
– C		14		8		15		2
– A		2		0		2		0

TABLE 4 Summary of frequency of occurrence and relative abundance of Japanese, cosmopolitan and undetermined copepods. ⚥ = adult pairs.

TABLE 5. NON COPEPODS

	TRIABUNNA f	TRIABUNNA RA	EDEN f	EDEN RA	CAPE LAMBERT f	CAPE LAMBERT RA	GLADSTONE f	GLADSTONE RA
JAPANESE								
Neomysis japonica	1 ♀	R	0	–	0	–	0	–
Pontogeneia c.f. *inermis*	1 ♀	R	0	–	0	–	0	–
Total species	2		0		0		0	
Multiple occ.	0		0		0		0	
Abundance – R		2		0		0		0
Oc		0		0		0		0
C		0		0		0		0
A		0		0		0		0
COSMOPOLITAN								
Evadne sp.	1	R	0	–	0	–	0	–
Podon sp.	6	Oc	1	Oc	1	R	1	Oc
Lucifer sp.	0	–	0	–	3	R	1	R
Sagitta sp.	6	Oc	5	R	6	Oc	1	Oc
Total taxa	3		2		3		3	
Multiple occ.	2		1		2		0	
Abundance – R		1		1		2		1
Oc		2		1		1		2
c		0		0		0		0
A		0		0		0		0
UNIDENTIFIED								
Cnidaria	1	Oc	4	Oc	0	–	0	–
Platyhelminthes	0	–	1	R	0	–	0	–
Polychaeta	8	Oc	7	C	4	Oc	1	Oc
Ostracoda	1	R	2	R	1	R	1	R
Cirripedia	2	R	4	R	4	Oc	0	–
Mysidacea	1	R	2	R	1	R	0	–
Isopoda	2	R	1	R	1	Oc	0	–
Atylus sp.	0	–	1	R	0	–	0	–
Corophium sp.	2	R	2	R	0	–	0	–
Euphausiacea	1	R	1	R	1	R	0	–
Penaeidae	2	R	1	R	2	R	0	–
Caridea, adults	0	–	1	R	2	Oc	0	–
Thalassinidea, juv.	1	R	0	–	0	–	0	–
Pinnotheridae	1	R	0	–	1	R	1	Oc
Brachyura larvae & juv.	4	Oc	0	–	2	R	0	–
Reptantia	0	–	0	–	2	R	1	Oc
Gastropoda larvae	6	Oc	4	Oc	5	R	0	–
Bivalvia larvae	8	C	5	C	7	C	0	–
Oikopleura	5	Oc	2	Oc	3	Oc	1	Oc
Eggs	3	Oc	2	R	2	Oc	2	Oc
Total taxa	16	–	16	–	15	–	6	–
Multiple occ.	10	–	10	–	10	–	1	–
Abundance – R		9		11		8		1
Oc		6		3		6		5
C		1		2		1		0
A		0		0		0		0

ALL CATEGORIES

Total taxa	21		18		18		9	
Multiple occ.	12		11		12		1	
Abundance – R		12		12		10		2
Oc		8		4		7		7
C		1		2		1		0
A		0		0		0		0

TABLE 5. Summary of frequency of occurrence and relative abundance of Japanese, cosmopolitan and undetermined non copepods. ⚥ = adult pairs; ♀ = gravid female.

Port		Eden	Cape Lambert	Triabunna	Gladstone
No. Voyages		8	8	8	4
Copepods -	Japanese	1.38 ± 0.52	1.38 ± 1.51	0.25 ± 0.71	0
	Cosmopolitan	2.88 ± 1.13	3.63 ± 2.00	1.50 ± 2.73	0.50 ± 1.00
	Unknown	2.50 ± 2.00	3.13 ± 3.31	1.00 ± 2.14	0.50 ± 1.00
	Total	6.75 ± 2.60	8.13 ± 5.69	2.75 ± 5.41	1.00 ± 2.00
Non-copepods	Japanese	0	0	0.25 ± 0.71	0
	Cosmopolitan	0.25 ± 0.46	1.25 ± 0.71	1.63 ± 0.74	0.75 ± 0.96
	Unknown	5.88 ± 2.98	4.75 ± 2.76	6.00 ± 2.39	1.75 ± 1.71
	Total	5.75 ± 2.96	6.00 ± 3.25	7.88 ± 2.47	2.50 ± 2.38
Total taxa		12.50 ± 4.84	14.13 ± 7.62	10.63 ± 6.95	3.50 ± 3.70

Table 6 - Mean number of taxa found per voyage in ballast water of various Australian ports between 1976 - 1978.

	E.-C.L.	C.L. - T.	T. - E.
All taxa	0.39	0.49	0.55
Copepods, all	0.41	0.79 (dis)	0.85 (dis)
Japanese	0.42	1.00 (dis)	1.00 (dis)
Cosmopolitan	0.42	0.61	0.69
Unknown	0.40	1.00 (dis)	1.00 (dis)
Non copepods, all	0.36	0.31	0.38
Japanese	-	-	-
Cosmopolitan	0.28 (sim)	0.42	0.41
Unknown	0.37	0.28 (sim)	0.37

Table 7 Bray Curtis Dissimilarity Measure where similar samples are close to Ø and dissimilar samples are close to 1. Frequencies of 1 were not used on the basis of freak occurrence. E = Eden, C.L. = Cape Lambert, T = Triabunna; (dis) = dissimilar comparisons, see Methods, (sim) = similar comparisons, see Methods.

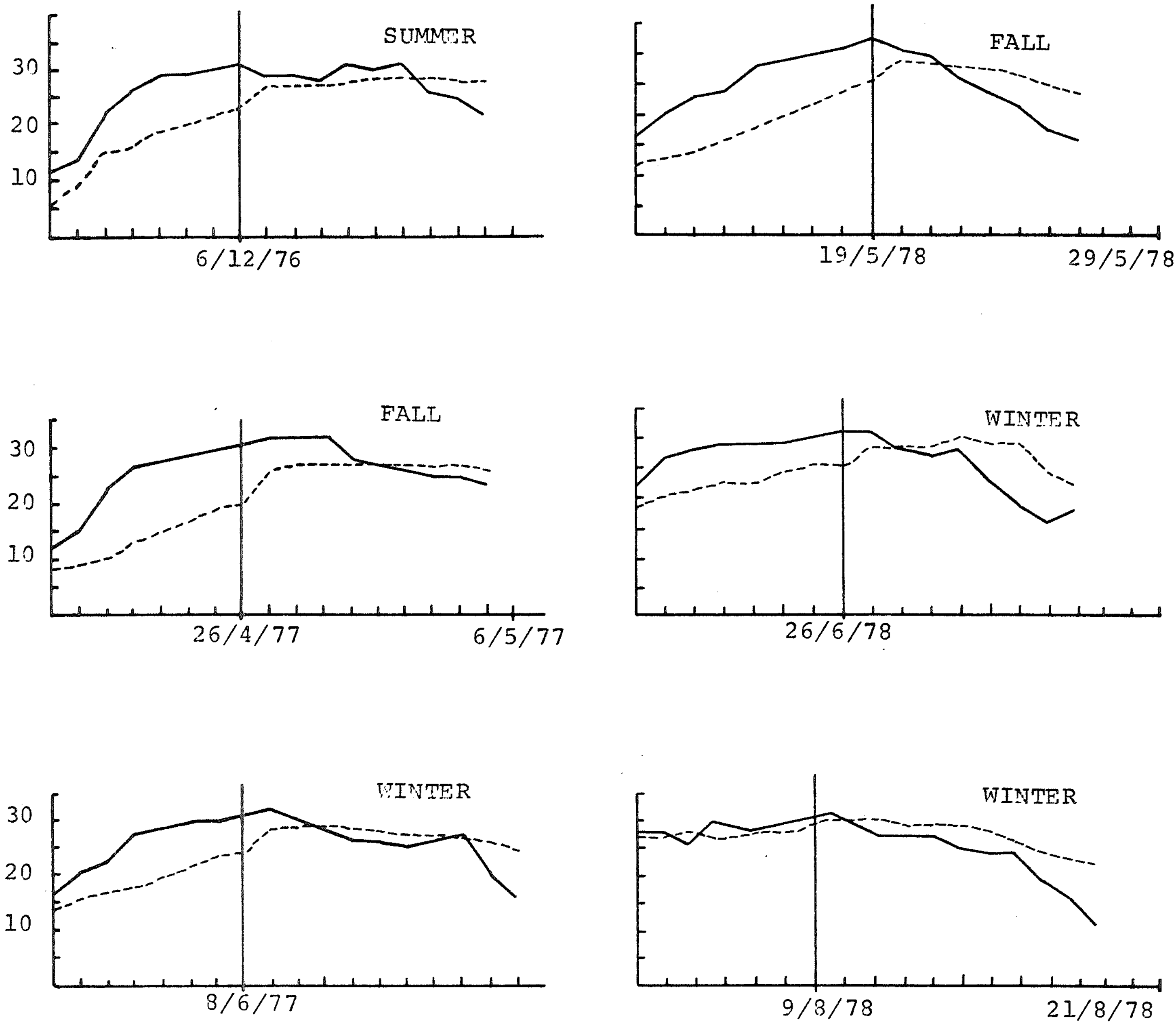
	TAXA	DATE COLLECTED	PORT	NO. OF INDIVIDUALS
JAPANESE				
mysid	*Archaeomysis grebnitzkii*	27.10.77	Eden	2
	Acanthomysis shrencki	27.10.77	Eden	2
amphipod	*Melita rylovae*	15.12.77	Eden	1
	Orchomene pacifica	15.12.77	Eden	1♀
		8.5.78	Eden	1
	Tiron c.f. *biocellata*	2.5.78	Eden	1
carid	*Alphens hoplocheles*	21.6.78	Eden	17
brachyuran	*Pinnixa rathbuni*	27.10.77	Eden	1
	Pinnaxodes mutsuensis	2.11.78	Eden	1
COSMOPOLITAN				
copepod	*Pleuromamma xiphias*	10.8.78	Sydney	2
amphipod	*Jassa falcata*	10.8.78	Sydney	1
penaeid	*Trachypenaeus curvirostris*	21.9.78	Sydney	4
carid	*Processa sulcata*	21.6.78	Eden	1♀
	Leptochela sydniensis	21.6.78	Eden	2
brachyuran	*Portunus hastatoides*	21.9.78	Sydney	4
	Charybdis variegata	21.9.78	Sydney	2
	Conchoecetes artificiosus	21.9.78	Sydney	2
UNKNOWN				
polychaete	*Nectoneanthes oxypoda*?	21.9.78	Sydney	1
	Nectoneanthes oxypoda	2.11.78	Eden	1
	Loimia medusa?	21.9.78	Sydney	1
	Loimia sp.?	2.11.78	Eden	3

	T A X A	DATE COLLECTED	PORT	NO. OF INDIVIDUALS
	Undetermined adults	13.3.78	Triabunna	19
	Undetermined juvenile	27.10.77	Eden	1
	Undetermined juvenile	8.5.78	Eden	frag.
	Undetermined juvenile	26.9.78	Cp.Lambert	2
leptostraca	Undetermined adults	15.12.77	Eden	4
	Undetermined adults	8.5.78	Eden	4
	Undetermined adults	26.7.78	Eden	9
mysid	*Acanthomisis*/*Neomysis* sp.	27.10.77	Eden	1
	Undetermined adult	13.3.80	Triabunna	1
amphipod	*Corophium* sp.1	8.5.78	Eden	8
	Corophium sp.2	8.5.78	Eden	6
	Corophium sp.3	8.5.78	Eden	7
	Corophium sp.4	2.11.78	Eden	1
	Caprella sp.1	2.11.78	Eden	1
	Caprella sp.2	2.11.78	Eden	1
	Undetermined adult	2.11.78	Eden	1
isopod	Undetermined juvenile	2.5.78	Eden	1
carid	Undetermined juvenile	27.10.77	Eden	8
macruran	Undetermined juvenile	2.5.78	Eden	1
brachyuran	*Eucrate alcocki*?	21.9.78	Sydney	3
	Xanthias sp.?	21.9.78	Sydney	1
	Undetermined juveniles	23.11.78	Sydney	2
	Undetermined juvenile	26.7.78	Eden	1

Table 8 - Mud taxa. frag. = fragment only, ♀ = gravid female

ROUTE				SALINITY			TEMPERATURE		
				TANK		WHARF	TANK		WHARF
FROM	TO	SEASON	DATE	S	B	S	S	B	S
SHIMIZU	EDEN	SUMMER	26.1.77	31.6	33.2	-	25.0	25.0	19.0
SHIMIZU	EDEN	AUTUMN	19.4.77	33.6	33.8	34.8	25.6	24.8	19.0
SENDAI	EDEN	AUTUMN	2.5.78	-	-	-	20.3	20.1	20.0
SHIMIZU	EDEN	WINTER	19.7.77	32.9	33.2	35.1	24.4	24.4	12.7
YOKOHAMA	EDEN	WINTER	26.7.78	34.3	34.0	35.2	25.2	25.2	12.4
MURORAN	EDEN	SPRING	27.10.77	32.6	32.6	34.8	25.3	25.0	18.3
MURORAN	EDEN	SPRING	31.10.78	33.7	33.7	35.6	25.5	24.8	14.9
$\overline{X}$				33.1	33.4	35.1	24.5	24.2	16.6
S				0.96	0.52	0.33	1.88	1.82	3.21
ISHINOMAKI	TRIABUNNA	SPRING	2.11.76	33.6	33.6	34.3	24.0	24.0	16.0
KUSHIMA	GLADSTONE	SPRING	11.11.76	-	-	-	32.2	30.3	-
SAIZAKI	CP.LAMBERT	SPRING	26.11.76	31.8	31.6	34.7	24.5	24.5	25.0

Table 9 - Salinity and temperature comparisons



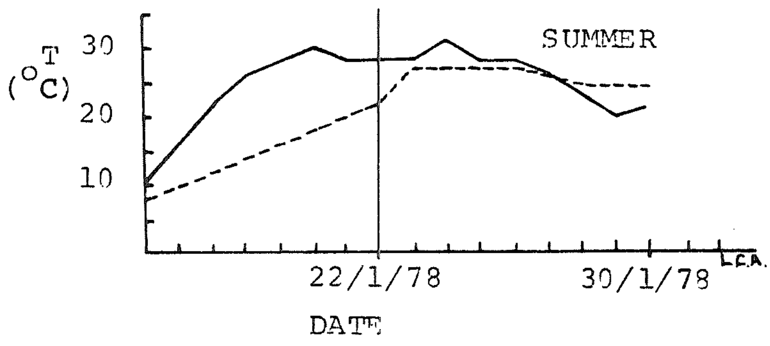
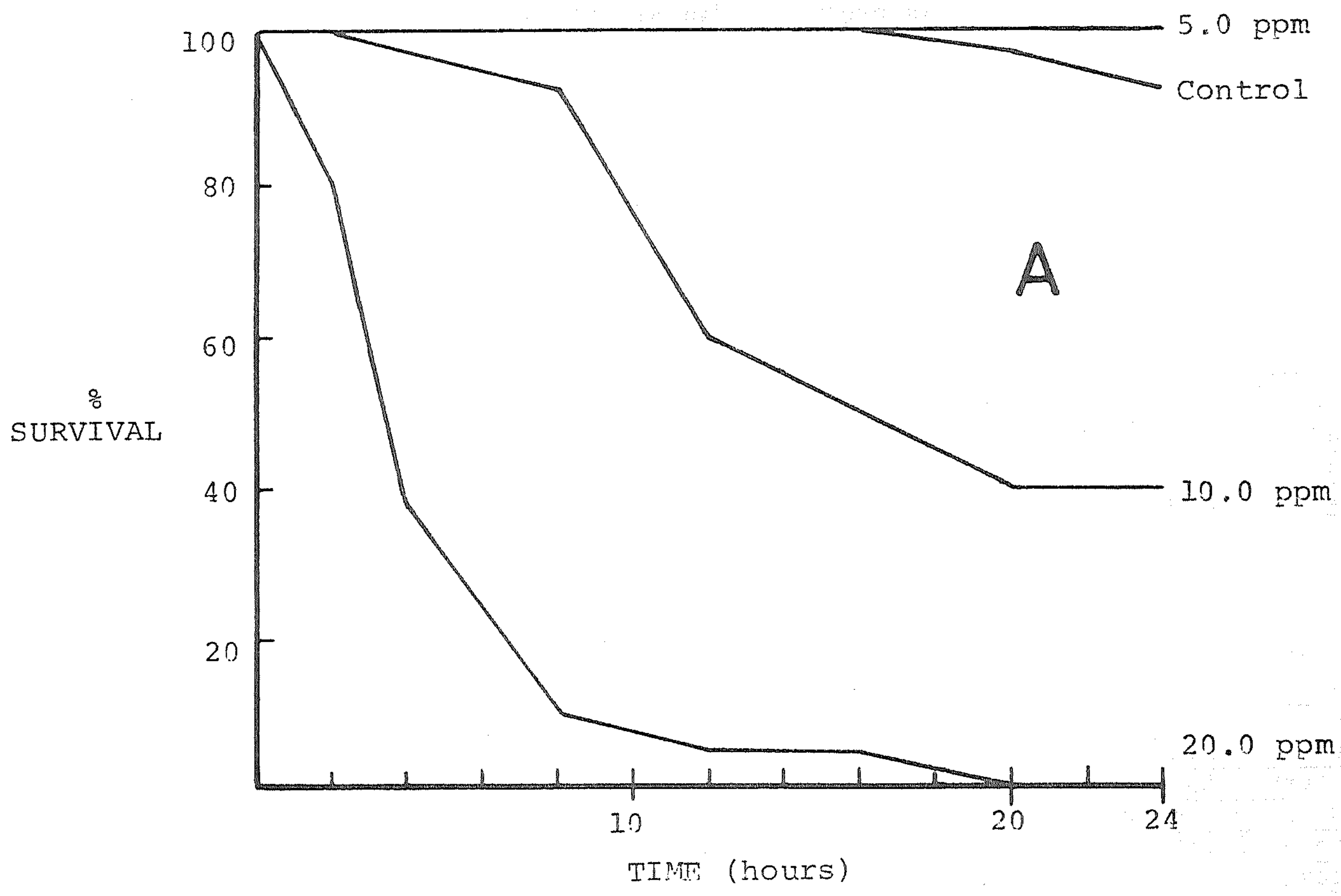


FIG.1. Temperature data taken enroute to Triabunna, 1976-78. Vertical line indicates mid-ocean exchange.

——— Ambient air temperature.

------- NO.4 cargo hold ballast water temperature.



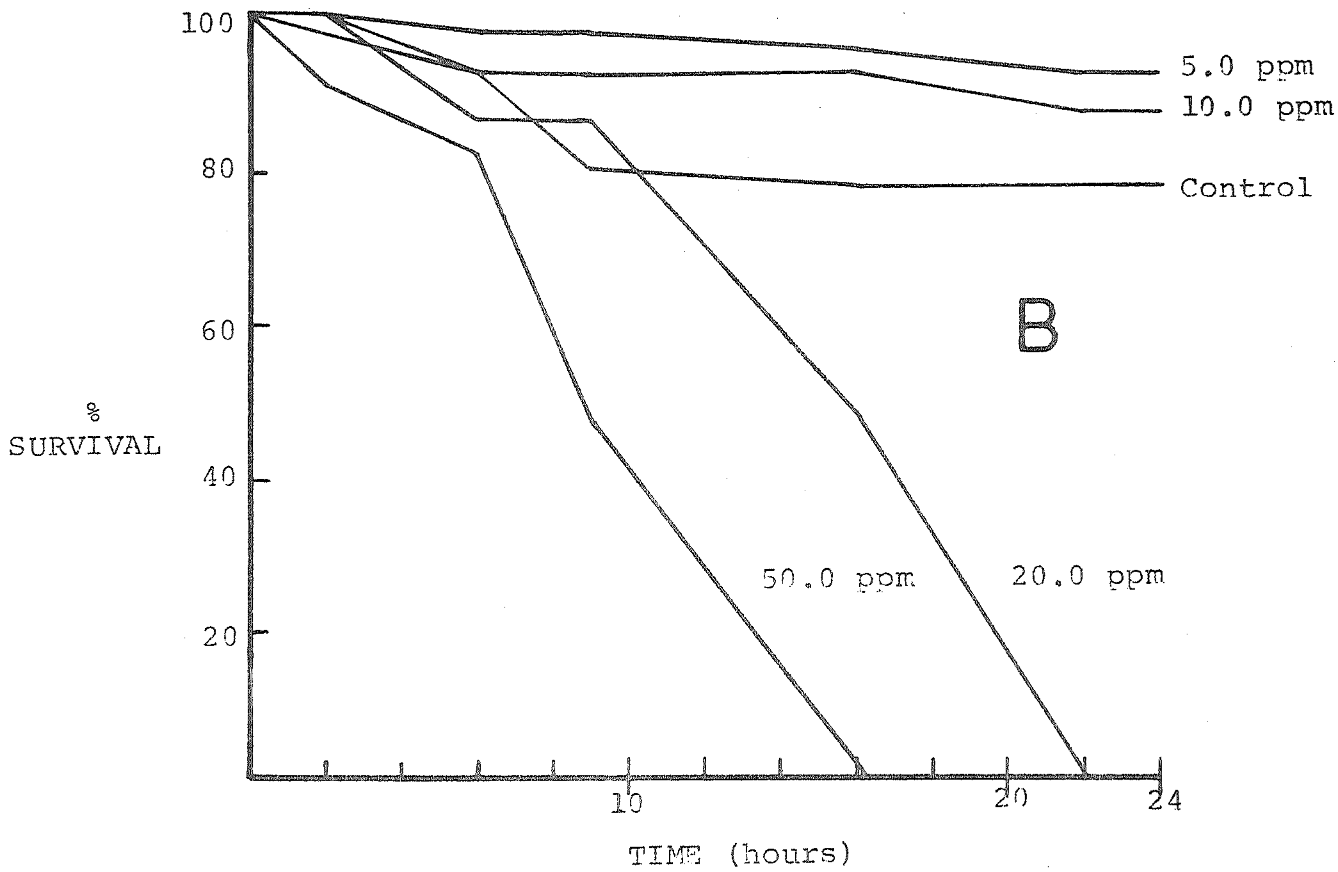


Figure 2 Representative toxicity curves

A. Sodium hypochlorite: A. australis, 4.1.79 see Appendix B6.

B. Calcium hypochlorite: A. australis, 15.8.78 see Appendix B2

APPENDIX A 1 Faunal Arrivals

COPEPODS: TRIABUNNA

	2.11.76	6.2.77	6.5.77	18.9.77	5.11.77	30.1.78	29.5.78	21.8.78
JAPANESE								
Calanus sinicus						70.7		
Centropages abdominalis								
C. yamadi								
Labidocera bipinnata								
Pontellopsis tenuicauda								
Corycaeus affinis						70.7		
Total species	0	0	0	0	0	2	0	0
COSMOPOLITAN								
Calanus vulgaris						70.7		
Eucalanus attenuatus								
Centropages orsini								
Temora turbinata								
Pseudodiaptomus hickmani						70.7		
Callanopia elliptica						70.7		
C. thompsoni								
Acartia clausii		274.5				70.7		
Tortanus forcipatus								
Oithona similis						989.1		0.9
Euterpe acutifrons						70.7		0.1
Clytemnestra rostrata						70.7		
Oncaea venusta						70.7		
Sapphirina darwini			1.6					
Total species	0	1	1	0	0	8	0	2
UNDETERMINED								
Calanus spp.?						70.7		
Eucalanus sp.						70.7		
Mecynocera sp.	2.9					70.7		
Ctenocalanus sp.	2.9							
Scolecithricella sp.								
Calanopia sp.								
Labidocera sp.								
Pontellopsis sp.								
Tortanus sp.								
Family Harpactidae						70.7		
Microstella?						70.7		
Microstella sp.								
Oithona sp.								
Oncaea sp.								
Corycaeus spp.?								
Oncaea/Corycaeus sp.						70.7		
Copilia sp.								
Unknown N								
" O								
" P								
" larvae								
Total taxa	2	0	0	0	0	6	0	0

COPEPODS: EDEN

	26.1.77	19.4.77	19.7.77	27.10.77	9.12.77	2.5.78	26.7.78	31.10.78
JAPANESE								
Calanus sinicus	119.7	0.4	1.5	16.7	1.9	0.2		3.0
Centropages abdominalis								
C. yamadi								
Labidocera bipinnata							2.6	
Pontellopsis tenuicauda								
Corycaeus affinis	20.0	0.4			0.3			
Total species	2	2	1	1	2	1	1	1
COSMOPOLITAN								
Calanus vulgaris	20.0							
Eucalanus attenuatus								
Centropages orsini								
Temora turbinata								
Pseudodiaptomus hickmani								3.0
Callanopia elliptica								
C. thompsoni								
Acartia clausii			1.5	16.7				
Tortanus forcipatus								
Oithona similis	119.7	2.5	9.6	232.1	0.3	0.2		18.2
Euterpe acutifrons								42.4
Clytemnestra rostrata	20.0		1.5				2.6	
Oncaea venusta	119.7		9.6	16.7	0.3	0.2	2.6	
Sapphirina darwini							2.6	3.0
Total species	4	1	4	3	2	2	3	4
UNDETERMINED								
Calanus spp.?			1.5					
Eucalanus sp.								
Mecynocera sp.			1.5					
Ctenocalanus sp.								
Scolecithricella sp.								
Calanopia sp.								
Labidocera sp.								
Pontellopsis sp.							2.6	
Tortanus sp.								
Family Harpactidae			1.5	16.7	0.3	0.2		
Microstella?	20.0		1.5					
Microstella sp.	20.0	0.4	9.6	16.7			36.2	3.0
Oithona sp.						0.2		
Oncaea sp.			1.5					
Corycaeus spp.?								
Oncaea/Corycaeus sp.	20.0		1.5					
Copilia sp.							2.6	
Unknown N								
" O								
" P								
" larvae								
Total taxa	3	1	7	2	1	2	3	1

COPEPODS: CAPE LAMBERT

	26.11.76	1.3.77	10.6.77	31.8.77	25.11.77	11.4.78	14.6.78	26.9.78
JAPANESE								
Calanus sinicus		8.0						0.2
Centropages abdominalis		8.0						
C. yamadi	85.0							
Labidocera bipinnata	♂85.0							
Pontellopsis tenuicauda	85.0							
Corycaeus affinis	509.7	8.0				1.0	10.5	0.2
Total species	4	3	0	0	0	1	1	2
COSMOPOLITAN								
Calanus vulgaris				19.6				
Eucalanus attenuatus								
Centropages orsini				3.3				
Temora turbinata			8.7	3.3			10.5	
Pseudodiaptomus hickmani						1.0	10.5	
Callanopia elliptica						1.0		
C. thompsoni	85.0							
Acartia clausii		8.0		3.3		1.0		
Tortanus forcipatus	85.0						10.5	0.2
Oithona similis	85.0	49.0		3.3		1.0	10.5	
Euterpe acutifrons		49.0				1.0		0.2
Clytemnestra rostrata				3.3				0.2
Oncaea venusta	85.0	8.0		3.3	0.1			
Sapphirina darwini								
Total species	4	4	1	7	1	5	4	3
UNDETERMINED								
Calanus spp.?	85.0			3.3		7.6	10.5	
Eucalanus sp.								
Mecynocera sp.								
Ctenocalanus sp.								
Scolecithricella sp.		8.0						
Calanopia sp.						1.0		
Labidocera sp.	85.0							
Pontellopsis sp.								
Tortanus sp.						1.0		
Family Harpactidae	85.0	8.0		3.3				
Microstella?								
Microstella sp.	1189.7	8.0		3.3		1.0		
Oithona sp.						1.0		
Oncaea sp.								
Corycaeus spp.?	85.0	8.0		3.3				
Oncaea/Corycaeus sp.	85.0			3.3				
Copilia sp.								
Unknown N				3.3				
" O				3.3				
" P				3.3				
" larvae	85.0							
Total taxa	7	4	0	8	0	5	1	0

Appendix A 4 . Faunal Arrivals

COPEPODS: GLADSTONE

	11.11.76	24.2.77	24.5.77	16.8.77
JAPANESE				
Calanus sinicus				
Centropages abdominalis				
C. yamadi				
Labidocera bipinnata				
Pontellopsis tenuicauda				
Corycaeus affinis				
Total species	0	0	0	0
COSMOPOLITAN				
Calanus vulgaris				
Eucalanus attenuatus	1.1			
Centropages orsini				
Temora turbinata				
Pseudodiaptomus hickmani				
Callanopia elliptica				
C. thompsoni				
Acartia clausii				
Tortanus forcipatus				
Oithona similis	7.8			
Euterpe acutifrons				
Clytemnestra rostrata				
Oncaea venusta				
Sapphirina darwini				
Total species	2	0	0	0
UNDETERMINED				
Calanus spp.?	16.7			
Eucalanus sp.				
Mecynocera sp.				
Ctenocalanus sp.				
Scolecithricella sp.				
Calanopia sp.				
Labidocera sp.				
Pontellopsis sp.				
Tortanus sp.				
Family Harpactidae				
Microstella?				
Microstella sp.	27.8			
Oithona sp.				
Oncaea sp.				
Corycaeus spp.?				
Oncaea/Corycaeus sp.				
Copilia sp.				
Unknown N				
" O				
" P				
" larvae				
Total taxa	2	0	0	0

Appendix A 5 Faunal Arrivals

NON COPEPODS: TRIABUNNA

	2.11.76	6.2.77	6.5.77	18.9.77	5.11.77	30.1.78	24.5.78	21.8.78
JAPANESE								
Neomysis japonica								♂0.22
Pontogeneia inermis								♀0.11
Total species	0	0	0	0	0	0	0	2
COSMOPOLITAN								
Evadne sp.		0.59						
Podon sp.	34.88	5.49	0.22	0.65	0.22		2.88	
Lucifer sp.								
Sagitta sp.	2.20	2.16		4.78	3.48	2.28		7.17
Total taxa	2	3	1	2	2	1	1	1
UNDETERMINED								
Cnidaria				1.63				
Platyhelminthes								
Polychaeta	2.44	4.71	3.15	4.02	5.33	13.04	9.85	1.20
Ostracoda							0.76	
Cirripedia		0.59				0.22		
Mysidacea						0.11		
Isopoda				0.11	0.11			
Atylus sp.								
Corophium sp.	0.24				0.54			
Euphausiacea						0.22		
Penaeidae				0.11		0.43		
Caridea, adults								
Thalassinidea, juv.						0.54		
Pinnotheridae						0.22		
Brachyura larvae & juv.	2.93	0.39		0.65	0.22			
Reptantia								
Gastropoda larvae			0.87	3.26	1.63	2.28	0.15	1.30
Bivalvia larvae	0.24	54.90	37.50	179.35	135.87	7.61	10.15	125.00
Oikopleura	5.12	5.88		0.11	1.30			1.09
Eggs					3.26	0.43		0.33
Total taxa	5	5	3	8	8	10	4	5

APPENDIX A 6 Faunal Arrivals

NON COPEPODS: EDEN

	26.1.77	19.4.77	19.7.77	27.10.77	9.12.77	2.5.78	26.7.78	31.10.78
JAPANESE								
Neomysis japonica								
Pontogeneia inermis								
Total species	0	0	0	0	0	0	0	0
COSMOPOLITAN								
Evadne sp.								
Podon sp.			4.93					
Lucifer sp.								
Sagitta sp.	2.21				0.05	1.96	0.24	0.23
Total taxa	1	0	1	0	1	1	1	
UNDETERMINED								
Cnidaria	6.63	1.40	0.14	0.35				
Platyhelminthes							0.14	
Polychaeta	212.63	53.51	18.59	1.40	0.16		0.19	98.48
Ostracoda							0.05	0.08
Cirripedia			0.85	0.88		0.20	1.42	
Mysidacea						0.20	0.05	
Isopoda				0.18				
Atylus sp.							0.09	
Corophium sp.	0.11	0.06						
Euphausiacea	0.11							
Penaeidae	0.21							
Caridea, adults							0.05	
Thalassinidea, juv.								
Pinnotheridae								
Brachyura larvae & juv.								
Reptantia								
Gastropoda larvae	0.10		11.83	1.23			0.05	
Bivalvia larvae			56.90	21.40	0.68		0.09	4.85
Oikopleura			4.79	0.17				
Eggs				0.35			0.47	
Total taxa	6	3	6	8	2	2	10	3

NON COPEPODS: CAPE LAMBERT

	26.11.76	1.3.77	10.6.77	31.8.77	25.11.77	11.4.78	14.6.78	26.9.78
JAPANESE								
Neomysis japonica								
Pontogeneia inermis								
Total species	0	0	0	0	0	0	0	0
COSMOPOLITAN								
Evadne sp.								
Podon sp.				0.89				
Lucifer sp.						0.77	0.08	0.08
Sagitta sp.	41.56	0.50	0.09	0.09		0.44	0.27	
Total taxa	1	1	1	2	0	2	2	1
UNDETERMINED								
Cnidaria								
Platyhelminthes								
Polychaeta	4.69		4.46	0.09			0.09	
Ostracoda				0.09				
Cirripedia		1.50	21.43	0.18			0.89	
Mysidacea	0.31							
Isopoda	1.56							
Atylus sp.								
Corophium sp.								
Euphausiacea				0.18				
Penaeidae				0.09		0.22		
Caridea, adults	1.56	0.50						
Thalassinidea, juv.								
Pinnotheridae	0.31							
Brachyura larvae & juv.			0.27				0.11	
Reptantia				0.27			0.22	
Gastropoda larvae		1.00	1.07	0.09			0.45	0.09
Bivalvia larvae		102.50	65.18	1.79	0.36	0.11	111.43	0.45
Oikopleura			2.86	3.39		0.67		
Eggs			4.02				0.18	
Total taxa	5	4	7	9	1	3	7	2

NON COPEPODS: GLADSTONE

	11.11.76	24.2.77	24.5.77	16.8.77
JAPANESE				
Neomysis japonica				
Pontogeneia inermis				
Total species	0	0	0	0
COSMOPOLITAN				
Evadne sp.				
Podon sp.	4.44			
Lucifer sp.			0.77	
Sagitta sp.	1.11			
Total taxa	2	0	1	0
UNDETERMINED				
Cnidaria				
Platyhelminthes				
Polychaeta			6.15	
Ostracoda			0.77	
Cirripedia				
Mysidacea				
Isopoda				
Atylus sp.				
Corophium sp.				
Euphausiacea				
Penaeidae				
Caridea, adults				
Thalassinidea, juv.				
Pinnotheridae	1.11			
Brachyura larvae & juv.				
Reptantia			1.54	
Gastropoda larvae				
Bivalvia larvae				
Oikopleura	4.44			
Eggs		0.56	1.54	
Total taxa	2	1	4	0

	CONTROL		10 ppm		100 ppm		500 ppm	
	A	B	A	B	A	B	A	B
TIME 0	0	0	0	0	0	0	0	0
1	0	0	0	0	4	1	3	3
2	0	1	1	0	6	1	7	4
5	0	1	2	3	19	18	21	20
9	0	1	2	7	20	20	-	-
18	0	1	3	16	-	-	-	-
24	0	1	5	16	-	-	-	-

APPENDIX B1 Calcium hypochlorite toxicity test
Date: 8.8.78
Test animal: *Acetes australis* (glass shrimp)
Starting time: 1415
T range (^{o}C): 18.4 - 19.0

	Control		5 ppm		10 ppm		20 ppm		50 ppm	
	A	B	A	B	A	B	A	B	A	B
TIME 0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	2	2
6	3	0	1	0	1	0	2	4	4	4
9	4	0	1	0	1	0	2	4	11	12
16	5	0	1	1	2	1	12	11	21	22
22	5	0	1	2	2	3	20	24	-	-
24	5	0	1	2	2	3	-	-	-	-

APPENDIX B2 Calcium hypochlorite toxicity test
Date: 15.8.78

Test animal: A. australis
Starting time: 1415
T range (^{o}C): 15.6 - 16.0

	Control		5 ppm		10 ppm		20 ppm		50 ppm		500 ppm	
	A	B	A	B	A	B	A	B	A	B	A	B
TIME 0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	5	5
6	0	0	0	0	0	0	0	0	0	0	18	19
10	0	0	0	0	0	0	0	0	0	0	23	21
18	0	0	0	0	0	0	0	0	2	1	-	-
24	0	0	0	0	0	0	0	0	2	1	-	-

APPENDIX B3 Sodium hypochlorite toxicity test
Date: 8.8.78
Test animal: *A. australis*
Starting time: 1415
T range (^{o}C): 18.4 - 19.0

	Control		0.5 ppm		1.0 ppm		2.0 ppm		5.0 ppm	
	A	B	A	B	A	B	A	B	A	B
TIME 0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
24	1	0	0	0	0	0	0	0	0	0
53	1	0	0	1	0	0	1	1	3	2

APPENDIX B4 Sodium hypochlorite toxicity test
Date: 24.8.78
Test animal: *A. australis*
Starting time: 1415
T range (^{o}C): 18.4 – 19.2

	Control		5.0 ppm		10.0 ppm		15.0 ppm	
	A	B	A	B	A	B	A	B
TIME 0	0	0	0	0	12	12	12	9
1	0	0	0	0	-	-	-	-
3	0	0	0	0	-	-	-	-
7	0	0	0	0	-	-	-	-
13	0	0	0	0	-	-	-	-
19	0	0	0	0	-	-	-	-

APPENDIX B5 Sodium hypochlorite toxicity test
Date: 18.12.78
Test animals: *Girella elevata*
Liza argentea
Starting time: 1145
T °C range: 20.0 - 21.0

	Control		5.0 ppm		10.0 ppm		15 ppm	
	A	B	A	B	A	B	A	B
TIME 0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	2	2
4	0	0	0	0	0	1	8	5
8	0	0	0	0	2	1	9	10
12	0	0	0	0	2	6	10	10
16	0	0	0	0	4	6	-	10
20	1	0	0	0	4	8	-	11
24	2	1	0	0	4	8	-	-
28	2	1	0	0	4	8	-	-
47	2	1	1	0	7	10	-	-

APPENDIX B6 Sodium hypochlorite toxicity test
Date: 4.1.79
Test animal: *A. australis*
Starting time: 1200
T range (^{o}C): 23.0 - 23.2

	Control		5.0 ppm		10.0 ppm		15.0 ppm	
	A	B	A	B	A	B	A	B
0	0	0	0	0	6	10	10	10
6	0	0	0	0	6	-	-	-
24	0	0	0	0	6	-	-	-
30	0	0	1	0	6	-	-	-
48	0	0	1	0	6	-	-	-
54	0	0	1	0	6	-	-	-
72	0	0	2	0	9	-	-	-
78	0	0	2	0	9	-	-	-

APPENDIX B7 Sodium hypochlorite toxicity test
Date: 8.1.79
Test animal: *A. australis*
Starting time: 1000
T range (^{o}C): 25.4 - 26.0