Final report to the Fishing Industry Research Committee

GUIDELINES FOR THE CONDUCT OF SURVEYS FOR DETECTING INTRODUCTIONS OF NON-INDIGENOUS MARINE SPECIES BY BALLAST WATER AND OTHER VECTORS - AND A REVIEW OF MARINE INTRODUCTIONS TO AUSTRALIA.

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February, 1987

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THE AUSTRALIAN MUSEUM

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SUMMARY

The discharge of ballast water from one port into another is not a recent phenomena, although its importance as a dispersal mechanism for marine species has only been fully realised in the last decade with increasing volumes of ballast water being discharged and more studies being carried out on the marine fauna. Australia with its large number of ports, and increasing volumes of ballast water arriving, is certainly at risk from ballast water introductions.

We have summarised the existing literature on introductions of marine organisms in Australia and have discussed possible ways in which these organisms have arrived in Australia. Some species may have arrived via ballast water but to date, the evidence is largely inferential rather than direct. However, we do know that organisms in ballast water may survive discharge and could potentially settle and establish populations which may have an impact on natural fauna.

At this stage it seems that the evidence is not strong enough to warrant expensive control measures for ensuring that the ballast water discharged is sterile.

Also to date, no successful control measures have been implemented in the world, largely on account of the problems of enforcing the necessary legislation. Effective legislation could only be implemented after both international agreement and determination of the funding of control measures proposed.

Whilst accepting the possibility that some ballast water introductions may have occurred into Australia, we need to improve the documentation of these cases and to ascertain if any of these introductions are posing a threat to our natural marine fauna. Such information can only be obtained by the

implementation of large scale monitoring programmes to initially determine the natural fauna of an area and identify any introductions which have occurred. Specific studies should then be initiated to study these introductions and to assess the impact, if any, on the natural fauna. Also, such 'baseline' studies would enable any subsequent introductions to be easily recognised.

Australian ports receiving large volumes of ballast water, especially from areas of similar latitude and/or water temperature regimes, are potentially those most at risk. In these ports, baseline studies together with a follow up programme of regular monitoring should be undertaken urgently to document the natural fauna and any introductions.

Only when this sort of data has been amassed, together with good evidence of the impact these introductions are having on the natural marine fauna, will it be feasible to press for control measures to be implemented.

Finally, we discuss some of the control measures which have been suggested. However, the main conclusion we draw from this review of ballast water introductions is that considerably more substantial data is required before any control measures can realistically be proposed and implemented.

Rationale for preparing Guidelines

During the late 1970's, a study by Williams et al., (1982) funded by Fisheries Industry Research Trust Account (FIRTA 76/18), showed that many ships coming into Australian ports were carrying ballast water with live animals originating from their home port where the ballast water was taken on board. These animals were shown under experimental conditions to survive being discharged through pumps into the open sea. This led Williams et al., (1982) to speculate that some of these organisms could survive and potentially establish populations in Australian waters. They reviewed the available literature which indicated that some marine introductions into Australia and elsewhere via ballast water may have occurred.

Subsequently, the Australian Museum received FIRTA (84/49) funding to undertake a baseline study of the macrobenthic marine invertebrates present in Twofold Bay, New South Wales, one of the ports where Japanese ships regularly discharge ballast water and one of Williams et al., (1982) study sites. The findings of the survey were reported to FIRTA and by Hutchings et al., (1986a; b; in mspt.).

Whilst undertaking this survey, considerable interest was expressed by various governmental agencies. It was felt that an additional report (FIRTA 86/110) providing a set of guidelines as to the conduct of surveys for detecting non-indigenous marine animals was a useful adjunct to the initial report. In addition, a critical review of the recent literature on marine introductions into Australia, including those attributed to ballast water and what control or monitoring measures should be implemented has been added to these Guidelines. These guidelines will be published by the Australian Museum as part of their Occasional Reports series (No. 3) to ensure that all of the available information on the potential problems of ballast water introductions is widely available. This will hopefully facilitate the making of rational decisions in the future regarding this potential problem. To date, the subject of possible ballast water introductions has received considerable media attention and often the full facts have not been presented. Currently some of the reports, namely Williams et al., (1982), are not widely available. This lack of information has caused unnecessary speculation.

Introduction

Within the literature there are numerous well-documented cases of introductions into the marine environment. Many of these were deliberate introductions of commercially important species, for example the oyster *Crassostrea virginica*, which was introduced successfully to the west coast of America and Europe. However, not only was the oyster introduced, but with it the oyster drill *Urosalpinx cinerea*. The oyster drill has become a major pest of the oyster industry along the west coast of America and subsequently in Europe. The oyster drill apparently has no natural predators in its new environment, and has been able to establish rapidly large populations. In Europe, the oyster drill has become the most important and widespread predator of oysters (Galtsoff, 1964).

Apart from these deliberate introductions, and accidental ones associated with them, many other marine organisms have apparently disjunct distributions which are difficult to explain naturally. Marine organisms often have a pelagic larval stage which may be dispersed naturally by ocean currents, resulting in some species occurring over a wide area. But some species, according to the literature, have disjunct distributions which cannot be explained naturally by dispersal of adults or larvae by ocean currents. Instead, other explanations have been put forward to explain these distributions. For example, several species of animals and plants have apparently been transported as fouling organisms on the bottom of ships, including the New Zealand barnacle *Elminius modestus* (see Bishop, 1951), the isopod crustacean *Cymodoce tuberculata* (see Chilton, 1910), and the alga *Arthrocladia villosia* (see Skinner and Womersley, 1983). Certain processes of interchange have operated for longer periods than the identification and documentation of the flora and fauna of a region. Some organisms are such "seasoned travellers" (Woods, 1974), that it is now very difficult to be sure of their country of origin. Rumours of deliberate 'plantings' and other quarantine improprieties abound in the literature, see Dartnall (1969) p. 53, Sumner (1974 p. 4), Springer and Goman (1975 p. 61), Medcof and Wolf (1975 p. 36), McKay (1984 p. 181, and 190), McDowall (1984 p. 206) and Carlton (1985 p. 315).

More recently, ballast water has been frequently suggested as a possible vector of introduced species. Studies both in Australia and overseas have shown that ballast water contains live organisms, often represented by larval or juvenile stages. It has been suggested that these organisms survive after being discharged with the ballast water, and then settle, reach maturity, breed and establish populations near where the ballast water is discharged. These populations may subsequently colonise nearby areas and gradually extend their distribution. It is very difficult to prove conclusively that a species has been introduced in this way, for it may be several years before a population becomes large enough to be recognised and reported in the literature. Also, in Australia the marine fauna and the normal distributions of many individual species are not well known. The absence of records from the intervening stretches of coast between population centres may mean no more than that collections have not been made. This is especially true for micro-molluscs, small crustaceans, polychaetes and many of the lower invertebrate phyla (coelenterates, bryozoans and all the meiofauna). This means that it is often very difficult to accurately document an introduction and the mechanism by which the organism has been introduced.

History of ballast water

Carlton (1985; in press) has presented a comprehensive account of the use of ballast water, the evidence suggesting it as a dispersal mechanism for marine organisms and the significance of its possible effects in this regard. An attempt is made here to summarise some of the facts and ideas presented by Carlton and to focus on the species suggested by him as having been introduced into Australia.

Definition, history and use

The use of water as ballast to ensure the stability (by counteracting the buoyancy) of unladen ships is not a recent innovation. Carlton (1985) records that the routine use of ballast water started in the late 1870's and early 1880's, overlapping with, and then superseding, the use of solid ballast. Ballast water was not widely used for sailing vessels (Springer and Gomon, 1975), but was preferred for motorized metal vessels (Carlton, 1985).

Water ballast is held, in most instances, in tanks specifically designed for that purpose. Their size, shape and configuration vary greatly with the needs of shipping (Williams *et al.*, 1982; Carlton, 1985). Some general designs are shown in Figure 6.

Ballast water and bilge water have often been erroneously used in the same context. Bilge water is the result of seepage from a variety of sources collecting in the lower part of a vessel and probably does not support life in motorized vessels (Dawson, 1973; Springer and Gomon, 1975; Carlton, 1985).

Water for ballast is taken from outside the ship, below the water line and entrained into the ballast tanks through intake hatch covers by gravity flow or pumping (Carlton, 1985). These covers have many holes usually of 1.0 to 1.5 cm diameter, which can be enlarged by corrosion (Springer and Gomon, 1975; Carlton, 1985). The amount of water taken on will depend on the ship's needs and prevailing conditions and can be altered in the harbour or at sea (Carlton, 1985). Typically, ballast water is taken on board in the harbour as the cargo is off-loaded. However, with the advent of very large container ships, loading and discharge of cargo may have to take place a considerable distance offshore in deeper waters.

Ballast water is apparently off loaded by pumping or gravity flow (Williams et al., 1982). This can occur when the vessel is underway or stationary (Carlton, 1985).

Ballast water regulations in Australia

Williams et al., (1982) state - "There are no treatment facilities for ballast water or mud in Australia. The method of disposal is overboard discharge". Similarly, our enquiries indicate that there are no quarantine laws currently enforced to prevent such discharge. The only legislation apparently affecting ballast water release in Australia is concerned with chemical pollution. In 1954, Australia was a signatory to the International Convention for the Prevention of Pollution of the Sea by Oil (known as the OILPOL Convention). As a result of the Convention, Federal Government legislation was enacted to prevent oil pollution in Australian waters. The states then adopted complementary legislation giving effect to the Convention, which is in parallel or mirror form in each State. Ballast water contaminated with oil is covered by the legislation.

In New South Wales, the legislation has taken the form of the Prevention of Oil Pollution in Navigable Waters Act, 1960. Under the Act it is an offence to discharge any ballast water to any New South Wales waterway if it will result in oil pollution.

This is policed in ports by Maritime Services Board (MSB) inspectors who are on duty twenty four hours daily to check the discharge (particularly at commencement and finish of operations) and to look for contamination (Mr. K. Gotham, MSB, pers. comm.). Federal Department of Transport officers may also make checks. However, there is no objection to release of ballast water which will not cause oil pollution.

Discussions with a number of maritime and port authority officers in all Australian states indicates the situation is essentially similar there. Individual port authorities may have additional regulations regarding the discharge of loosely defined substances such as "deleterious matter". Apparently, these are not rigorously enforced so as to prevent introduction of marine organisms in ballast water. Dawson (1973) and Carlton (1985) have indicated that in many cases such restrictions may often be broken.

Ballast water which is at risk of producing pollution may be discharged to a treatment facility where the oil and water are separated. The water is then discharged from the facility to the sea.

Such systems are primarily designed for the use of ships which carry water on the ballast leg of the voyage in tanks which then carry petroleum on the cargo leg. In Australia the facilities occur on shore, generally only at port facilities which handle the bulk-shipping of petroleum.

Carlton (1985) states that he has not considered ballast water containing petroleum in his review. Similarly, other workers have limited their discussions to the discharge of uncontaminated ballast water.

As with bilge water, oily ballast water is apparently not considered likely to support a great range of life though it seems it has never been checked. The chances of living organisms subsequently surviving discharge to an onshore facility and then to the sea appear restricted, though we have been unable to confirm this.

The International Convention for the Prevention of Pollution from ships, (MARPOL Convention), recently signed by the Federal Government may also affect the discharge of ballast water in Australian ports. This enlarges on the OILPOL Convention by legislating against discharge of noxious substances other than oil, such as sewage and garbage. The states are yet to pass complementary laws under this Convention. However, it is unlikely that when passed they will be more effective in preventing the introduction of marine animals via ballast water than the present legislation.

Ballast water as a dispersal mechanism

The hypothesis that ballast water may act as a mechanism for the dispersal and introduction of marine organisms is not a new one. Carlton (1985) gives examples dating from 1908 where this mode of transport was invoked to explain distributions. Peters and Panning (1933) brought this suggestion to the fore in explaining the appearance of the Chinese mitten crab (*Eriocheir sinensis*) in Germany (see also Medcof, 1975; Williams *et al*., 1982; Carlton, 1985). More recently, Carlton (in press) has suggested the actual transport routes of species introduced via ballast water. He also suggests that the transport via ballast water across the Pacific may be far more prevalent than across other oceans. However, it should be pointed out that the marine invertebrate fauna of much of the Pacific is poorly known and that species with an apparently disjunct distribution may be a reflection of the limited collecting of the species, rather than its true natural geographic range.

An example which predates the early suggestions of ballast water transport given by Carlton, occurs in the Australian literature. Fulton and Grant (1900) record that ballast was suggested as the means by which the European shore crab (Carcinus maenas) made its way to Australia. However in a later paper by Fulton and Grant, (1901), it is suggested that ship fouling was the vector for this introduction, and this has since gained favour (Rosenzweig, 1984; Joska and Branch, 1985, see also case history - this report), though with little justification.

After World War II with the escalation of bulk-shipping and the production of larger, faster ships and shorter harbour-residence times, came the realisation that ballast water was becoming an increasingly 'cleaner' environment (i.e. less contaminated with product with physical properties remaining close to that when first taken on board) and an increasingly feasible means of dispersal (Dawson, 1973; Walford and Wicklund, 1973; Carlton, 1985). This is even more likely with the water renewed on every trip. Fouling of ships, which had previously been regarded as an important vector for the distribution of marine organisms (Allen, 1953), was concurrently on the decline with the advent of increased fuel costs and antifouling technology designed to increase ship speed, and thereby, lower running costs (Williams et al., 1982; Carlton, 1985).

Examination of ballast water in ballast tanks

The first detailed examination of ballast water itself was recorded by Medcof (1975) and carried out in Australia (Carlton, 1985). This study showed that living marine organisms were present in the ballast water, and could survive oceanic transport.

Williams et al., (1982) reported on follow up studies which confirmed and reinforced Medcof's findings. They also showed that sediment which accumulates in ballast tanks and is disposed of overboard could act as an additional dispersal mechanism, and this was confirmed by Hutchings *et al.*, (1986a).

Overseas studies of ballast water have been conducted in the United States and Canada (Carlton, 1985). Together these studies show that an extremely wide variety of organisms are to be found in ballast tanks, including larval and juvenile stages and small adults.

Medcof (1975) and Williams *et al.*, (1982) addressed the question of whether these animals survived their discharge. Overall their data indicates it would be possible for marine animals to withstand the physical and chemical rigours associated with this, but were not conclusive. However, as Williams *et al.*, (1982) state, - "the amount and frequency with which water is discharged makes it a prime candidate for the successful invasion of introduced species".

Case study at Twofold Bay

Hutchings *et al.*, (1986a,b) aimed to further build on Medcof (1975) and Williams *et al.*, (1982) studies, by establishing if exotic marine animals had colonised a port (Twofold Bay, N.S.W.) which receives ballast water primarily from a single source (Japan). If non-indigenous animals with a Japanese origin were found this would provide the final link in the chain of transport already described. Williams *et al.*, (1982) had already indicated that transport to this area on the hulls of the ships coming from Japan would be unlikely. Hutchings *et al.*, (1986a; in mspt.) specifically looked for introduced invertebrate species in shallow coastal environments in Twofold Bay.

Hutchings *et al.*, (1986a,b) reported a number of exotic species present in the Bay. These were the ascidian *Stylea plicata*, the molluscs *Theba pisana*, and *Crassostrea gigas*, and the crustaceans

Notomegabalanus algicola, Carcinus maenas and Eurylana arcuata. Subsequent research (Hutchings et al., in mspt.) has shown that an opisthobranch mollusc - Polycera capensis (Quoy and Gaimard) - collected during this study may also be an immigrant to the Bay (see checklist of marine introductions to Australia, in this report).

Of these introductions the Pacific oyster, (C. gigas) is native to Japan. No special significance could be given to this record as the oyster had previously been deliberately introduced nearby and could easily have spread to the Twofold Bay by means other than by ballast water (Medcof and Wolf, 1975). Crassostrea gigas has also become established in a number of areas which do not receive ballast water from Japan so other forces appear to be involved (Medcof and Wolf, 1975).

It is worth noting however that Dinamani (1971) suggested ballast water as a possible vector to explain the occurrence of the oyster C. gigas in New Zealand, though Dromgoole and Foster (1983) favoured a deliberate introduction as an explanation. More importantly, Medcof (1975) found that the physical and chemical conditions of the ballast water arriving in Twofold Bay, from Japan, were near optimum for the larvae of C. gigas. Though no bivalve mollusc larvae were found in his sampling, they were, obtained by Williams et al., (1982).

Hutchings et al., (1986a) also state that the cirolanid isopod (marine slater) Eurylana arcuata may have been introduced through ballast water into Twofold Bay. This method of transport has been suggested for this isopods introduction into America, as has ship fouling (Bowman et al., 1981). Of course, it may also have been introduced to Australia via ship fouling. Although details of the animal's favoured habitats given by Jansen (1981) do not support this interpretation. More intense sampling of ballast water and ship fouling assemblages would be needed to clarify this situation.

Other non-indigenous marine species at Twofold Bay are believed to have resulted from the direct import as ship fouling organisms or from the 'natural' spread of animals already brought to Australia in this way (Hutchings et al., 1986a). This also applies to the mollusc Polycera capensis (Hutchings et al., in mspt.).

Because Hutchings et al., (1986a) did not conclusively show that a colonisation of organisms carried in ballast water at the relatively small port of Twofold Bay had taken place, it should not be assumed that this could not occur. In fact, the evidence points to the conclusion that such introductions and invasions can, and do, take place.

A review of the introductions attributed to ballast water discharge

Carlton (1985) lists 72 cases from around the world where ballast water has been put forward to explain the distribution of marine organisms. Of these he ranks 43 as probable, 28 as possible and one as unlikely events of this nature, based on the biology and ecology of the taxon, the history of the dispersal and the likelihood of an alternative dispersal mechanism. He also lists 45 examples from the many available in the literature, of marine species reported as having disjunct distributions or suddenly extending their range (often across biological barriers - i.e. physical parameters such as distance or water temperature regimes which limit the natural dispersal of organisms). Of these he interprets 14 as being instances of probable ballast water transport, and the remainder as being possible instances. It appears that Carlton has accepted the identifications of the species in the original literature citation. Many of these species belong to taxonomically confused groups and in some cases misidentifications, or difficulty in biogeographical interpretations, are likely. Also in some cases Carlton (in press) has assumed that disjunct distributions are evidence of ballast water introductions. This may in fact be an artifact, representing well studied areas as opposed to poorly known areas. In other instances, species suggested as possible ballast water introductions by the original author have been quoted by Carlton as 'positive' ballast water introductions.

Australian Introductions

Included in Carlton's (1985) tables are 3 examples of probable ballast water transport to Australia; the small goby fishes Acanthogobius flavimanus and Tridentiger trigonocephalus (as recorded by Friese, 1973, and Hoese, 1973), and the shrimp Palaemon macrodactylus (as recorded by Williams et al., 1978, and Holthuis, 1980). Two species of polychaete worm Boccardia proboscoidea and Pseudopolydora paucibranchiata (as recorded by Blake and Kudenov, 1978) and a native bivalve mollusc Notospisula trigonella (as recorded by Wilson and Kendrick, 1968) are given as examples of cases where ballast water transport possibly played a role in determining their distribution in Australia. Our research (this report - see Table 1, Checklist of marine introductions to Australia, footnote 31) indicates that the example of Palaemon macrodactylus is questionable. Blake and Kudenov (1978), whilst recording Pseudopolydora paucibranchiata in Port Phillip Bay, Victoria, do not give any explanation of its apparently disjunct distribution (Japan, New Zealand, Eastern North Pacific). An alternative to Carlton's (1985; in press) interpretation of this species being a ballast water introduction is that the species may have been misidentified and several closely related species may have been confused.

Since Carlton's (1985) review, a number of other possible introductions to Australia where ballast water is discussed as a dispersal mechanism have been reported. These are; the marine fishes Lateolabrax japonicus (as recorded by Paxton and Hoese, 1985), Sparidentex hasta (as recorded by Anon. 1985; Bodeker, 1985; Harvey and Beard, 1985), the crustaceans Neomysis japonica (as recorded by Hutchings, 1983), Eurylana arcuata (as recorded by Hutchings et al., 1986a) and the bivalve mollusc Musculista senhousia (as recorded by Willan 1985a, b, in press; Slack-Smith and Brearley, in press). Using Carlton's (1985) criteria these would most likely be rated as probable ballast water introductions.

These examples can be used to make an important point. Larger animals such as the fish L. japonicus or sedentary animals such as the bivalve mollusc M. senhousia are unlikely to be positively identified from ballast water samples as it is their younger stages (eggs or larvae) which are more likely to be taken aboard. Such unidentifiable stages make up a large proportion of ballast water fauna (Williams et al., 1982).

Thus, the evidence indicating that ballast water was the means by which all the animals mentioned above arrived in Australia is difficult to prove beyond doubt. Also, some animals may arrive in several ways. However, in the case of the goby, T. trigonocephalus, and the mysid, (shrimp like) crustacean N. japonica, particularly convincing evidence does exist. A specimen of T. trigonocephalus was reported from sea water tanks from an Australian ship (Paxton and Hoese, 1985), whilst N. japonica was taken in ballast water from Japan sampled at Triabunna, Tasmania, by Williams et al., (1982). Recently, Leis (unpublished data) has identified an additional larval fish, Terapon jarbua, from the ballast water collection by Williams et al., (1982) at Eden. This species occurs in the tropical Indo-Pacifice including Japan and previously the southern most record of the species was from Lake Illawarra on the N.S.W. coast. It is not known if this larval fish would have survived in Twofold Bay.

Such evidence certainly supports Carlton (1985; in press) who concluded that Australia was in one of three regions in the world where the trading and shipping trends of the last decade or so favoured ballast water introductions on a large scale.

Introduction to checklist of marine species introduced to Australia

In compiling this review it became apparent that information on introduced species already brought to Australia was scattered throughout the published and unpublished literature and needed to be synthesized. Little follow up work had been done to determine if any of these species had established self-sustaining populations, and, if they are having any effect on the ecology of the area. We have attempted to collate all the information from the many diverse sources and this is summarised in Table I.

As Carlton (1985) has noted, finding references to introduced marine animals in the literature is a painstaking and difficult task. Walford and Wicklund (1973) have also commented on this and summarised the other taxonomic problems inherent in listing introductions. They note that documentation of an accidental introduction involving shipping depends upon - "a systematic biologist of the right speciality being at the right place at the right time. It depends equally on his collecting one or more specimens of the exotic species, on his knowing that it is indeed exotic, and on his publishing the record. The question of whether or not the species really is exotic depends of course on the quality of earlier faunal records". Carlquist (1974) concluded that drastic disjunct distributions may sometimes be the result of incorrect taxonomic interpretation. Womersley (1979) elaborates on the idea of taxonomic doubts by stating that - "the now inadequate descriptions of most of the earlier described species makes thorough checking of species from other areas a formidable task which has rarely been tackled in detail". Lack of good taxonomy gave many introductions "freedom from recognition for some years" (Crisp and Chipperfield, 1948).

Weir (1977) has similarly remarked that the ability to perceive an exotic varies from person to person and depends upon factors such as experience and adequate background knowledge of native species. Williams et al., (1982) state that "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".

This problem is certainly not unique to Australia, although our large (and often inaccessible) coastline with numerous ports exacerbate it. For example, both Skerman (1960) and Dromgoole and Foster (1983) have noted that detection of introduced marine species around New Zealand is hampered by lack of taxonomic studies.

Thus the correct identification of the organism and interpretation of its biogeography, is of great importance in determining if an introduction has occurred. In preparing our checklist, we have assumed all the identifications and their reported analysis in the literature, are correct except where commented on in the footnotes. There is little doubt that many marine animals occurring in Australia (but not included in the checklist) have remarkable distributions. However, the identification of these species, and checking of the records, is beyond the scope of the present study. We therefore envisage that this checklist may be far from complete. However, we believe it will provide a good data base for future researchers to follow. We foresee the addition of many names to the checklist and the removal of others as collection records grow, taxonomic problems are resolved and knowledge of distributions increase. Originally we had intended to merely give literature references to introduced species. However, it soon became apparent that there was a need to qualify the inclusion of many of the species given, to maximise the value of the checklist. Detailed comments are given for the polychaetes, some molluscs and crustaceans where the relevant specialist was available for comment.

Where a large body of information exists, we have tried to establish a detailed case history of the arrival and effects of individual species in Australia. In other instances we have only been able to make general comments on the Australian records (see footnotes attached after Table I) or in more recent examples we have allowed the literature stand on its own. These interpretations await critical analysis from workers with more specialized expertise.

Criteria used to decide the dispersal mechanism (if one had not previously been recorded) follows Carlton (1985) and includes; the biology and ecology of the taxon, the history of the dispersal and the likelihood of an alternative dispersal mechanism. However, it was not always possible to resolve this on the information available. Future researchers may be able to reassess this. Changes may have to be made as further data on the life cycle and natural history of the species becomes available.

Other suggested dispersal mechanisms for introduced marine species which we have noted from the literature, in addition to ship fouling or with a deliberate introduction, are summarised by Walford and Wicklund (1973). To these we add; drilling platforms (Powell, 1976; Benech, 1978; Foster and Willan, 1979; Joska and Branch, 1986), in the wood of packing crates (Popham, 1983), in sea water intake pipes (Newman, 1963; Slack-Smith and Brearley, in press) the wrapping of bait discarded overboard (i.e. dunnage) (Dromgoole and Foster, 1983), wet fishing nets (Powell, 1976) and bait wells (Kinzie, 1984). These should be kept in mind when adding to the checklist.

Where facts are available to accurately document the time of the introduction we have done so. These facts may include age of the specimens first collected, density of populations when first encountered or absence from previous collections in localities where the species was subsequently abundant. Some of this information is available in the literature cited or has been obtained by us and is included in the footnotes to the table. Where this information is unavailable, we have given the earliest collection record found as the date of the introduction, though we agree with Matsui et al., (1964) - "All too frequently however, an invasion is well underway, or essentially completed, before notice of the introduction itself has been made" and Carlton (1985) - "The date of first collection is not necessarily and indeed rarely is coincident with the date of introduction".

Important definitions when evaluating the table appear in Carlton (in press) and are:

(i) Native - species believed to have originated in the region in question.

(ii) Introduction - whereby a species is transported by human activity (often across large natural barriers) into a region where it did not exist in historical times (although, in rare instances, the species may have existed in the region in prehistorical or geological time).

(iii) Range expansions - whereby a species disperses by natural mechanisms into a region where it did not formerly exist.

(iv) Cryptogenetic species - taxa that cannot be identified as being either a native species, an introduced species or a range expansion based on historical, archaeological, palaeontological, biogeographical, systematic, genetic and ecological evidence.

In studying our table it will become apparent that many of the species listed as introductions are in fact 'cryptogenetic' in status. Dr. W. Rudman of the Australian Museum advises that the opisthobranch gastropod molluscs represent a good example of this. As many species feed on fouling organisms and are thus conspicuous members of fouling assemblages, there seems little doubt that they have been transported to many parts of the world on ships hulls. However, as this group had been poorly collected (unlike many shelled molluscs) prior to the advent of SCUBA, and require specialized preservation and identification, the natural range of many animals remains in doubt. Thus, caution should be exercised in assuming what has been introduced. As Kinzie (1984) notes, the probability that an organism may be described from an area where it has been introduced, rather than where it is native, is significant. A possible example of this is the isopod Eurylana arcuata (Hale), first described from Australia but now thought to be an introduction here (Bowman et al., 1981). This situation is most likely to apply to organisms whose biology is suited to transport by fouling of ships hulls, particularly encrusting forms such as bryozoans and barnacles. Their transport inadvertently by man is likely to have occurred long before biologists described them.

The probable origin of the introduction to Australia given in the Table I is that recorded in the literature cited. If no origin is given in the literature and none has been suggested to us, then the known distribution of the species exclusive of Australia is given. For those species with very wide distributions, a general term such as cosmopolitan may be used. In this case the world distribution can be found in the sources cited.

We do not wish to comment further on this except to say that the present limited distribution records in Australia of many of the species listed do appear to support the probability that they were introduced here. Unfortunately a qualification that must be kept in mind is that it may alternatively reflect the paucity of studies on the marine life in Australia, or overseas. We hope that future collecting and possibly genetic studies such as those of Woodruff *et al.*, (1986) may resolve the origin of many species. The way in which they were transported to Australia is often highly debatable, although it appears in some cases that transport via ballast water is a plausible mechanism.

We acknowledge the contribution of Williams *et al.*, (1978) who produced the first summary of marine organisms introduced to Australia and Rob Williams (New South Wales Department of Agriculture-Fisheries Division), in particular, who supplied us with an updated draft whose format we have largely followed. A number of specialists in marine biology were consulted, and our special thanks go to the following for this help;

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Bryozoans:	Dr. D. Gordon (New Zealand Oceanographic Institute).
Polychaetes:	Mr. D. Petch (University of Melbourne)
Molluscs:	Mr. P. Colman, Mr. I. Loch, Dr. W. Rudman (Australian Museum). Dr. R. Willan (Queensland University). Ms. S. Boyd, Mr. R. Burn, Ms. T. Cochran (Museum of Victoria).
Brachiopods:	Dr. J. Richardson (Museum of Victoria).
Crustaceans:	Dr. N. Bruce (Australian Museum), Dr. J. MacIntyre and Mr. R. Buckworth (University of New South Wales), Ms. D. Jones (Western Australian Museum).
Echinoderms and Ascidians:	Dr. F. Rowe (Australian Museum)
Fish:	Dr. B. Hutchins (Western Australian Museum),

Dr. D. Hoese and Mr. A. Gill (Australian Museum).

General: Mr. W. Zeidler (South Australian Museum); Ms. A. Green, Ms. E. Turner (Tasmanian Museum); Mr. R. Hanley (Northern Territory Museum of Arts and Sciences); Dr. R. Ainslie (Electricity Trust of South Australia); Ms. S. Slack-Smith (West Australian Museum).

TABLE 1

CHECKLIST OF MARINE ORGANISMS INTRODUCED TO AUSTRALIA

Numbers in species column refer to footnotes after Table. For explanation of symbols see end of Table.

SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
RHODOPHYTA (Red seaweed)						
Antithamnionella spirographidis (Schiffner)	Europe	?1968	H	S.A.,	Wollaston, 1968	Yes
				N.S.W.	Womersley, 1981	Yes
Polysiphonia brodiaei (Dillwyn)	N. Europe, Washington California or Japan	1940 1959 1973	H	Tas., Vic.	Womersley, 1979	Yes
				S.A.	Womersley, 1981	Yes
Polysiphonia pungens Hollenberg	Pacific coast of Canada	1969	H	Vic.	Womersley, 1979	Yes
					Womersley, 1981	Yes
PHAEOPHYTA (Brown seaweed)						
Arthrocladia villosa (Hudson)	Temperate North Atlantic or Mediterranean	1981	"by shipping"	S.A.	Skinner & Womersley, 1983	Yes

SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
Stictyosiphon soriferus (Reinke)	North Atlantic or Mediterranean	1969 1975 1979	"by shipping"	Vic. S.A. W.A.	Skinner & Womersley, 1983	Yes
Striaria attenuata Greville	North Atlantic, Mediterranean or New Zealand	1950 1978 1985	"by shipping"	Tas. W.A. N.S.W.	Skinner & Womersley, 1983 King & Wheeler, 1985	Yes Yes
BRYOZOA (Lace coral) Anguinella palmata van Benden	Atlantic coasts	1953	H	N.S.W.	Allen, 1953	No
Bugula flabellata Thompson	Atlantic & Medit. coasts	?1950's	H	N.S.W., S.A.	Allen & Ferguson Wood, 1950 Allen, 1953	No No
Conopeum tubigerum Osburn	Atlantic coast (West Indies)	1953	H	Qld.	Allen, 1953	No
Schizoporella unicornis Johnston	Japan	? 1940's post 1953	? H H	Qld., N.S.W. W.A., S.A.	Allen, 1953 Ferguson Wood & Allen, 1958	No No

SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
Watersipora arcuata Banta	Mexico	(post ? 1889)	H	Qld., N.S.W.	Allen, 1953	No
				S.A., W.A.	Ferguson Wood & Allen, 1958	No
					Wisely, 1958	No
					as W. cucullata Banta, 1969a; b	No
					Brock, 1985	No
HYDROZOA .. (Anemone)						
Bougainvillia ramosa van Beneden	Northern hemisphere	1918 or earlier	H	N.S.W.	Briggs, 1931	No
					Allen, 1953	No
POLYCHAETA .. (Worms)						
1. Hydroides norvegica Gunnerus	European coasts	1885	H	Australia generally	Haswell, 1884 (in Allen, 1953)	No
2. Mercierella enigmatica Fauvel	India	1932	H	N.S.W.	Allen, 1953	No
		1938	H	W.A.	Monro, 1938 (in Allen, 1953)	No
			?T	Southern Australia	ten Hove & Weerdenburg, 1978	Yes

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENC[E] SPECIMEN STATED A[S] LODGED
3.	Boccardia proboscidea Hartman	Japan or Eastern North Pacific	1977	T or H	Vic.	Blake & Kudenov, 1978 (in Carlton, 1985)	Yes
4.	Polydora ciliata Johnston	Europe	? 1885	U	N.S.W.	Haswell, 1885	No
			1972	U	W.A.	Day, 1975	?
5.	Pseudopolydora paucibranchiata (Okudu)	Japan, New Zealand or Eastern North Pacific	1973	T or H	N.S.W.	Blake & Kudenov, 1978	Yes
			1975	T or H	Vic.	Blake & Kudenov, 1978	Yes
						Carlton, 1985	No
			1979	?	Vic	Dorsey, 1982	No
			1979	?	W.A.	Hartmann-Schröder, 1981	Yes
			1979	?	S.A.	Hutchings & Turvey, 1984	Yes
	MOLLUSCA .. (Shellfish) Gastropoda .. (Snails & Slugs)						
6.	Aeolidiella indica Bergh	Japan, New Zealand, South Africa, Mediterranean or New Zealand	?	H or T	N.S.W., Qld.	Willan & Coleman, 1984	?

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
	Janolus hyalinus (Alder & Hancock)	Europe ?	1958	H	Vic.	Burn, 1958 as Janolus hyalina Miller & Willan, (in press)	? ?
8.	Maoricolpus roseus (Quoy & Gaimard)	New Zealand	Between 1920's-1940's	O	Tas.	Greenhill, 1965 Dartnall, 1969 Turner, 1983	Yes No No
9.	Okenia plana Baba	Japan	1977	H	N.S.W., Qld. Vic.	Willan & Coleman, 1984 R. Burn (pers. comm.)	? ?
10.	Polycera capensis (Quoy & Gaimard)	S. Africa	1927	H	N.S.W.	Allan, 1932, as Polycera conspicua Thompson, 1975 Burn, 1978 Willan & Coleman, 1984	Yes No No ?

SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
Polycera hedgpethi Marcus	California	1973	H	N.S.W.,	Willan & Coleman, 1984	?
		1973		Vic.		
		1970's		W.A.	R. Burn (pers. comm)	?
Thecacera pennigera (Montagu)	Unknown	1951	H	N.S.W.	Allen, 1953 Allan, 1957 Willan, 1976 Burn, 1978 Willan & Coleman, 1984	? No No Yes ?
Zeacumantus subcarinatus (Sowerby)	New Zealand	1920's	U	N.S.W.	Finlay, 1927 Iredale, 1936 as *Zeacumantus subcarinata*	No Yes

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
	Bivalvia .. (Clams)	Japan	1947	D	Tas., W.A.	Thomson, 1952	No
12.	*Crassostrea gigas* (Thunberg)		1953	D	Vic.	Thomson, 1959	No
			? 1961	U	N.S.W.	Medcof & Wolf, 1975	Yes
			mid 1970's	D	S.A.,	Coleman, 1986	No
			1985	U	Qld.		
			1986	U	Vic.	Coleman & Hickman, 1986	No
13.	*Musculista senhousia* (Benson in Cantor)	Pacific coast of Asia	1982	H, T	W.A.	Willan, 1985b	Yes
						Slack-Smith & Brearley, (in press)	Yes
14.	*Neilo australis* (Quoy & Gaimard)	New Zealand	1965	O	Tas.	Greenhill, 1965	Yes
						Dartnall, 1969	No
15.	*Ostrea lutaria* Hutton	New Zealand	1880's	D	Tas.	Dartnall, 1969	No
						Sumner, 1974	No

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
	Paphirus largillierti (Philippi)	New Zealand	1950's or earlier	O	Tas.	Greenhill, 1965 Dartnall, 1969	Yes No
17.	Perna canaliculus (Martyn)	New Zealand	? 1876	O, H	Tas.	May, 1923 Dartnall, 1969 as Mytilus canaliculus Lucas, 1980	No No No
18.	Theora lubrica Gould	Pacific coast of Asia	1971	T	W.A.	Chalmer et al.,1976 Slack-Smith & Brearley,(in press)	No No
	Polyplacophora .. (Chitons)						
19.	Amaurochiton glaucus (Gray)	New Zealand	? 1910	O	Tas.	May, 1923 Dartnall, 1969	Yes No

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
20.	BRACHIOPODA (Lamp shells) <u>Terebratella inconspicua</u> (Sowerby)	New Zealand	?1901	O	Tas.	Tate & May, 1901 Lodder, 1902 as <u>Terebratella rubicunda</u>	No
						Dartnall, 1969 as <u>Terebratula inconspicua</u>	No
21.	CRUSTACEA Cirrepedia .. (Barnacles) <u>Balanus improvisus</u> Darwin	Atlantic coasts	?1940's	H	"Southern Australia"	Bishop, 1951	?No
22.	<u>Megabalanus rosa</u> (Pilsbry)	Japan	1981	?H	W.A.	Jones, in prep.	?Yes

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENC SPECIMEN STATED A. LODGED
	Megabalanus tintinnabulum (Linnaeus)	Cosmopolitan	1949	H	W.A.	Jones, in prep.	Yes
24.	*Notomegabalanus algicola* (Pilsbry)	South Africa	1943	H	N.S.W.	Allen, 1953 as *Balanus algicola*	?
	Mysidacea .. (Shrimps) *Neomysis japonica* Nakazawa	Japan	1977	T	N.S.W.	Hutchings, 1983	Yes
	Isopoda .. (Slaters) *Eurylana arcuata* (Hale)	New Zealand or Chile	1925	H or T	N.S.W., S.A.	Bowman *et al.*, 1981 Hutchings *et al.*, 1986a as *Cirolana arcuata* Bruce, 1986	Yes Yes Yes

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENC. SPECIMEN STATED A. LODGED
25.	*Cirolana hardfordi* (Lockington)	West coast of U.S.A.	1972 1980	H	N.S.W., W.A., Vic.	Bruce, 1986	Yes
26.	*Paracerceis sculpta* (Holmes)	California U.S.A., Brazil, Mexico or Hawaii	1975	H	Qld.	Harrison & Holdich, 1982b	Yes
27.	*Paradella dianae* (Menzies)	California U.S.A., Brazil, Puerto Rico or Marshall Islands	1971 1980	H H	Qld., W.A.	Harrison & Holdich 1982a	Yes
	Sphaeroma serratum (Fabricius)	Occurs widely	1980	H	W.A.	Holdich & Harrison, 1983	Yes
	Sphaeroma walkeri Stebbing	Indian Ocean	1927 1967	H	N.S.W., Qld.	Carlton & Iverson, 1981 Harrison & Holdich, 1984	? Yes

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENC SPECIMEN STATED A. LODGED
	Decapoda .. (Crabs & shrimps) Cancer novaezealandiae (Jacquinot & Lucas)	New Zealand	1880-1930	O	Tas.	McNeil & Ward, 1930	Yes
			?	?	Vic.		
29.	Carcinus maenas (Linnaeus)	Europe	1900	H	Vic.	Fulton & Grant, 1900; 1901	?No
		Unknown	1976; 1980	U; H	S.A.	Zeidler, 1978;	?No
						Rosenzweig, 1984	Yes
		Unknown	1965	U	W.A.	Zeidler, 1978	?No
30.	Halicarcinus innominatus Richardson	New Zealand	1926	O, H	Tas.	Lucas, 1980	Yes
						Dartnall, 1969	No
31.	Palaemon macrodactylus Rathbun	China, Korea, Japan, West coast of U.S.A.	1979	U	N.S.W.	R. Buckworth (unpublished)	Yes

	SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
	ECHINODERMATA .. (starfish, sea urchins, sea cucumbers)						
	Patiriella regularis (Verrill)	New Zealand	1930-1952	O	Tas.	Dartnall, 1969 Turner, 1983 Turner, 1986	Yes Yes ?Yes
	ASCIDIACEA .. (Sea squirts)						
33.	Molgula manhattensis (De Kay)	North Atlantic	1967 1975	H H	Vic., Qld.	Kott, 1976 Kott, 1985	Yes Yes No
34.	Styela clava Herdman	North western Pacific or Europe	1972	H	Vic.	Holmes, 1976 Kott, 1985	No Yes
	Styela plicata (Lesueur)	Widespread	?1878	H	N.S.W. subsequently reported from W.A., S.A., Qld.	Kott, 1985	Yes

SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
VERTEBRATA Pisces .. (Fish) Acanthogobius flavimanus (Temminck & Schlegel)	Japan	1971	T	N.S.W.	Hoese, 1973 Middleton, 1982 Bell et al., in prep.	Yes ?No No
Tridentiger trigonocephalus	Japan	1973	T	N.S.W. W.A., Vic.	Hoese, 1973 Paxton & Hoese, 1985	Yes Yes
Lateolabrax japonicus (Cuvier)	Japan	1982	T	N.S.W.	Paxton & Hoese, 1985	Yes
35. Salmo trutta Linnaeus	Europe and western Asia	1864	D	Tas.	Merrick & Schmida, 1984	?

SPECIES	POSSIBLE ORIGIN OF INTRODUCTION	POSSIBLE DATE OF OF INTRO.	PROBABLE MEANS OF INTRO.	NEW LOCATION	REFERENCE	REFERENCE SPECIMEN STATED AS LODGED
Sparidentex hasta (Valenciennes)	West coast of India & Persian Gulf	1985	T	W.A.	Bodeker, 1985 Harvey & Beard, 1985 Anon., 1985	Yes Yes No

KEY TO PROBABLE MEANS OF INTRODUCTION
H = Hull, fouling spp.
U = Uncertain
D = Deliberate
T = Ballast tanks
O = With oysters

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Footnotes for checklist of marine species introduced to Australia

We have attempted to locate specimens in museums to try and confirm the reported introduced species, but in some cases no specimens could be located. The results of these searches are indicated in the table. Rarely did the author, initially reporting the introduction, indicate reference material was deposited in a museum, for subsequent verification. This is especially true of the older records.

Polychaeta

1. Hydroides norvegica Gunnerus

It seems likely that the Australian records are incorrect identifications. A recent revision of all the serpulids held by the Australian Museum by Dr. H. ten Hove of the Zoölogisch Museum, Amsterdam found no specimens of H. norvegica in the extensive Australian Museum holdings. Hydroides norvegica has often been confused with Hydroides elegans (Haswell) (Zibrowius, 1971; ten Hove, 1974). In an extensive revision of the genus Hydroides by Zibrowius (1971), H. norvegica was found to be restricted to the Atlantic and Mediterranean, whereas H. elegans typically a harbour fouling species occurs throughout the tropics and occurs in Australia. The two species are very similar morphologically, but differ in the structure of the collar setae and in the composition of the tube.

2. Mercierella enigmatica Fauvel

A serpulid species which was originally described from Normandy, France and has since been reported from a wide variety of localities. Ten Hove and Weerdenburg (1978) undertook an extensive study of many of the records of

Mercierella enigmatica and found that all the tropical records of this species could be assigned to one of the following species: -

Ficopomatus macrodon Southern, which occurs in brackish waters adjacent to the Gulf of Bengal and the Gulf of Siam.

Ficopomatus miamiensis (Treadwell), which is restricted to the Atlantic tropical and subtropical areas in northern and middle America.

Ficopomatus uschakovi (Pillai), which occurs in eastern Australia, north of Sydney and in Western Australia at Carnarvon.

However, ten Hove and Weerdenburg (1978) did confirm that Mercierella enigmatica occurred in temperate areas in the southern hemisphere. They suggest that these temperate southern hemisphere records including those in southern Australia may be the result of transport via ballast water. This taxonomic confusion highlights the problems in accepting identifications in the literature at face value.

3. Boccardia proboscidea Hartman

Blake and Kudenov (1978) note only that their records of this species from Port Phillip Bay, Victoria, are the first record of this species from the southern hemisphere. Carlton (1985) considers this to mean it is an introduction. Carlton suggests ballast water transport as a possible dispersal mechanism and boring or fouling of ships hulls as alternative possible dispersal mechanisms. Subsequently, the species has been recorded from the northwestern shores of Port Phillip Bay (Dorsey, 1982), the western coast of Eyre Peninsula (Hutchings and Turvey, 1984) and from Fremantle, Western Australia (Hartmann-Schröder, 1981). Petch (pers. comm.) has recorded it from Victorian sewage outfalls of Black Rock near Connewarre, Anglesea, Lorne, Apollo Bay, Warrnambool, Port Fairy, Portland, and from Gunnamatta Beach on the Mornington Peninsula. He has also found it amongst Galeolaria colonies from Wye River and Flinders. Petch (in mspt. to be submittted to the Australian Journal of Marine and Freshwater Research) further suggests that this species is a recent migrant to SE Australia. In 1978, it was known to occur only around the Werribee Sewage treatment farm, on the shores of Port Phillip Bay, whereas now it occurs widely throughout Victoria. Petch (in mspt. to be submitted to Zoological Journal of the Linnean Society) has studied all these Australian populations as well as material from the west coast of the U.S.A. and Japan and can find no morphological variation between these populations. However, he is planning to undertake a comparative electrophoretic study of populations of the species in Australia and in California, USA, to test whether or not they are the same species, or if they represent sibling species. This study will then facilitate the discussion as to how B. proboscidea or a closely related species arrived in Australia.

4. Polydora ciliata Johnston

Neither Haswell (1885) nor Day (1975) record this species as an introduction. Day (1975) could not be sure of his identification as he had only one incomplete specimen. Blake and Kudenov (1978) in their extensive revision of spionids from SE Australia did not record P. ciliata as present. Haswell's material has not been located so his record must be considered dubious.

5. Pseudopolydora paucibranchiata (Okuda)

Blake and Kudenov (1978) note that this species has possibly been introduced to Australia, but give no dispersal mechanism. The species was originally described from Japan. Carlton (1985) suggests that ballast water transport and boring or fouling of ships hulls are possible dispersal mechanisms. Subsequently, the species has been recorded from South Australia and other SE Australian localities (Hutchings and Turvey, 1984) and from several sites (Lake Merimbula, Jervis Bay, Port Hacking, Hawkesbury River) along the N.S.W. coast. The apparent disjunct distribution of this species may be an artifact, as the polychaetes of much of the Pacific region are poorly known. None of the workers recording this species from Australia have been able to examine Japanese material of the species, so it is possible that the species has been misidentified. The species was originally described from Japan.

Species 1-5 are all small polychaete species which could easily have also been transported on oyster shells, fouling organisms on ships as well as via ballast water.

Mollusca

6. *Aeolidiella indica* Bergh

The taxonomic status of this species has been questioned. We have included it as an introduction to Australia on the advice of Dr. R.C. Willan. However, Dr. W.B. Rudman considers this to be a widespread Indo-West-Pacific species whose Australian distribution is entirely natural.

7. *Janolus hyalinus* (Alder & Hancock)

Burn (1958) in a paper dealing with Victorian nudibranchs does not record this species as an introduction and makes no comment on how a probable European species occurs in Victoria. It is included on the advice of Dr. R.C. Willan, whose paper (Miller and Willan, in press) discusses this introduction.

8. *Maoricolpus roseus* (Quoy & Gaimard)

Greenhill (1965) in her paper on Tasmanian molluscs notes that this species was not recorded in previous collections made from the area. She suggests that the species probably became established between the 1920's and 1940's in Tasmania. The earliest collection record is from 1963. Dartnall (1969) indicates that the dispersal mechanism was probably with oysters brought to Tasmania from New Zealand. Turner (1983) supports this. Specimens collected as recently as March, 1986 are held in the Tasmanian Museum's collections (E. Turner, pers. comm.), so obviously this species has successfully colonised some areas of Tasmania.

9. *Okenia plana* Baba

This species has also been recorded from California and New Zealand (Willan and Coleman, 1984). We have noted that it is probably a Japanese species on the advice of Dr. R.C. Willan. Mr. R. Burn has told us that the species also occurs in Victoria and that it was first collected in New South Wales in 1977.

Willan and Coleman (1984) note that the closely related *O. pellucida* Burn, may have achieved its patchy distribution through shipping. This is probably the case, however we have not recorded it as an introduction to Australia in view of its limited overseas distribution (confined to New Zealand).

10. *Polycera capensis* Quoy and Gaimard

Willan and Coleman (1984) reported the Australian range of this species as being from Broken Bay to Kiama (N.S.W.). Hutchings *et al*. (1986a) reported this species from Twofold

Bay, but at that time did not realize it had previously been noted as an introduction to Australia by Willan and Coleman (1984).

11. Polycera hedgpethi Marcus

Willan and Coleman (1984) also record this species from South Africa and New Zealand. We have noted that its probable origin is California on the advice of Dr. R.C. Willan. Mr. R. Burn has indicated to us that the first N.S.W. and Victorian specimens were collected in 1973, and it was also recorded from Western Australia at about the same time.

12. Crassostrea gigas (Thunberg)

See case history.

13. Musculista senhousia (Benson in Cantor)

See case history.

14. Neilo australis (Quoy & Gaimard)

Greenhill (1965) does not give a dispersal mechanism for the introduction of this species to Tasmania from New Zealand. It seems likely that it may have been transported with shipments of oysters from New Zealand as with the other cases cited here and suggested by Dartnall (1969). It is not well represented in the Tasmanian Museum's collections, the most recent record being from 1977 (E. Turner pers. comm.).

15. Ostrea lutaria Hutton

Two distinct species of oyster, O. angasi and O. lutaria have often been confused in the literature and this causes some problems in interpreting the evidence for the introduction of

O. lutaria into Australia.

Dartnall (1969) records that O. angasi was the oyster transported from New Zealand to Australia. However Powell (1979) lists O. angasi as one of the species that O. lutaria was often referred to. Ostrea lutaria is a New Zealand species, whilst O. angasi occurs naturally in Australia. Sumner (1974) suggests that relict populations of O. lutaria may exist in Tasmania, however our enquiries have failed to substantiate this.

Another species of oyster has been introduced into Tasmania Saccostrea commercialis this time from the mainland. Sumner (1972) notes that attempts were made to breed oysters from New South Wales in Tasmania during the 1880's. Presumably these were the Sydney rock oyster Saccostrea commercialis (Iredale and Roughley). This species has not been found alive in southern Tasmania for most of this century, however in January 1986 a population was found at Puncheon Head Island, Franklin Sound, Furneaux Group (E. Turner, pers. comm.). This represents a considerable range extension for the species. It is interesting to note that these recent Tasmanian records of S. commercialis are close to Flinders Island, a domestic port. An introduction by shipping from mainland Australia is possible, either in ballast water or by ship fouling. However, dispersal by natural means or an alternative man aided mechanism is also plausible.

16. Paphirus largillierti (Philippi)

Greenhill (1965) notes that this species was well established in Tasmania by 1963, and some specimens were 8 to 10 years old when collected. The Australian Museum has specimens collected from Tasmania in 1953 (P. Colman, pers. comm.). This supports Greenhill (1965) who suggests earlier workers may have confused the identity of this species. Greenhill

(1965) does not give a dispersal mechanism, though, it is probable that P. largillierti was introduced to Tasmania with shipments of O. lutaria as with other cases cited here and suggested by Dartnall (1969). It is well represented in the collections of the Tasmanian Museum, being most recently recorded in November 1985 (E. Turner, pers. comm.).

17. Perna canaliculus (Martyn)

May (1923) noted that this species was rare and may have been introduced from New Zealand, but did not suggest a dispersal mechanism. Dartnall (1969) repeated May's record and discussed the possibility that the import of oysters from New Zealand could be the dispersal mechanism for a number of introductions including P. canaliculus. It seems unlikely that this was the mechanism for the introduction of P. canaliculus however, as specimens collected from Birdport, Tasmania dated 1876 are held at the Australian Museum (P. Colman, pers. comm.). The importation of New Zealand oysters apparently did not occur until the mid 1880's (Dartnall, 1969; Sumner, 1972). Lucas (1980) notes that P. canaliculus may have been introduced, alternatively, through ship fouling. In any event it does not appear to have become well established, if at all, as no specimens are held in the collections of the Tasmanian Museum (E. Turner, pers. comm.).

18. Theora lubrica Gould

Chalmer et al. (1976) and Slack-Smith and Brearley (in press) note that this is a recent arrival in Western Australia but do not record it as an introduction or give a dispersal mechanism. Powell (1976) felt that its presence in New Zealand was more likely to be the result of a natural dispersal rather than an introduction involving shipping. Willan (1985b) argues against this. If it is an introduction to Australia the likely dispersal mechanism would appear to be ballast water as this is an infaunal species and not an encrusting mollusc.

Powell (1976) notes that Theora fragilis (A. Adams) (as Neara fragilis) which has previously been widely recorded from Australia is a possible synonym of T. lubrica. We have been unable to verify this, and it needs to be resolved by future workers.

19. Amaurochiton glaucus (Gray)

There are numerous specimens of this animal in the Tasmanian Museum's collections dating from 1910 to March, 1985, (E. Turner, pers. comm.).

Brachiopoda

20. Terebratella inconspicua (Sowerby)

This species does not appear to have become established, there are no records of it in collections held by the Tasmanian Museum (A. Green, pers. comm.) or in the Australian Museum (P. Colman, pers. comm.) or other collections held in Australia (J. Richardson, pers. comm.). We suggest that the original identification may have been incorrect or else that the species failed to establish self-sustaining populations.

Crustacea

21. Balanus improvisus Darwin

Bishop's (1951) conclusions are somewhat speculative. There have been no records from Australia to confirm B. improvisus was introduced here (Allen, 1953; Jones, in prep.).

22. Megabalanus rosa (Pilsbry)

Allen (1953) noted that aircraft carriers and other vessels returning to Australia from service in Japanese and Korean waters carried this species as well as Balanus albicostatus Pilsbry and Megabalanus volcano (Pilsbry) although he does not record where these ships docked or the presence of any of these species on the coastline.

Jones (pers. comm.) is undertaking a review of the barnacles occurring in Australia. Megabalanus rosa has been recorded from Port Hedland and Shark Bay, Western Australia by Jones (in prep.), who suggests it is an introduction. Both Port Hedland and Carnarvon (situated in Shark Bay) are international ports.

The introduction of M. rosa to Western Australia appears to be fairly recent with the first specimens being taken in 1981 (D. Jones, pers. comm.). We have tenatively noted the dispersal mechanism as ship fouling.

It seems unlikely that B. albicostatus and M. volcano became established in Australia, as neither has been recorded here since Allen's original record (D. Jones, pers. comm.).

23. Megabalanus tintinnabulum (Linnaeus)

Apparently early reports (see Allen 1953) of this species from the east coast of Australia may have been erroneous as it is yet to be re-recorded there (Allen, 1953; Jones, in prep.), and no specimens are present in any of the collections of museums along the east coast.

Specimens have however been collected from Western Australia since 1949 (D. Jones, pers. comm.). Jones (in prep.) notes that most of the collection localities in Western Australia are ports and that the species is a well known cosmopolitan species, transported as a fouling organism on ship hulls.

As the species is so widely spread overseas the origin of the Australian representatives could have been from a number of sources. Jones (in prep.) gives the species presently known distribution.

The presence of M. tintinnabulum in Western Australia may be of some concern as it is a noted fouling species overseas.

24. Notomegabalanus algicola (Pilsbry)

Apparently this species is still confined to N.S.W. (Jones, in prep.). Hutchings et al., (1986a) found it commonly at Twofold Bay during sampling from 1984-85.

The presence of undetected introduced barnacles in Australia is a distinct possibility. The taxonomy of the group has been largely neglected in Australia, and the group is easily dispersed by man both as adults and juvenile stages. Other well known and widely distributed foulers such as Balanus amphitrite (Darwin) and Chirona amaryllis (Darwin) may have had their Australian distribution at least enhanced by shipping. Basic information to confirm this is lacking at present.

25. Cirolana hardfordi (Lockington)

The few records of this species from Australia are on the whole, limited to ports, however two specimens have been collected from Bass Strait (Bruce, 1986). Bruce did not report it as an introduction to Australia but noted that the species has - "a discontinuous distribution with two disjunct North Pacific populations and a southern Australian population". We have included it as an introduction to Australia on the advice of Dr. N. Bruce. Its association with mussels and collection from a ship's hull (Bruce, 1986) indicates ship fouling as the likely dispersal mechanism.

This species may have the potential to be a pest species. It can rapidly reach high population densities. Cirolana hardfordi is known as a voracious scavenger and has been implicated as a possible predator (Johnson, 1976). A similar species is known to attack fish (Stepien and Brusca, 1985).

26. Paracerceis scultpa (Holmes)

Harrison and Holdich (1982b) cite trans-Pacific shipping as the likely vector for the introduction but give no further details. Ship fouling appears the likely dispersal mechanism in view of the details on the natural history of this species as given by Carlton and Iverson (1981).

27. Paradella dianae (Menzies)

Harrison and Holdich (1982a) note that this species has only been found in Australia near international ports and it is often associated with fouling organisms. In view of this and the disjunct distribution for the species, as reported by Harrison and Holdich (1982a), we include it as an introduction to Australia.

28. Cancer novaezealandiae (Jacquinot & Lucas)

This species is well represented in the Tasmanian Museum's collections, the most recent record is from November, 1978 (A. Green, pers. comm.). McNeil and Ward (1930) recorded the species from Port Phillip Bay, Victoria though recent surveys of this bay have not recorded it again (Poore et al., 1975).

29. Carcinus maenas (Linnaeus)

See case history.

30. Halicarcinus innominatus Richardson

The most recently collected specimen of this species in the Tasmanian Museum's collection dates from November 1970 (A. Green, pers. comm.).

31. Palaemon macrodactylus Rathbun

See case history.

Echinodermata

32. Patiriella regularis (Verrill)

The earliest records of this species in the Tasmanian Museum's collection date from 1952 (E. Turner, pers. comm.). Turner (1983; 1986) notes that this species appears to be expanding its range in Tasmania at the expense of the native fauna.

Ascidiacea

33. Molgula manhattensis (De Kay)

Kott (1976; 1985) states that populations of this species in Australia may be ephemeral.

34. Styela clava Herdman

Holmes (1976) notes that the larval life of this sedentary species is in the order of twenty four hours. Transport by ballast water to Australia would therefore be unlikely, however the species could be further dispersed within Australia by this mechanism.

Pisces

35. Salmo trutta Linnaeus

This species, the familiar brown trout, has been introduced to many of Australia's inland waters. Only in Tasmania can it also be found in estuaries or inshore seawaters (Merrick and Schmida, 1984).

Individual case histories

a. The introduction and spread of the Pacific Oyster Crassostrea gigas (Thunberg) in Australia

The Pacific oyster, C. gigas, was originally introduced into southern Australia from its native Japan as a replacement for the mud, or native, oyster Ostrea angasi Sowerby (Coleman, 1986). The production of the native oyster O. angasi had declined because it had been overfished in the 1800's (Sumner, 1972; Coleman, 1986). Attempts to cultivate O. angasi in Tasmania and South Australia, using New South Wales culture methods had failed (Wolf and Medcof, 1973-74; Grove-Jones, 1986). The Pacific oyster, Crassostrea gigas was subsequently introduced into Tasmania and Western Australia after the Second World War, in an attempt to revitalise the oyster industry (Ferguson Wood, 1948). It was also suggested that an export canning industry using C. gigas be initiated (Ferguson Wood, 1948).

During the 1950's, disappointing results were obtained from this species introduced into southern Tasmania and Victoria. Subsequently, surviving individuals of C. gigas were found in the Tamar River (northern Tasmania) in the late 1950's and have flourished since (Sumner, 1980b). By the late 1960's C. gigas was found in increasing numbers in New South Wales estuaries (Wolf and Medcof, 1973-4). To account for its sudden reappearance, it was proposed that it had been spread in ballast water via trans shipping but Wolf and Medcof (1973-4), Coleman and Hickman (1986) and Coleman (1986) argue for 'natural' dissemination. This introduced species is not harmful in itself but it is a competitor for the same space as that occupied by the native, New South Wales rock oyster Saccostrea commercialis (Curtin, 1986b). Crassostrea gigas is a vigorous pioneering species and appears to thrive under a great variety of conditions (Wolf and Medcof, 1973-4). The species is easy to culture, grows quickly and has a high meat yield (Wolf and Medcof, 1973-4). Several New South Wales estuaries appear favourable to this species during its post-larval development (Medcof and Wolf, 1975). The Pacific oyster has recently appeared in Port Stephens, which supplies 70% of the oyster spat grown in other (N.S.W.) estuaries (Holiday and Nell, 1985). Thus the spat of C. gigas could easily be transported accidently with S. commercialis into most N.S.W. estuaries (Coleman, 1986).

Coleman (1986) has reviewed the literature on the Pacific oyster in Australia and abroad, and discusses the pros and cons of its presence here. To date, this is the only well known, deliberately introduced marine species which was planned to bring commercial benefits but also has attained the status of a pest species in N.S.W. estuaries, at least according to some authorities.

The adverse consequences perceived with the establishment of C. gigas in New South Wales and Victorian estuaries are: the accidental introduction of other, and sometimes harmful, species; harmful interactions with other native species; loss of aesthetic and amenity value of the environment caused by massive settlement of the oyster in intertidal areas; and inter-breeding or competition between the Pacific oyster and native oyster species (Coleman, 1986; Curtin, 1986b). We will deal with each of these points in turn.

The fear that Pacific oysters will bring "pests, parasites or diseases with them" (Wolf and Medcof, 1973-4) per se is only a quarantine matter for imported adult oysters, not local breeding populations already here (Coleman and Hickman, 1986).

There is no information on whether there are harmful interactions with other native species (Coleman, 1986).

Coleman (1986) has suggested that massive intertidal settlement of C. gigas could lead to loss of the aesthetic and amenity value of this environment. Such nuisance settlement has occurred in British Columbia (Quayle, 1964), New Zealand (Dinamani, 1981; Dromgoole and Foster, 1983) and in Tasmania (Sumner, 1974, 1980b). The 'nuisance' value is caused by the oyster covering the intertidal shoreline such that the setting of nets is difficult or dangerous, fishing lines become entangled amongst the oysters and there is danger of cuts and abrasions by the sharp edges of the oyster. While there may be a reduction in waterfront property values, a new recreational fishery is borne (Coleman, 1986).

Interbreeding between Pacific oysters and the native oysters, Ostrea angasi and Saccostrea commercialis has been reported by Coleman (1986). It is unknown if the hybrids are undesirable (Curtin, 1986b) or whether the genetic mixing in the hybrid offspring will upset hardiness and resistance to disease (Andrews, 1979, in Coleman, 1986).

We have not attempted to enter the discussion on the advantages or disadvantages of cultivating C. gigas, as this is beyond the scope of this study. More information on this subject can be found in Thomson (1952); Willson (1970); Sumner (1979; 1980a, 1981); Anon. (1980; 1984; 1986); Curtin (1986a); Dix (1986); and Nell (1986).

b. The introduction of the bivalve *Musculista senhousia* (Benson in Cantor) in Australia.

A number of recent papers have dealt with the arrival of *Musculista senhousia* in Australasian waters (Willan, 1985a; b; in press; Slack-Smith and Brearley, in press) within the last decade. These papers contain thorough descriptions of the animal as well as discussing the nomenclature, taxonomy, ecology, biology, distribution and introductions for the species. The information below is a summary of these papers.

Musculista senhousia is a bivalve mollusc of the family Mytilidae, which also contains the familiar edible or blue mussel *Mytilus edulis* (Linnaeus). Large specimens of *M. senhousia* are over 2.5cm long. The elongate, inflated shell is delicate and distinctively marked. It is smooth, has a green horny outer covering (which may be lost in dead shells) and has radiating reddish-brown lines at the posterior end (Willan, 1985a; Slack-Smith and Brearley, in press).

Musculista senhousia is flexible in its ecology, being able to adapt to a variety of habitats. It has been reported from the intertidal zone to depths of 20m (Slack-Smith and Brearley, in press). On soft substrates, such as mud, colonies may be formed as individuals secrete tough hair-like threads (byssal threads) for attachment. These become interwoven and trap sediment forming 'nests' or mats (Willan, 1985b; Slack-Smith and Brearley, in press). Such behaviour has led to the common name of 'bag mussel' for this species.

On hard substrates *M. senhousia* is an encrusting species, attaching with its byssal threads but apparently not forming dense colonies (Willan, 1985b; Slack-Smith and Brearley, in press).

Musculista senhousia is indigenous to eastern Asia, it was originally described from China. Slack-Smith and Brearley (in press) cite references which show that the species ranges naturally from the western Pacific coasts of Siberia and the Kurile Islands south to Singapore.

Willan (in press) has commented that an early (1913) record of *M. senhousia* from Queensland, Australia cannot be verified and is likely to be erroneous.

Recent records of *M. senhousia* in Australia date from February 1982 when juvenile specimens were collected in the Swan River estuary, Western Australia. Adult specimens were obtained in January 1983 from the same locality. Subsequent surveys have indicated that it is abundant in much of the estuary and expanding its distribution.

It has also been found outside the estuary close to the entrance. This spread and the persistance of the colonies indicates that reproduction is taking place effectively (Slack-Smith and Brearley, in press). The estuary encompasses the busy international port of Fremantle Harbour. The species has not been reported from anywhere else in Australia.

Musculista senhousia has also been reported by Willan (1985a; b; in press) from Auckland Harbour, New Zealand. Its establishment there between the mid to late 1970's and 1980 is almost exactly the same period as that which is reported for Western Australia.

The sudden isolated nature of these first records, far removed from native shores, and the fact that they are both from major port areas, makes it difficult to conclude they are a result of a natural expansion of the species range. As Willan (1985b) states when referring to a number of molluscs including *M. senhousia* recently found in New Zealand - "It is in fact, difficult to conceive the arrival of these species as anything but man-aided".

Other introductions of *M. senhousia* have apparently occurred overseas. This species was first reported from the west coast of the United States in 1944 and has since established itself and continues to spread (Willan, 1985b). In this case *M. senhousia* is believed to have been brought into the U.S.A. with shipments of Japanese oysters (Slack-Smith and Brearley, in press).

The type of dispersal mechanism leading to the establishment of *M. senhousia* in Australia is not known, although Slack-Smith and Brearley (in press) have suggested transport amongst fouling organisms on ships hulls or water intake pipes and ducts, or alternatively as larvae in the ballast water of bulk cargo ships.

Willan (1985b) has also suggested ship fouling or ballast water as the likely vector for the introduction in New Zealand.

To resolve which of these is the correct dispersal mechanism is perhaps not possible at present as we lack basic information such as the length of the larval life of *M. senhousia* (Slack-Smith and Brearley, in press). However, some general comments can be made;

(i) the likelihood of fouling as a dispersal mechanism has been substantially and continually reduced since World War II with the development of antifouling technology, faster boats and shorter harbour-residence times (Williams *et al*., 1982; Carlton, 1985).

(ii) Carlton's (1985) comments that - "Sea-water ballast is frequently discharged in many technically restricted places", and - "Caution must, therefore, be exercised in assuming where and when ballast water is actually discharged", should be kept in mind in evaluating Slack-Smith and Brearley's (in press) statement that "shipping regulations prohibiting the dumping of ballast water inside the [Fremantle] harbour reduce the possibility of introduction by this means". Furthermore our discussions with the Fremantle Port Authority Harbour Masters Office suggest that no such regulations exist, and that clean ballast water (i.e. believed to be free of petroleum products) is frequently discharged within the harbour limits, though some exchange may take place before entry to the harbour.

(iii) Williams _et al._, (1982) predicted that Western Australia was the state most at risk to introductions by ballast water as it receives over half the total dumped in Australia. This appears to be very accurate when it is considered that in the last decade and a half, almost a dozen exotic marine species have been detected from Western Australia (see checklist of marine introductions to Australia, Table I in this report). The majority of these have been from the Swan River estuary. Ballast water has been suggested as the dispersal mechanism for a number of these additions.

Carlton (1985) has also suggested that ballast water transport may also explain the extension in range of the native bivalve mollusc _Spisula trigonella_ to the Swan River estuary around 1964, against natural current movements, as reported by Wilson and Kendrick (1968). This explanation may also be plausible for the similar extension in range for the gastropod _Nassarius burchardi_ reported by Slack-Smith and Brearley (in press), though a great deal more study is needed to confirm this.

The origins of the colonies of _M. senhousia_ in the Swan River estuary are unknown. Willan (1985b) indicates that the origin of the New Zealand introduction is probably Japan. He cites the amount of shipping received from there and the recent history of the colonisation of New Zealand waters by organisms previously known from Japan as evidence for this. Such an argument may be equally applicable to Australia as we also have a preponderance of bulk trade with that country (Williams et al., 1982). This is clearly demonstrated in the tables of Castles (1986a) showing the amount and origin of overseas shipping received by Australia. At least seven marine species known from Japan have been found in Australia in the last fifteen years (see Table I).

Whatever the origin and mode of introduction of M. senhousia to Australia, its presence is cause for some anxiety. Overseas experience (U.S.A. and New Zealand) indicates that once present, M. senhousia has the ability to rapidly establish dense colonies.

Mat building by this species (as already described) is of particular concern as it has the capacity to radically alter the biota and movement of soft sediments. Colonies of the bag mussel may be so thick as to exclude other infaunal species, stabilize fine sediments and their faeces leads to further sedimentation (Willan, 1985b).

This 'nesting' behaviour is occurring in the Swan estuary with densities as high as 2,600 individuals/m^2, which exceeds those reported from its native shores (Slack-Smith and Brearley, in press).

In conclusion, M. senhousia is another recent addition to the fauna of the Swan River estuary. It has the potential to become a pest and its effects and continued spread will need to be closely monitored.

c. The introduction and spread of Carcinus maenas (Linnaeus) in Australia.

A good general description of this species including its distinguishing characters appears in Joska and Branch (1986). It is included in the keys of Stephenson (1972) to swimming crabs of the Indo-Pacific. In summary, Carcinus maenas is a brachyuran (crab) belonging to the family Portunidae, which contains the swimming crabs. *Carcinus maenas* however is not a recognised swimmer, its hind legs are flattened and tapered to a point, rather than being paddle shaped like the majority of other swimming crabs. Juveniles vary in colour, whilst the adults upper surface is a distinctive green colour. Specimens collected by Hutchings *et al*., (1986a) from Twofold Bay, N.S.W., reached a size of eight centimetres or more in width across the carapace (shell).

Carcinus maenas is known under a variety of common names, including the European shore-crab, North Atlantic edible shore-crab, and green crab. It is native to Europe, but has a wide distribution elsewhere, much of which can be attributed to introductions (Stephenson, 1972; Joska and Branch, 1986).

The first records of *C. maenas* in Australia date from the turn of this century (Fulton and Grant, 1900; 1901). Apparently at this time *C. maenas* was very common in Port Phillip, Victoria, ranging from Frankston to Portarlington. It was not known from elsewhere on the coast.

Previous studies of the crustacean fauna from Port Phillip Bay in 1856 had failed to record this species. This, coupled with its limited distribution, led to the conclusion that *C. maenas* had been introduced to Australia in Port Phillip Bay after 1856, but a number of years prior to 1900.

It is suggested in Fulton and Grant (1901) that the vector for *C. maenas* dispersal to Australia could have been the fouling communities of ships coming from Europe, attracted by the gold rushes of the 1850's - "many of these vessels were far from seaworthy and had been patched up with false bottoms which had become riddled with *Teredo navalis* and were fouled with marine growths, affording ample shelter for the fry and young crabs on their long voyage, which would leave the ship on her coming to anchor".

Another possible dispersal mechanism had earlier been noted by Mr. G.M. Thomson, a crustacean taxonomist who is quoted by Fulton and Grant (1900) as saying - "There is no great difficulty in its being introduced, say in ballast, etc., for it is most abundant in the old country".

It is unclear whether Thomson was referring to solid ballast which had long been used, or ballast water which had recently come into vogue (Carlton, 1985). In either case, this is one of the earliest literature records of ballast as a possible dispersal mechanism for marine animals.

Since that original record of C. maenas in Victoria, the species has considerably extended its geographical range in Australia. Allen (1953) reported that it ranged from Western Port to Mallacoota, Victoria. It now occurs from Port Phillip Bay, Victoria, to as far north as Narooma, New South Wales (Zeidler, 1978), being common at Twofold Bay, New South Wales (Hutchings et al., 1986a). Such an extension of range from a single point is thought to be more characteristic of a colonising species than a native one.

Carcinus maenas has also been recorded from South Australia and Western Australia by Zeidler (1978), and again in South Australia by Rosenzweig (1984). Both these authors state these isolated colonies are unlikely to have resulted from natural dispersal of the species within Australia, but from separate recent introductions.

Rosenzweig (1984) suggests that the introduction vector could have been fouling communities as put forward in Fulton and Grant (1901). However, ballast water as a dispersal mechanism would seem equally plausible, unless it can be shown that the crab tends to favour encrusting habitats such as those found on fouled objects.

The origin of these latest non-indigenous colonies in South and Western Australia may have been from populations already established in Australia or from further overseas introductions.

A similar but more spectacular colonisation by C. maenas occurred in America and is briefly summarised by Vermeij (1981). Overseas experience indicates that the crab does not breed well in areas of high wave action (Joska and Branch, 1986) and is susceptible to cold winters (Vermeij, 1981).

Unfortunately, the factors which may restrict the spread of C. maenas in Australia such as the presence of predators or competitors are an unknown quantity. It is uncertain whether its reproduction here corresponds with that reported overseas. Without some study of the biology of this species in Australia, it is difficult to predict how far it can continue to extend its range and at what rate.

Attention to the continued spread of C. maenas in Australia, and study of it, would be wise for two reasons;

(i) fears expressed by Joska and Branch (1986), that the introduction of this large aggressive predator in South Africa could threaten the existence of a number of native species, appear well founded. They may be equally applicable to the Australian situation and are not to be taken lightly in view of the problems C. maenas caused the American shellfish industry, as reported by Joska and Branch (1986). Carcinus maenas became a pest of the soft shell clam (Mya arenaria) industry based in New England. Investigation by the National Shellfisheries Association showed that C. maenas was responsible for the decline in numbers of clams. The clam harvesters erected fences and put out poison baits to try and stop the crabs getting at the clams, however Joska and Branch (1986) do not report on the success of these measures.

Similarly *Carcinus maenas* is known to attack young oysters (Walford and Wicklund, 1973).

Vermeij (1981) however has stated that in America - "The northward spread of *C. maenas* is not known to have resulted in the extinction or population decline of any other species".

To resolve these conflicting views monitoring of populations of *C. maenas* in Australia should be implemented.

(ii) *Carcinus maenas* in Australia may represent an untapped resource. Joska and Branch (1986) report that it has been a highly regarded food in Europe since the nineteenth century and is still eaten today. Thus it is possible that commercial opportunities exist for the aquaculture or fishing of this species within Australia.

In conclusion, *C. maenas* is a large distinctive crab easily recognised whose presence in Australia poses some questions, and perhaps, problems. More detailed information on the mechanisms by which *C. maenas* is transported may facilitate the restriction of the species.

d. The introduction and spread of *Palaemon macrodactylus* Rathbun in Australia.

Williams *et al.*, (1978; 1982) noted this species as an introduction to South Australia via ballast water. We have not been able to verify these records, and have not included them, though they may well be legitimate.

The only Australian records we know of where voucher specimens were deposited in a recognised institution (and thus can be verified) appear in Buckworth (1979). He records *P. macrodactylus* from an ash dam for Vales Point Power Station, Lake Mannering, N.S.W. Voucher specimens from this study are held at the Australian Museum. A note with the specimens, and in the register, records that they were originally identified as Palaemon serenus (Heller), but specimens from the same sample were checked by Dr. L.B. Holthuis in 1978 and subsequently reassigned to P. macrodactylus.

Carlton (1985) repeated Williams et al., (1978) record and also cited Holthuis (1980) as noting an introduction of P. macrodactylus to Australia. Holthuis (1980) simply states - "Now also found in Australia" and gives no further details on the information upon which this statement is based, though it is likely that he was referring to Buckworth's specimens.

Buckworth (1979) does not discuss a dispersal mechanism for the introduction. Newman (1963) considered transport of this species to San Francisco Bay, U.S.A., via oysters or ship fouling, and rejected both as unlikely for such a subtidal, swimming organism. Newman (1963) proposed that the dispersal mechanism was possibly the sea water system of a ship (i.e. - internal plumbing using sea water).

Carlton (1985) considered that the introduction to San Francisco could alternatively have involved ballast water transport and notes that subsequent introductions to other areas of California may have been the result of an accidental or deliberate release by fishermen using the species for bait.

The shrimp was first known from the Indo-West Pacific (i.e. China, Korea, Japan) (Newman, 1963; Holthuis, 1980). If it is found to occur in international ports in Australia, it would have to be regarded as an animal likely to have been transported via ballast water, with the most plausible origin being Japan.

However Lake Mannering, N.S.W., is not connected with an international port. Therefore, the presence of P. macrodactylus in N.S.W. as reported by Buckworth (1979) remains a mystery at present.

Reports of the species from South Australia need to be thoroughly checked and documented.

e. Introduced Fish in Australia

Currently, five introduced species of fish are known from Australian coastal waters. The gobies, Acanthogobius flavimanus and Tridentiger trigonocephalus, were first reported as common in Sydney Harbour by Hoese (1973). Subsequently, Middleton (1982), found reproductively maturing females and juveniles of A. flavimanus in the Sydney region. Tridentiger trigonocephalus has since been collected from Melbourne and Perth, and also in a seawater tank of an Australian ship in Sydney Harbour (Paxton and Hoese, 1985). The Japanese Sea Bass, Lateolabrax japonicus, was collected in Sydney waters in 1982 and 1983 and this represents the first record from Australia (Paxton and Hoese, 1985). The Sobaity Sea Bream (Sparindentex hasta) has been collected in the Swan River, Perth (Anon. 1985; Bodeker, 1985; Harvey and Beard, 1985). In all cases, entrapment in the ballast water of cargo ships was considered the most likely mode of transportation for their introduction (Anon. 1985; Bodeker, 1985; Friese, 1973; Harvey and Beard, 1985; Hoese, 1973; Paxton and Hoese, 1985).

Exotic freshwater fish are imported into Australia in considerable numbers to support the aquarium trade. The trade includes both salt- and freshwater species of fishes, with many of the fresh water species being cultured (Kohler and Stanley, 1984). Currently between 9 to 12 million fish are imported annually for this aquarium trade (McKay, 1986). Some of the popular aquarium fish are poorly known taxonomically and accurate identification is therefore difficult. With this volume of imported fishes, the task of identification of approved and prohibited fishes is an enormous one, especially when juvenile fishes or mixed consignments are encountered. It is not surprising, therefore, that in recent years a number of prohibited species of fish have been imported into Australia (Hocutt, 1984; McKay, 1984). McKay (1984) has reported 22 species of exotic freshwater fishes established in Australia. Many of these species may have been imported for the aquarium trade and subsequently been released or discarded into natural waterways. However, this is difficult to prove, as there are no records kept of the numbers of individuals and/or species of exotic fish entering Australia. It is possible that some imported marine and/or euryhaline species may have been discarded into the sea and survived, although no cases have been documented.

McKay (1984) suggests that a public education programme to aquaint fish fanciers with the dangers of introducing exotic fish discarded from aquarium tanks into the environment should be implemented. We now have reports of such warnings appearing on the bags of aquarium fish sold in northern New South Wales/Queensland.

<u>Comments on the distribution of algae by man's activities</u>

Williams <u>et</u>. <u>al</u>., (1982) and Carlton (1985) have made mention of the entrainment of planktonic algae in a ships' ballast tank. However, other workers appear to have not considered the possibility of free floating macro-algae in ballast water. At this stage we do not know if ballast water is an important vector for such algae or not, perhaps future studies should at least consider the possibility.

Like the animals, transfer by shipping has long been used to explain the disjunct distribution of algae once an 'alien' species was found. Slow, wooden hulled sailing ships may have dispersed many fouling species before adequate recording of indigenous species began. Modern antifouling technology has probably decreased the chances of dispersal of fouling species, rapid port-turn-around times and fast ships are less conducive to their settlement and survival (Foster and Willan, 1979). The antifouling paints may be good, but they are not perfect. The occurrence of fouling macro-algae, in particular Enteromorpha and Ectocarpus, on conventional antifouling paints has been well documented (see Callow, 1986). Evans (1981) has observed that marine algal cells possess a great plasticity and remarkable capacity to exploit any deficiences, however small, in increasingly sophisticated antifouling technology.

Another method by which marine species can be introduced is via "barges and oil platforms which are towed across the oceans at low speed, their submerged parts are not coated with antifouling paints, and they are moored for long periods in different parts of the world" ... with ... "approx. 14,000m^2 of submerged surface on the floating platform" offered up to support the growth of marine fouling organisms (Foster and Willan, 1979). Oil rigs have been used to explain new records of marine animals in South Africa (Joska and Branch, 1986) and New Zealand (Foster and Willan, 1979). They could also be responsible for transfer up and down the coastline. For example, since 1983, oil rigs from Bass Strait have made at least 3 visits to Eden for maintenance and seaworthy checks.

Secondly, algal spores are known to survive very long periods in total darkness (up to 120 days) before germinating (Moss and Sheader, 1973) and could potentially be transported via ballast water.

In Australia, we have reports of three Rhodophyta algae being introduced into southern Australian waters ... namely Antithamnionella spirographidis, Polysiphonia brodiaei and P. pungens ..." which may well have come on ships' hulls" (Womersley, 1981). This was followed with the first records of three northern hemisphere Phaeophyta (algal) species, Striaria *attenuata*, *Stictyosiphon soriferus* and *Arthrocladia villosa* in the same area (Skinner and Womersley, 1983). In both papers, the introductions were explained by ship fouling ... "since the known Australian localities are near harbours" (Skinner and Womersley, 1983). These papers do not discuss whether they are 'pest' species or have any nuisance value, only that they occur.

Assessment of the volume of ballast water entering Australia and the ports involved

To date we have summarised the existing data on introduced species to Australia and indicated which ones may have been transported via ballast water. As yet, we have not discussed the volume of ballast water entering Australia or the number of Australian ports involved which will put into context the likelihood of ballast water introductions.

No records are kept in the maritime industry of the amount of ballast water which has been or is transported (Carlton, 1985). Such information would be impractical to measure in the field. Gathering the data would be costly and time consuming. The amount of ballast water taken aboard depends on the ship and such variables as prevailing weather conditions (Williamson, 1975).

It is, however, possible to calculate an estimate (with limitations to be discussed) of the amount of ballast water entering Australia based on statistics gathered and presented by the Australian Bureau of Statistics. These statistics show the amount of shipping entering or leaving Australia including a measure of ship size and load condition. Prior to 1 July 1979, the measurement of ship size used was registered net tonnage, this was then replaced by deadweight tonnage (DWT) (Cameron, 1982). These terms can be defined as follows:

Net tonnage

"A volumetric measure consisting of the gross tonnage less the volume of non-earning spaces, e.g. master's cabin, crew accommodation, wheelhouse, galley, etc., and an allowance for machinery spaces" - (Cameron, 1978). This was usually an imperial measure.

Deadweight tonnage (DWT)

"A measure of the total mass (weight) of cargo, fuel, potable water, boiler feed water, ballast, stores, crew and their gear, etc. It is equal to loaded displacement tonnage less light displacement tonnage" - (Cameron, 1978).

Gross tonnage

"A measure of the enclosed internal volume of a ship and its superstructure, with certain spaces exempted. It is also an indicator of the total volumetric size of a ship" - (Cameron, 1978).

Alternative definitions appear in Williamson (1975) and Cameron (1982).

The load condition is recorded as either "with cargo" or "in ballast". "Ships with cargo are those ships which arrived at or departed from an Australian port carrying overseas cargo. This includes ships which carried overseas cargo that was not loaded or unloaded at the port. Ships in ballast are those ships which arrived at or departed from an Australian port without cargo" - (Castles, 1986b).

Williams *et al*., (1982) addressed the question of how much ballast water entered Australia. They based their figures for

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1975/76-77/78 on net tonnage of ships arriving in ballast, noting that these would be a maximum figure. Amount of ballast water entering Australia estimated by this method for 1973/74-78/79 is illustrated in Figure 1. The figures given by Williams et al., (1982) differ slightly from those recorded by Cameron (1980, 1981a) and shown in Figure 1. The reason for this difference may be due to a later revision of the data by the Australian Bureau of Statistics as discussed by Castles (1986b).

More recently, MacDonald Wagner Pty. Ltd. produced a draft EIS for a proposed silica export facility at Shelburne Bay, Queensland. They produced a figure showing the amount of ballast water discharged from Japan into Queensland for 1974-86. Their calculations were based on 40% of the DWT (as indicated by Williamson, 1975) of the ships entering the appropriate ports (D. Ross, of MacDonald Wagner Pty. Ltd. pers. comm.). Williamson (1975) states that ballast amounting to 30% of the DWT is the minimum required to provide adequate stability on unladen carriers.

As there is a direct relationship between DWT and amount of ballast carried, and as DWT is now used by port authorities, we have also used this measure. We have estimated the amount of ballast water as 30% of the DWT of ships entering Australia in ballast. This estimate is a minimum. It was done for the period 1979/80-83/84 by consulting Cameron (1982-1985) and Castles (1986a), and shown in Figure 2.

There are a number of limitations to this estimate that should be noted:

(i) We have assumed that ships in ballast always completely empty their tanks on arrival in Australia.

(ii) Despite (i), the figures are probably an under-estimate of the amount of ballast water received from overseas as in many cases unladen vessels could be expected to carry greater than 30% of the DWT in ballast (Williamson, 1975).

(iii) Ships which are recorded as entering Australia with cargo but carry low density commodities such as cars, or not loaded to their full carrying capacity, may be expected to hold some ballast water (Williamson, 1975). Some exchange of water could thus also occur from these ships.

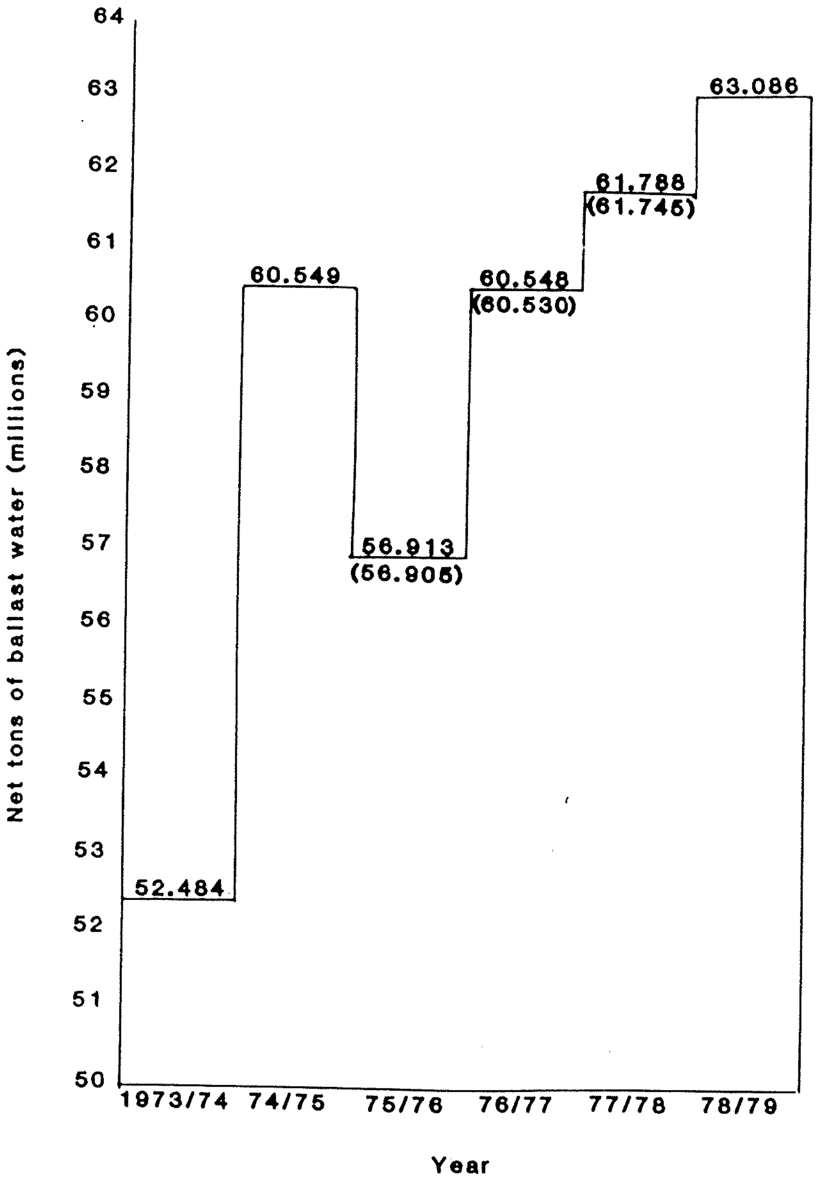
(iv) Not all vessels arriving in Australia are included in the statistics (e.g. naval or survey vessels, or those under 200 registered net tonnes).

(v) The figures do not indicate the true scale of ballast water use in Australia as they do not take into account domestic shipping. Domestic use of ballast water may be of great importance in transporting animals around the country. This should be considered in conjunction with (ii), (iii) and (iv).

Figures 1 and 2 cannot be compared directly, however, both sets of data indicate the following. Firstly of the Australian states, Western Australia receives the greatest volume of ballast water. Secondly, the volume of ballast water being discharged into Australia is continuing to increase, except for a decline during 1980/81-82/83.

Figure 3 shows the number of ships entering Australia in ballast for the period 1976/77-85/86 as documented by Cameron (1981b) and Castles (1986b). Examination of Castles (1986a) shows that, based on the DWT of the international ship arrivals, Western Australia received over a third of the countries ballast water in 1983/84. The figures also show that undoubtedly Japan is the major source of ballast water arriving in Australia today and in the recent past, possibly accounting for over a third of the total.

FIGURE 1. Amount of ballast water entering Australia 1973/74 - 78/79 based on net tonnage of ships arriving in ballast.

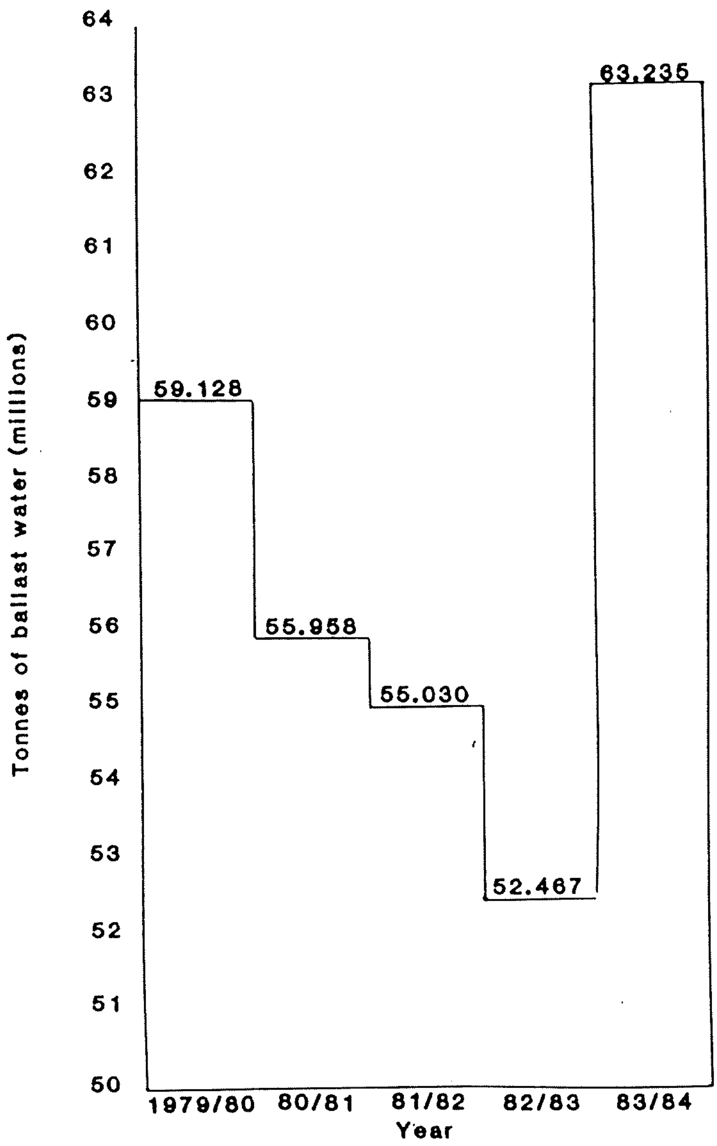


These figures would represent a maximum amount.

The amounts given by Williams et al. (1982) for 1975/76 - 77/78 appear in brackets under those taken from Cameron(1980,81a) for comparison.

FIGURE 2. Amount of ballast water entering Australia 1979/80 - 83/84

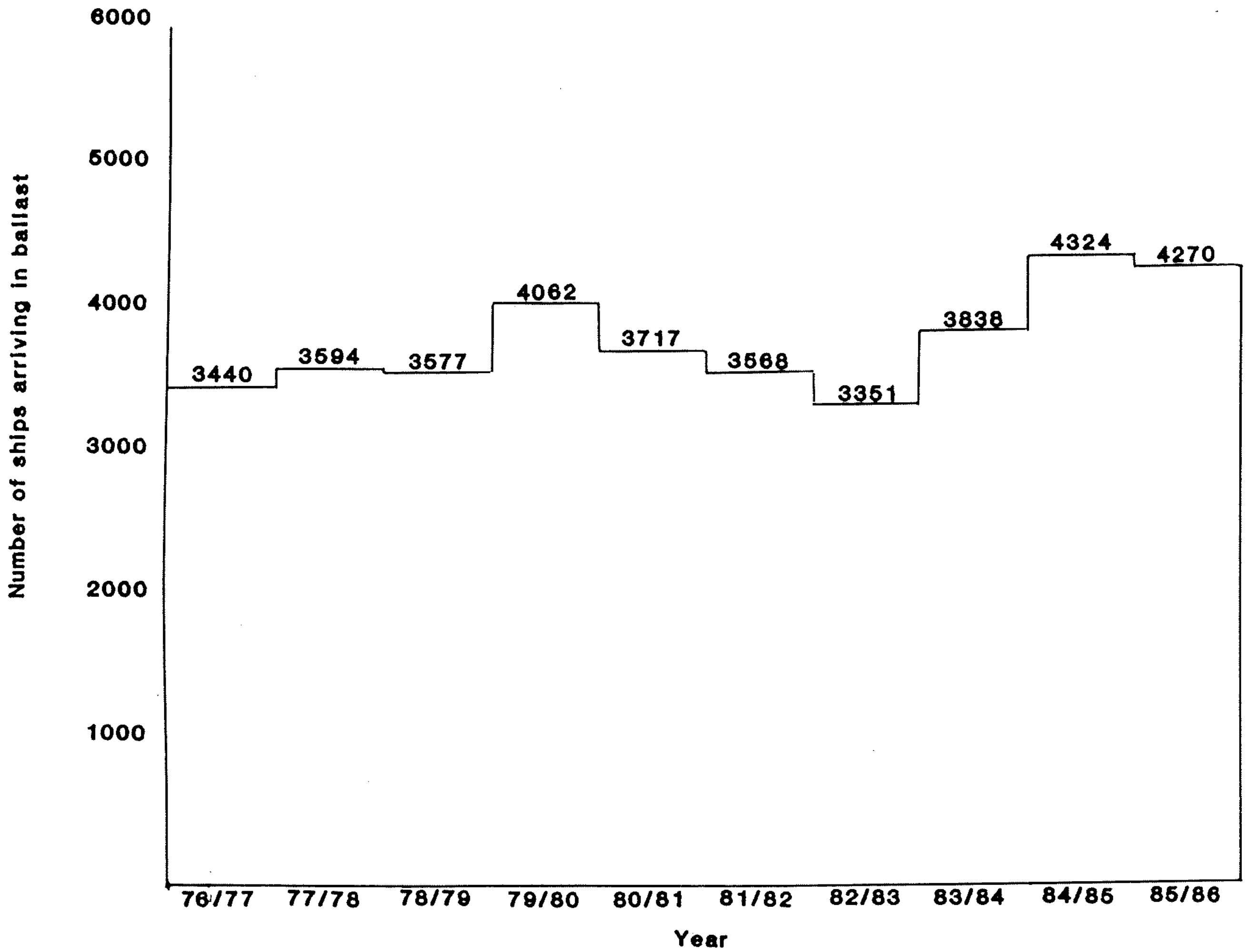
based on the deadweight tonnage of ships arriving in ballast.



These figures would represent a minimum amount.

1 ton = 1.016 tonne

FIGURE 3. Number of ships entering Australia in ballast 1976/77 - 85/86.



Note: The figures given for 1981/82 - 85/86 were calculated from a graph appearing in Castles (1986 b).

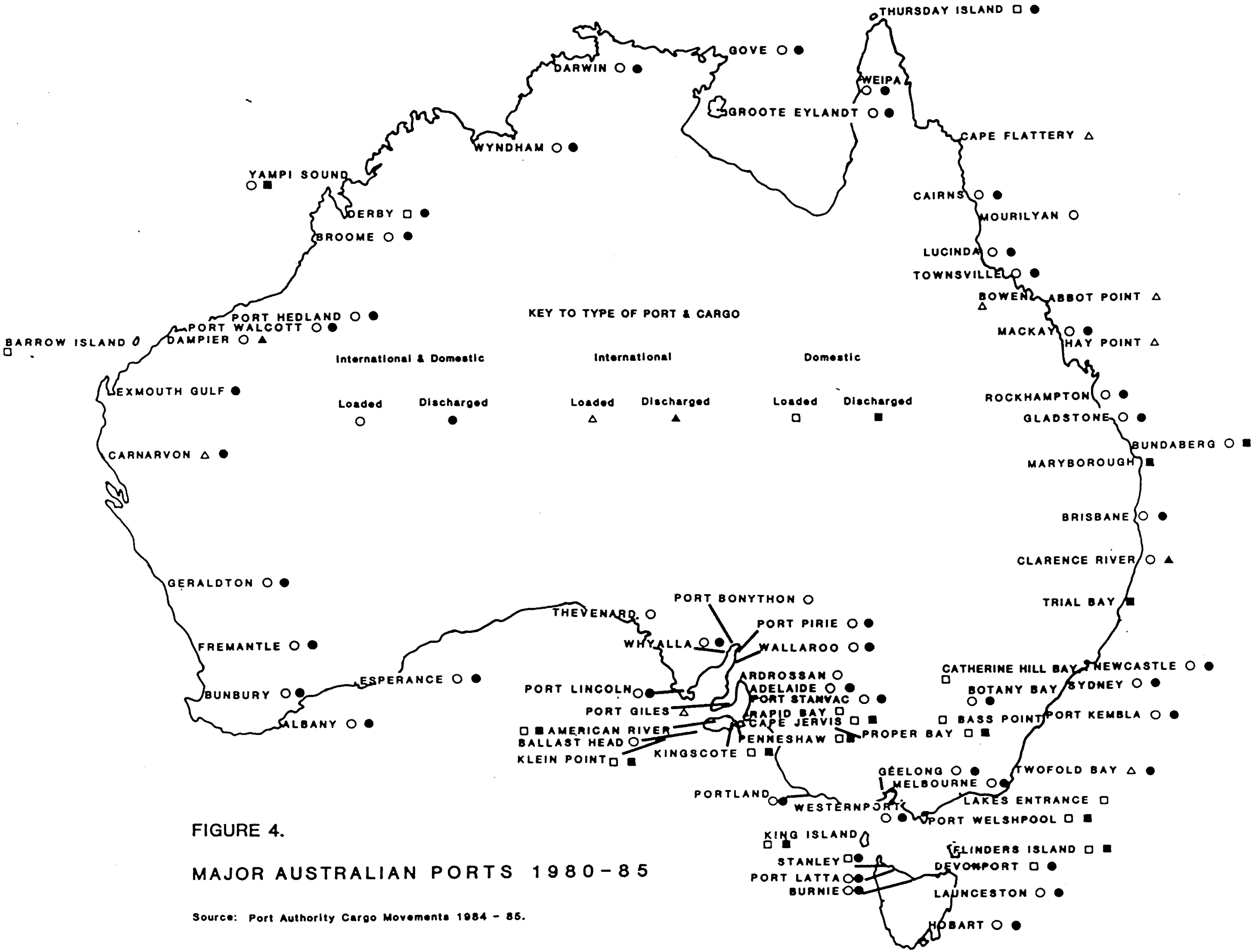


FIGURE 4.

MAJOR AUSTRALIAN PORTS 1980-85

Source: Port Authority Cargo Movements 1984 - 85.

Federal Department of Transport, Sea Transport Statistics, Canberra.

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In Figure 4 we have indicated the major Australian ports operating in the last five years under Federal Department of Transport jurisdiction. It should be noted that other areas may previously have operated as ports and that the activity of a port often changes with time. The figure also indicates the type of port and the shipping it receives.

Ports where cargo is loaded receive the majority of ballast water discharged. The amount each receives depends on the size and frequency of the ships arriving. Ports catering for the bulk overseas export trade where large ships arrive unladen at regular intervals assume particular importance.

Some information on the relative activity of such ports at various times can be gained from the Australian Bureau of Statistics Year Books which show overseas vessel and cargo movements, number of vessels calling, an indication of the size of the ships and amount of cargo moved by them. Also the Port Authority Cargo Movement Sea Transport Statistics provided by the Federal Department of Transport allow a similar analysis of the ports based on the amount of cargo loaded.

Ports which receive the larger amounts of ballast water are probably more at risk to introductions. Unfortunately, in Australia, many of these are in isolated areas where the fauna is least known.

The problem is not potentially limited to ports receiving overseas ships. Ports in Western Australia receiving ballast water from Australian east coast ports may allow introductions of species not normally occurring in the west. Many marine organisms have limited distributions and some species occurring on the east coast of Australia do not naturally occur on the west coast and vice versa.

Ports receiving large amounts of ballast water from areas of similar temperature regimes are probably those most at risk and should be investigated first by the relevant port authorities.

Many factors need to be taken into account in assessing the risk of a port receiving ballast water introductions. The major ones are:

1. Volume of ballast water received, and frequency.

2. Source of ballast water, i.e. if it comes from areas of similar latitude and/or temperature regimes.

3. Hydrological conditions in the mooring vicinity where the ballast water is discharged, and if these processes tend to retain the ballast in a confined area or rapidly disperse it out to sea.

4. The salinity regime of the area where ballast water is discharged, which may vary seasonally, especially in northern Australia.

5. Length of voyage between the port receiving the ballast water and the port where it is coming from.

It is beyond the scope of this study to accurately determine which ports are most at risk, but we would suggest that they are where large volumes of ballast water are discharged. Such ports are often in remote areas of Australia, where the fauna is relatively unknown. Ports such as Sydney and Melbourne are also at risk, but at least the fauna is relatively well known in these areas compared to more remote parts of Australia and surveys should be able to detect new introductions more easily than in less studied ports.

Furthermore, an overseas introduction that occurs at a port receiving both international and domestic shipping could theoretically be passed on to other ports receiving only domestic shipping.

Strategies needed to ascertain if introductions of marine species have occurred in a particular area

Before embarking on costly control measures of sterilising or chemically treating ballast water it is essential that we review whether such measures are necessary and if they are, can they be enforced.

In Table 1, we list the known marine introductions into Australia and in some cases it seems likely that they were introduced via ballast water. However, we have little information if any as to the effect these introductions are having on the natural fauna.

In order to ascertain if any introductions have occurred in a port region and to detect any subsequent introductions and the impact, if any, of these introductions. It is necessary that the natural fauna of the area be known with 'baseline' surveys carried out to document the fauna. Because of the limited knowledge of the marine fauna along much of the Australian coast, this causes many problems which can be minimised.

Initial planning strategies

To identify areas where ballast water introductions are likely to occur. Ballast water is typically taken on board in ports which normally are located in protected bays or estuarine situations. Thus organisms pumped up with the ballast water will typically be small adult organisms or their larval or juvenile stages which become, encrusting or fouling species on wharf piles, jetties or rocks; or estuarine species living in seagrass beds, soft sediments or marine species living in shallow protected bays. These habitats need to be identified within the port area being surveyed. See Figure 5 for habitats sampled in Twofold Bay, N.S.W. by Hutchings _et al_., (1986a).

FIGURE 5 Range of Habitats sampled in Twofold Bay, N.S.W.

- Hard substrata (epifauna)
  - natural
    - intertidal
      - marine
        - sheltered..Murrumbulga Pt.
        - exposed......Munganno Pt.
      - estuarine (oysters)....Nullica River, Fisheries Creek.
    - subtidal
      - sheltered...........Murrumbulga Pt.,
      - exposed................Munganno Pt.,
  - artificial-wharf piles, breakwater................Munganno Pt., Quarantine Bay.
- Soft substrata (infauna)
  - marine
    - shallow, Posidonia (seagrass beds)......Quarantine Bay
    - deep (10-20m)-pipe dredge sampling marine sand....over entire bay
  - estuarine
    - lagoon, Ruppia (seagrass beds).........Fisheries Creek
    - tidal, Zostera (seagrass beds)..........Nullica River, Curalo Lagoon, Shadracks Creek.
    - saltmarsh...........................Fisheries Creek, Curalo Lagoon.

These habitats can be identified using the following sources:

a. Aerial photos available from the relevant State Department - typically 'Lands'.

b. Seagrass maps may be available from fisheries departments. In N.S.W. such maps are available for Department of Agriculture, Fisheries Division (West, et. al., 1985) and wetland maps from Department of Environment and Planning - (82 topographical map overlays produced to accompany the planning instrument: "State Environment Planning Policy 14 - Coastal Wetlands" gazetted in the N.S.W. parliament on the 12 December 1985).

c. Naval charts - showing bathymetry and anchorage sites.

d. Commonwealth Mapping Authority maps of the area indicating location and naming of creeks, bays, etc.

e. On site reconnaissance trip to ground truth aerial photos.

A literature search should be carried out to determine what if any previous studies have been carried out in the area, this may include information on the geology and sedimentology of the area. In Appendix I we have listed the major biological surveys carried out along the Australian coast. We know that this list is incomplete, but it will provide a starting point.

Additional information can be obtained by contacting the relevant state museums, local councils, conservation groups, Department of Planning and Environment (or equivalent), state fisheries (or equivalent) to ensure that all the available literature on the area in terms of published reports, EIS, planning applications are sighted before embarking on the survey.

In some cases the relevant harbour or port authority may be able to provide current and historical data on origins and volume of shipping.

Sampling strategy

Seasonal sampling in each of the major habitats selected should be carried out at least over a 12 month period, as many species occur seasonally. A variety of collecting techniques need to be employed to adequately sample the fauna in each of the selected habitats, see Appendix 2. Detailed collecting of the meiofauna will not be very helpful at the moment in documenting whether any introductions have occurred because of the taxonomic problems involved. Such problems are not restricted to Australia. As a result, no attempt has been made to document introduced meiofaunal species. The survey should concentrate on the fauna where taxonomic expertise is available and on groups where known introductions have occurred, see Table I. All material should be well labelled with precise locality and date of collection given. Most marine material should be preserved in 7% neutralised formalin and subsequently stored in 70% alcohol, and identified as far as possible. However, echinoderms should be preserved in absolute alcohol then transferred 70% alcohol and molluscs are kept in formalin (5% strength for long term storage) - for details of the appropriate methods see Hangay and Dingley, (1985). In Appendix 3, a bibliography is given of the major references useful in identifying the Australian fauna. It is essential that a reference collection, of organisms found, be deposited in a state museum, and registered for easy retrieval and later verification if needed.

Results of the baseline study should be kept on record and easily available for any subsequent study.

A baseline survey of an area is a time consuming exercise but once a detailed inventory of an area is carried out it will enable subsequent surveys to easily pinpoint new successful introduction. Obviously no survey is 100% successful in completely documenting the entire fauna, or in pinpointing any odd individual which has survived introduction. Basically, the interest is in species which have survived introduction and established breeding colonies. In this case, additional studies need to be designed and carried out to investigate if they are having any impact on the native fauna and if control measures are necessary.

Strategies available for the treatment of ballast water

If sufficient evidence can be obtained that ballast water introductions have occurred in Australia and pose a threat to the natural fauna, a series of strategies for the treatment of ballast water have been suggested.

These strategies are based on the preliminary findings of Williams et al., (1982) and on discussions held with people in the maritime industry as to the cheapest and most effective method of killing ballast water biota.

We have presumed that the marine fouling found on ship hulls in the pre-war days (Ferguson Wood and Allen, 1958; Skerman, 1960) is not a consideration here (Allen, 1953; Williams et al., 1982; Carlton, 1985). Rising fuel costs and the need for shorter in-transit times forces the shipping companies to ensure the hulls are kept clean with regular dry docking and to use modern effective anti-fouling paints. Williams et al., (1982) confirms this statement with inspections made of some ship hulls.

Table 2. Outline of suggested ballast water treatements

Treatment	Cost	Safety	Simplicity	Effectiveness	Creates advantage	Creates disadvantage
treated water, stored onshore	capital intensive	depends on biocide used	pumping/ transfer technology needed	100%	responsibility placed on 'donor' countries	prohibitive cost of treatment work at all ports
adding biocide	moderate	reasonable	skilled labour not needed	100% (depends on length of journey)	100% kill of water + mud biota over the length of journey	difficult to police, availability of - and handling - biocide
screening + filtering water intake ultraviolet light (ultrasound, micro screen...)	installing filters	modest	needs regular cleaning of screens	dependent on technology of screen	relatively cheap	effectiveness unknown and uninvestigated
Mid ocean exchange	minimal	depends on weather, during heavy seas no exchange may occur	depends on weather	depends on where exchange takes place	removal of unwanted animals and exchanged for 'harmless' planktonic forms	impossible to police. No effect on mud biota. Depends on weather en route

In Table 2 we have summarised the ballast water treatments which have been suggested.

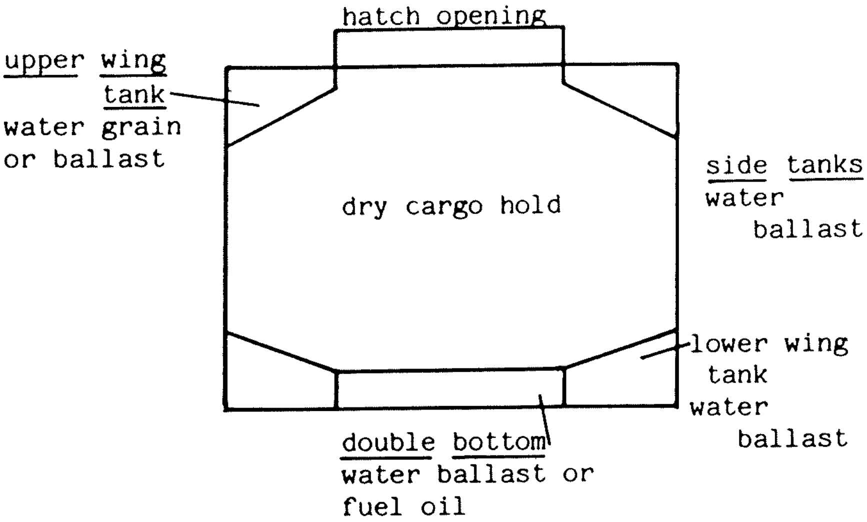
Physical restraints preventing animals being sucked up with the ballast water as it taken on board include the possible use of using a more effective (and very) fine screen on the intake valves currently used to exclude debris. Such screens would have to exclude larvae, copepods, eggs, etc. and probably a mesh size of 500um would have to be used. This procedure would result in slower discharge or uptake, but if the screens are accessible to be cleaned regularly, overall berthing times may not be grossly affected. The screens would also have to be checked regularly for signs of corrosion. It has already been observed that the animals do survive the ballast tank pumps and associated piping, but it is unknown if that passage effects their viability (presumably not since gravity discharge is the norm, Williams _et al._, 1982, p. 15). The screens should be able to exclude animals as well as algal spores and fronds.

Another method, includes discharging the water ashore, where it is treated and subsequently discharged, but costs are prohibitive.

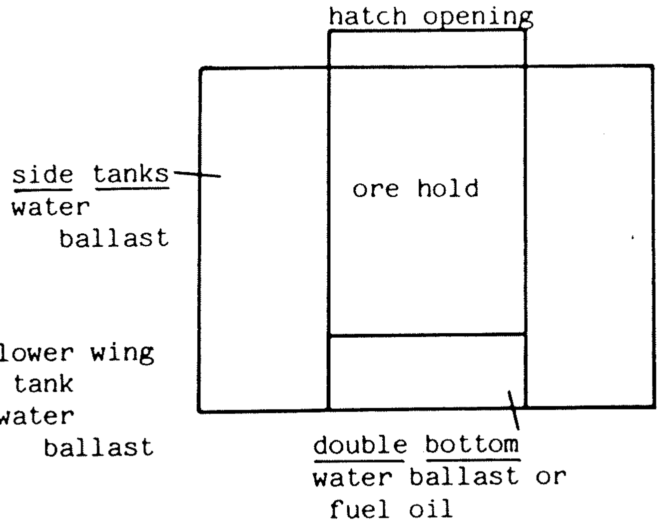
Ultrasound, ultraviolet light or an electrical current could be passed through the water as it is taken on at the inlet valve. As yet, there is no information on its likely effectiveness.

An alternative approach to this is to utilise the findings of Williams _et al._, (1982) that solar heating of the wing ballast tanks (Figure 6) and longer journey time did reduce the number of living animals present in the ballast water.

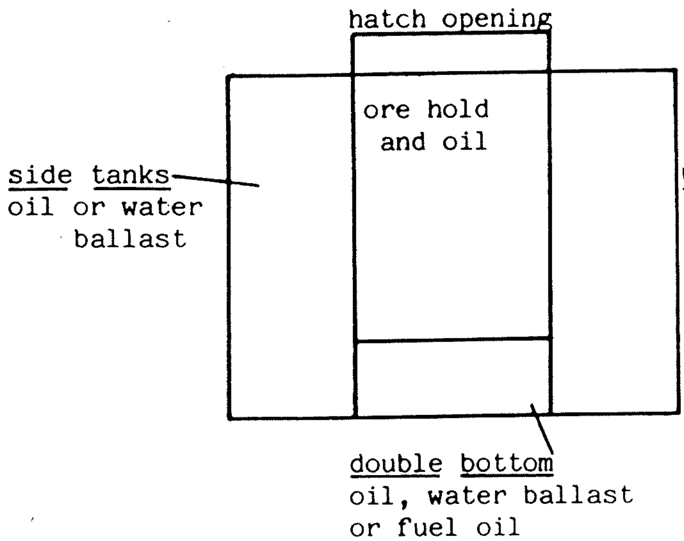
The mid-ocean exchange method is where the encaptured animals are ejected along with the donor-port ballast water, and exchanged with supposedly less harmful mid-ocean planktonic forms during an exchange of ballast water while en route. The overall effectiveness of this exchange appears doubtful for 3 reasons: it has no effect on the mud biota found in the bottom of the ballast tank, and it may be difficult to enforce and there may be some weather conditions in which mid-ocean exchange is not carried out for safety reasons. A specialist would also need to be employed to check if the plankton in the ballast water was mud, oceanic or estuarine.



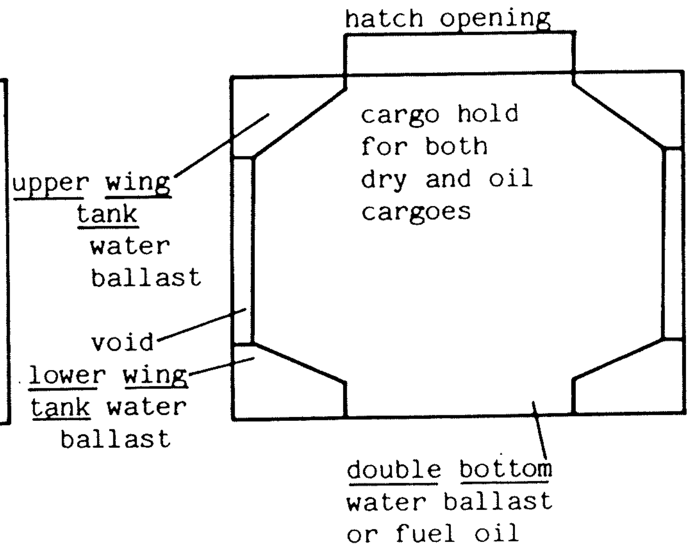
a) General - Purpose Bulk Carrier Cross Section



b) Ore carrier Cross Section



c) Oil / Ore Carrier Cross Section



d) Oil-Bulk-Ore Carrier Cross Section

Fig 6. Typical midship cross-section for different types of cargo ships. (Williamson, 1975)

The use of biocide has the advantage of eliminating all risk from ballast water and mud fauna. Chlorination of the seawater has been suggested as the most suitable and cost effective agent available. Chlorine gas, as used at New South Wales' ELCOM power stations for their coolant water treatment, would be unsuitable. Its usage is technically difficult requiring specialist staff using expensive, unyielding equipment. A result of dissolving chlorine gas is lowering the pH, and any resulting corrosion would be (economically) intolerable. In contrast, sodium hypochloride is easy to use, requiring no specialist training and relatively easier to manage on board. It is supplied at the industrial strength of 12 1/2% w/v and all that is needed is to dispense the required amount.

The effectiveness of biocide depends on when it is added and how effectively it is distributed through the ballast water. There are three possibilities to when it could be administered 1) adding while loading the ballast water 2) or en route 3) or just prior to discharge. The first option has the advantage of maximum time for the biocide to act and it can be well mixed by the force of the incoming ballast water. The second option has less time and would be difficult to enforce. The third option has the minimum time for the biocide to mix and react, but could potentially be enforced by the local port authority.

Williams et al., (1982) provide some details on the concentration of sodium hypochloride which would be required and the costs involved.

Sodium hypochloride added to the ballast water to make a well mixed final concentration of 20 p.p.m. 'free chlorine' would give a 100% sterilization after 24 hours (B. Copper, pers. comm.). At the 1986 bulk price of Australian 35c/L, treatment of 13,500 tonnes of ballast water (the amount of ballast water used by a 45,000 tonne Eden woodchip ship), at a concentration of 20 p.p.m.

free chlorine, would require 2,160 litres sodium hypochloride at a cost of $756, depending on handling techniques. About 20-22 such vessels visit Eden's port in Twofold Bay each year. The cost of sterilizing all these ships per year would cost the shipping agent $15,120-$16,632. A cost benefit analysis, once the method is refined, should determine the exact cost. The environmental effect of discharging 270,000-297,000 tonnes of treated ballast water into a port like Eden is unknown. The effect in an enclosed estuary may have a considerable impact on the fauna. To ensure there is minimal free residual chlorine, a simple "dechlorination" process is available where a reducing agent like sodium thiosulphate or sodium metabisulphite is added to the water (B. Copper pers. comm.). The power-generating stations discharge water with chlorine at 1 p.p.m. into coastal lagoons and lakes. However, no detailed published results on the long term affect this has on the fauna are available (B. Hodgson, pers. com.). The concentration of free chlorine would be easily checked by inspectors using cheap and convenient swimming pool kits. A test of the sterilization's effectiveness could be a visual inspection of the contents of a plankton net hauled repeatedly through the ballast tank.

In remote ports, far from centres of chlorine manufacture in Australian capital cities, it would be more economic to use dry forms like 'tropical bleach' to offset the freight charges. Handling the dry form requires more complicated techniques.

DISCUSSION

In this report we have attempted to review all the available literature on introductions of marine animals into Australia and to assess the possible means by which they were introduced into Australia. Some of these species appear to have been introduced by ballast water however it is very difficult to prove this conclusively. Although we do know from experiments that organisms in ballast water can survive discharge. However, as Carlton (in press) has pointed out the volume of ballast water being discharged into Australian ports is increasing and that the potential for introductions is thereby also increasing.

Williams et al., (1982) concluded that none of the animals identified from ballast water or mud in their studies were likely to be a threat as a competitor, commensal, predator or parasite of an Australian marine species. However, they did qualify their statement by making the point that nominating which species when introduced into a new locality could pose a threat, is a complex question about which little is known. Furthermore, they indicated that many of the organisms not identified in their survey (such as juvenile polychaete worms and molluscs) had the potential to be pests in Australia.

It is this potential of ballast water to introduce marine pests which has alarmed many people. In Australia, Friese (1973) was probably the first to warn of the dangers of an introduction, though Grainger (1973) also reported on it. The study by Williams et al., (1982) increased the awareness in the scientific community of the potential problems associated with the discharge of ballast water into Australian ports. This study also recommended the treatment of ballast water to reduce this problem of introducing exotic species. Further public and scientific interest was aroused with the discovery of more introductions and this has been reflected in the articles of Parr (1984; 1985), Anon. (1985), Bodeker (1985), Harvey and Beard (1985). Paxton and Hoese (1985) have subsequently echoed Williams et al., (1982) call for sterilization of ballast waters to ensure harmful introductions do not occur. Willan (in press) has reinforced this with his call for quarantine at ports and the realisation that a harmful species in the shape of Musculists senhousia may have already arrived, although the means by which it arrived is still being debated.

However, it seems at this stage totally unrealistic to contemplate expensive control measures to eliminate all living organisms in ballast water including those in the sediment of the ballast water tanks. These control measures would not only involve the relevant port authorities in Australia but shipping companies from many countries.

Instead of implementing costly control measures for ballast water, we should be concentrating on documenting introductions via ballast water and other vectors. Secondly, these introductions should be monitored to assess the impact they are having on the natural fauna.

Only then can a well reasoned case be made for the treatment of ballast water and perhaps only at selected ports receiving ballast water from specific locations probably with similar temperature regimes to those of the Australian port. To date, we do not believe that the evidence is available to indicate that any of the introductions reported as arriving via ballast water have subsequently become pests. Nor should the possibility that ship fouling may still be an important dispersal mechanism for introducing marine organisms be overlooked.

The funds which would potentially be paid by the shipping companies to treat their ballast water, should be paid into a fund - as a subsidy to pay for initial baseline studies of the port and for subsequent monitoring to be carried out to document any future introductions. Such baseline studies will not only facilitate the identification of introductions by ballast water or as fouling organisms on the bottom of boats but expand the basic knowledge of the marine fauna of Australia. This will facilitate future research on the Australian marine ecosystem. Providing that the baseline studies are carried out in an organised way with voucher specimens being deposited in a state museum and reports being made available.

Although repeated calls have been made for the sterilisation of ballast water, no reliable methods of obtaining this are currently available (Doyle, 1984-5). All the methods outlined in Table 2 have some problems and research into simple but effective methods should also be implemented as soon as possible.

RECOMMENDATIONS

1. To identify the ports most at risk to introductions.
2. To initiate baseline surveys of these ports, with the reports being widely available and voucher specimens being lodged in the relevant state museum.
3. A regular sampling programme to be established once the baseline survey is completed, to monitor any introductions identified.
4. Studies initiated to investigate the impact these introductions, if any, are having on the natural fauna.
5. These surveys to be partially funded by a subsidy imposed on ships discharging ballast water into the port.
6. If an introduced species is having an impact on the local fauna, then the process of discharging untreated ballast water must be reviewed and the necessary actions taken to avoid further such introductions into Australian ports.
7. Onshore facilities should be available for the discharge of sediment from the bottom of ballast water tanks.
8. Research should be undertaken into methods of 'cleaning' ballast water, i.e. as to the most cost effective and having least impact on the environment.

9. To encourage scientists reporting disjunct distributions to fully elucidate any comments that they may make, regarding introductions and to indicate dispersal mechanisms.

Acknowledgements

In addition to those people acknowledge for their contributions on page 25 and 26, we wish to thank R.J. Williams (Division of Fisheries, Department of Agriculture, New South Wales) for his continued interest and assistance; B. Copper (I.C.I. Chemicals), D. Ross (McDonald Wagner Pty. Ltd.); K. Gotham (Maritime Services Board of N.S.W.), and B. Hodgson (Electricity Commission of N.S.W.) for their co-operation; A. Reid for artwork and P. Dempsey for typing the manuscript.

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APPENDIX I

List of major biological surveys of estuaries or nearshore coastal areas carried out according to State

During the past decade or so a large number of environmental surveys have been carried out throughout Australia. Some of these have been published in the scientific literature and should be easily available. However, many surveys have been carried out to satisfy State or Commonwealth environmental legislation, with an Environmental Impact Statement (EIS) being prepared. The quality of EIS's varies considerable but may provide useful data on the fauna of a particular area. In more comprehensive EIS's, the identification of the animals and plants has been confirmed by the relevant experts and voucher specimens deposited at the relevent state museum/herbarium. Copies of all EIS's within a State are lodged with the Government Department responsible for the environmental legislation. In N.S.W., it is the Department of Planning and Environment. Local councils also have copies of EIS's relevant to their shire. The Environment Centre of N.S.W. has established a comprehensive cross-referenced list of EIS's prepared in N.S.W.. Similar listings are held by co-ordinating Conservation Councils in the other States.

We have not listed the EIS's available for each coastal area but we have listed a random selection of the major published surveys according to State, as a starting point to help facilitate the planning and execution of marine surveys.

New South Wales

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APPENDIX 2 Collecting Methods

Intertidal rocks have species living well-cemented onto the rocks and in amongst crevices and under rocks. General qualitative collecting of a representative of the fauna involves collecting from all these microhabitats, using oyster knifes to scrape off the surface; a hammer and chisel to split open the rocks to reveal crevices where sediment and associated fauna collects; and carefully turning over rocks to collect the fauna and seiving the sand/gravel between boulders and then returning the boulder to its original position. Quantitative collecting involves using transects and collecting all the animals within a quadrat. Drift wood stranded between the boulders may contain wood borers and attached animals.

Many organisms live in amongst algae, tufts of algae or algal holdfasts and should be carefully washed in a container to collect this fauna.

Similar techniques are used underwater using SCUBA gear, with the compound ascidians, kelp holdfasts or coral communities etc. being transferred immediately to plastic bags as they are scraped off the surface, to retain all the animals living cryptically within these habitats.

Intertidal sediment Standard volumes of sediment collected using a hand held corer and sieved through a 0.5mm mesh and all the animals collected from the sieve.

Subtidal sediment Standard volumes of sediment collected using an airlift (Christie and Allen, 1972) and the sediment filtered through a 0.5mm mesh sized bag, and the contents fixed and then sorted under a microscrope for animals. Sorting of animals is facilitated by staining the samples with Rose Bengal at the same time as fixing the samples. All living tissue will be stained pale pink by this vital stain. This is particularly helpful when collecting in seagrass beds.

Mangrove and Saltmarsh habitats

The fauna of mangroves includes infaunal species which live in the sediment; encrusting species on the base of the mangroves and on the pneumatophores, buttress or prop roots; wood boring species living on fallen logs within the mangroves and epifaunal species on the surface on the mud, on mangrove leaves and trunks. For more details see Hutchings and Recher (1982). Each of these habitats needs to be investigated. Similarly in the salt marsh, a limited fauna lives within the sediment, other species predominantly gastropods live on the surface of the mud and in amongst the bases of salt marsh plants. Cryptic species live under any fallen logs or debris trapped in the salt marsh.

Reef habitats

Coral reef substrates provide many habitats for fauna and flora, including sessile organisms living on the substrate, and species which bore into coral substrate, and organisms which cannot themselves bore but utilise the burrows made by borers. A variety of techniques need to be employed see Coral Reef: Research Methods - edited by Stoddart and Johannes (1978).

Pelagic communities

A variety of netting techniques and use of rotenone are needed to collect the fish and mobile crustaceans and cephalopods living in shallow inshore areas, and in seagrasses during high tide.

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APPENDIX 3

Major taxonomic references and general works for common groups found in marine surveys

Note: These are only a starting point and further references may have to be consulted to fully identify the Australian fauna.

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GLOSSARY

While preparing this report it became apparent that certain words have been widely used in the ballast water literature, and we list them here together with a definition of their meaning. We would encourage a standard (scientific) usage between the workers in this field. Such a restriction of terms is useful as it avoids confusion in usage and lengthy qualifying statements when work of this nature is discussed.

For further reading, we recommend chapters 1 of Woods (1974) and Weir (1977); and Lincoln, et. al., (1982).
The following terms are used frequently in the literature:

Biogeography	The study of the geographical distribution of organisms.
Characteristic port assemblage	Species lists taken from port and harbours in many parts of the world showing remarkable similarities in composition, and it may be asked to what extent these species are truly cosmopolitan (Ryland, 1967). The disparate distribution and the occurrence "... in or near harbour areas raises the possibility of its spread by shipping" (Womersley, 1979).
Control	(A term which rarely stands alone and is usually qualified in some way) any action which has, as its objective, the amelioration of the harm caused by pests, and in which man plays some deliberate role. [A more realistic assessment would suggest 'management' rather than 'control'] (Woods, 1974).

Coelenterates	A group of animals consisting of 2 layers of cells including corals, jelly fish and hydroids.
Disjunct	Distinctly separate; used of a discontinuous range in which one or more populations are separated from other potentially interbreeding populations by sufficient distance to preclude gene flow between them.
Dispersal mechanism	A mechanism for the outward spreading of organisms or propagules from their point of origin or release.
Endemic	Local, indigenous, peculiar to a district or native to a special locality and restricted to a particular geographical region.
Exotic	Introduced from a foreign country, not native, extraneous, anything introduced from abroad, alien, an organism or species that has been introduced into an area (or zoogeographic zone).
Geographic range of species	Breeding range
Insular	Pertaining to islands, used of an organism that has a restricted or limited habitat or range.
Macrobenthic	The larger organisms living in the substrate; exceeding 1mm in length.
Meiofauna	The small interstitial animals that pass through a 1mm mesh sieve but are retained by a

	0.1mm mesh.
Niche	"Free biological place" (Walford and Wicklund, 1973), suitable biotope.
Non-indigenous	Not native, exotic.
Phyla	A group of animals, which have been derived from a common ancestral group.
Range expansion	Whereby a species disperses by natural mechanisms into a region where it did not formerly exist.
Setae	Fine bristles or hair like structures.
Vector	Any agency responsibile for the introduction or dispersal of an animal or plant species.