A Review of Exotic Marine Organisms Introduced to the Australian Region.
II. Invertebrates and Algae

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Abstract

The occurrence of exotic marine invertebrates and algae in the Australian region is reviewed, with particular emphasis being placed on those species which might have significant ecological impacts on endemic biota and/or their habitats or on fisheries in this region. All marine and estuarine invertebrates and algae known or thought to have been introduced, either deliberately or accidentally, are listed, together with their probable areas of origin, probable dates and means of introduction, their present areas of occurrence, and general comments on relevant aspects of their biology and status, as appropriate. Those species which might have significant ecological impacts are discussed in some detail, probable pathways for their introduction (particularly ships' ballast water) discussed, and some recommendations made regarding their future control.
Introduction

Until relatively recently, few reports have appeared on introduced marine invertebrates and algae which might have significant ecological impacts on endemic fauna and habitats in the Australian region.

With regard to exotic marine organisms in general, Williams et al. (1978) listed 20 such species which had apparently been
introduced to Australian waters. Carlton (1985), in his worldwide review of marine introductions attributed to the discharge of ships' ballast water, also listed a number of marine organisms which were thought to have been introduced to Australian waters by this means. Carlton (1987) subsequently identified 14 major routes of transoceanic dispersal of introduced species in the Pacific, and listed Australia as one of the major receiver areas. The most recent and comprehensive listing of introduced marine organisms in Australia was that by Hutchings et al. (1987). These authors have also discussed in more detail those species thought to have been introduced into Twofold Bay, southern New South Wales (NSW), in the ballast water of woodchip carriers from Japan (Hutchings et al. 1988).

Some caution needs to be used in interpreting the species listings presented in the above reviews, as the authors have of necessity been obliged to accept the identifications given in the literature they reviewed. In many cases voucher material necessary for confirming these identifications was not available, and as many invertebrate groups are poorly known in the Pacific area, it is possible that some of the so-called "introduced" species listed have been misidentified and in fact represent undescribed endemic Australian species.

The present paper assesses the extent of both deliberate and accidental introductions of invertebrates and algae to marine and estuarine waters in the Australian region, with particular emphasis being placed on those species which might have significant impacts on native marine fauna and habitats, or on fisheries, in this region. The probable pathways by which these introduced marine organisms may have entered Australian waters are then discussed, and some recommendations made regarding their future control. A previous paper (Pollard and Hutchings, this vol.) reviews the occurrence of exotic marine fishes from the same perspectives.

**Introduced Marine Organisms**

Table 1, which is based primarily on and updates the checklist presented by Hutchings et al. (1987), lists those species of exotic marine invertebrates and algae known or claimed to have been introduced to Australian waters. This table includes notes on their probable areas of origin, probable dates and means of introduction, their present areas of occurrence within Australia, and also other
Table 1. List of exotic marine invertebrates and algae introduced to Australia. For explanation of symbols and abbreviations used, see end of table.

<table>
<thead>
<tr>
<th>Species</th>
<th>Possible origin of introduction</th>
<th>Possible date of introduction</th>
<th>Probable means of introduction</th>
<th>Locations within Australia</th>
<th>References</th>
<th>General comments</th>
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<tbody>
<tr>
<td><strong>CRUSTACEA</strong></td>
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<tr>
<td><strong>Decapoda</strong> (crabs and shrimps)</td>
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</tr>
<tr>
<td><em>Carcinus maenas</em> (Linnaeus)</td>
<td>Europe</td>
<td>1900</td>
<td>H</td>
<td>VIC</td>
<td>Fulton and Grant 1900, 1901; Zeidler 1978, 1988; Rosenzweig 1984; Zeidler 1978.</td>
<td>See text.</td>
</tr>
<tr>
<td><em>Cancer novaezelandiae</em> (Jacquinot &amp; Lucas)</td>
<td>New Zealand</td>
<td>1880-1930</td>
<td>0</td>
<td>TAS</td>
<td>McNeil and Ward 1930.</td>
<td>Most recently recorded from TAS in 1978, though not recorded from VIC since 1930.</td>
</tr>
<tr>
<td><em>Palaemon macrurax</em> Rathbun</td>
<td>China, Korea, Japan, west coast of USA</td>
<td>1979</td>
<td>U</td>
<td>NSW</td>
<td>Buckworth 1979.</td>
<td>See text.</td>
</tr>
<tr>
<td><strong>Isopoda</strong> (isopods)</td>
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</tr>
<tr>
<td><em>Cirolana hardyi</em> (Lockington)</td>
<td>West coast of USA</td>
<td>1972</td>
<td>H</td>
<td>NSW, WA, VIC</td>
<td>Bruce 1986.</td>
<td>Australian records mainly limited to ports. A potential pest species which can rapidly reach high population densities.</td>
</tr>
<tr>
<td><em>Eurylana arcuata</em> (Hale)</td>
<td>New Zealand or Chile</td>
<td>1925</td>
<td>H or B</td>
<td>NSW, SA</td>
<td>Bowman et al. 1981; Hutchings et al. 1986a (both as <em>Cirolana arcuata</em>); Bruce 1986.</td>
<td>Also introduced to California</td>
</tr>
<tr>
<td><em>Paracaridae sculpta</em> (Holmes)</td>
<td>California USA, Brazil, Mexico or Hawaii</td>
<td>1975</td>
<td>H</td>
<td>QLD</td>
<td>Harrison and Holdich 1982b.</td>
<td>Only found in Australia near international ports, often associated with fouling organisms.</td>
</tr>
<tr>
<td><em>Paradea dianae</em> (Mantley)</td>
<td>California USA, Brazil, Puerto Rico or Marshall Islands</td>
<td>1971</td>
<td>H</td>
<td>QLD</td>
<td>Harrison and Holdich 1982a.</td>
<td></td>
</tr>
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<td>Species</td>
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<tr>
<td><em>Sphaeroma serratum</em> (Fabricius)</td>
<td>Widespread</td>
<td>1950</td>
<td>H</td>
<td>WA</td>
<td>Holdich and Harrison 1983.</td>
<td></td>
</tr>
<tr>
<td><em>Sphaeroma walkeri</em> Stebbing</td>
<td>Indian Ocean</td>
<td>1927</td>
<td>H</td>
<td>NSW</td>
<td>Carlton and Ivenson 1981; Harrison and Holdich 1984.</td>
<td>Also introduced to California.</td>
</tr>
<tr>
<td>Myzidaeae .. (shrimps)</td>
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<tr>
<td>Cirripedia .. (barnacles)</td>
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<tr>
<td><em>Balanus improvisus</em> Darwin</td>
<td>Atlantic coast</td>
<td>?1940s</td>
<td>H</td>
<td>&quot;Southern Australia&quot;</td>
<td>Bishop 1961.</td>
<td>No recent records of this species in Australia to confirm its presence.</td>
</tr>
<tr>
<td><em>Notomegabalanus algicola</em> (Pilsbry)</td>
<td>South Africa</td>
<td>1943</td>
<td>H</td>
<td>NSW</td>
<td>Allen 1963 (as <em>Balanus algicola</em>).</td>
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<tr>
<td>MOLLUSCA</td>
<td></td>
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<tr>
<td>Bivalvia .. (clams)</td>
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<tr>
<td><em>Crassostrea gigas</em> (Thunberg)</td>
<td>Japan</td>
<td>1947</td>
<td>D</td>
<td>TAS, WA</td>
<td>Thomson 1962 (as <em>Gryphaea gigas</em>).</td>
<td>See text.</td>
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<tr>
<td></td>
<td></td>
<td>1986</td>
<td>U</td>
<td>VIC</td>
<td>Coleman and Hickman 1986.</td>
<td></td>
</tr>
<tr>
<td><em>Ostrea luraria</em> Hotton</td>
<td>New Zealand</td>
<td>1880s</td>
<td>D</td>
<td>TAS</td>
<td>Dartnall 1962; Summer 1974.</td>
<td>See text.</td>
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<tr>
<td>&lt;i&gt;Perna canaliculus&lt;/i&gt; (Martyn)</td>
<td>New Zealand</td>
<td>? 1876</td>
<td>O, H</td>
<td>TAS</td>
<td>May 1923; Dartnall 1969 (as &lt;i&gt;Mytilus canaliculus&lt;/i&gt;); Lucas 1986.</td>
<td>See text.</td>
</tr>
<tr>
<td>&lt;i&gt;Nicola australis&lt;/i&gt; (Quoy and Gaimard)</td>
<td>New Zealand</td>
<td>1965</td>
<td>O</td>
<td>TAS</td>
<td>Greenhill 1965; Dartnall 1969.</td>
<td>May have arrived with shipments of &lt;i&gt;Ostrea litoraria&lt;/i&gt;.</td>
</tr>
<tr>
<td>&lt;i&gt;Papulus longissimii&lt;/i&gt; (Philippi)</td>
<td>New Zealand</td>
<td>1960s or earlier</td>
<td>O</td>
<td>TAS</td>
<td>Greenhill 1965; Dartnall 1969.</td>
<td>Most recently recorded in TAS in 1988. May have arrived in shipments of &lt;i&gt;Ostrea litoraria&lt;/i&gt;.</td>
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<tr>
<td>Polyplacophora – (chitons)</td>
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<tr>
<td>Gastropoda – (snails and slugs)</td>
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</tr>
<tr>
<td>&lt;i&gt;Acanthina indicus&lt;/i&gt; Bergh</td>
<td>Japan, New Zealand, South Africa, Mediterranean or New Zealand</td>
<td>?</td>
<td>H or B</td>
<td>NSW, QLD</td>
<td>Willan and Coleman 1984.</td>
<td>May be a widespread Indo-Pacific species occurring naturally in Australia.</td>
</tr>
<tr>
<td>&lt;i&gt;Jasus hypsilophus&lt;/i&gt; (Alder and Hancock)</td>
<td>Europe</td>
<td>1956</td>
<td>H</td>
<td>VIC</td>
<td>Burn 1988 (as &lt;i&gt;Jasus hypsilophus&lt;/i&gt;); Miller and Willan 1986.</td>
<td></td>
</tr>
<tr>
<td>&lt;i&gt;Macrurina stocksii&lt;/i&gt; (Quoy and Gaimard)</td>
<td>New Zealand</td>
<td>Between 1920s and 1940s</td>
<td>O</td>
<td>TAS</td>
<td>Greenhill 1965; Dartnall 1969; Turner 1983.</td>
<td>Most recently recorded from TAS in 1988. May have arrived in shipments of &lt;i&gt;Ostrea litoraria&lt;/i&gt;.</td>
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<tbody>
<tr>
<td><em>Okenia plana</em> Bebe</td>
<td>Japan</td>
<td>1977</td>
<td>H</td>
<td>NSW, QLD, VIC</td>
<td>Willan and Coleman 1984; R. Burn (pers. comm.)</td>
<td>Also apparently introduced to New Zealand and California.</td>
</tr>
<tr>
<td><em>Polyacra capensis</em> (Quoy and Gaimard)</td>
<td>S. Africa</td>
<td>1927</td>
<td>H</td>
<td>NSW</td>
<td>Allen 1932 (as <em>Polyacra cospusculo</em>); Thompson 1976; Burn 1978; Willan and Coleman 1984.</td>
<td>Most recently recorded from Twofold Bay in 1986.</td>
</tr>
<tr>
<td><em>Polyacra hedgeli</em> Marcus</td>
<td>California</td>
<td>1973</td>
<td>H</td>
<td>NSW, VIC, WA</td>
<td>Willan and Coleman 1984; R. Burn (pers. comm.)</td>
<td>Also apparently introduced to New Zealand and South Africa.</td>
</tr>
<tr>
<td><em>Zoecumans subarminatus</em> (Sowerby)</td>
<td>New Zealand</td>
<td>1920s</td>
<td>U</td>
<td>NSW</td>
<td>Finlay 1987; Iredale 1936 (as <em>Zoecumans subarminatus</em>).</td>
<td></td>
</tr>
</tbody>
</table>

**注意：**

- *"TDIACEA... (sea squirt)"
- *"ECHINODERMATA... (starfishes)"


**Styela plicata** (Lesson) Widespread, 1979, H, NSW, subseqently reported from WA, SA, QLD, Kott 1985.

**ECHINODERMATA... (starfishes)**


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### Table 1. Continued

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<th>General comments</th>
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<tbody>
<tr>
<td><strong>BRACHIOPODA .. (lamp shells)</strong></td>
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<tr>
<td>Terebratella inconspicua</td>
<td>New Zealand</td>
<td>? 1901</td>
<td>O</td>
<td>TAS</td>
<td>Tate and May 1901; Ladder 1902 (as Terebra-</td>
<td>Does not appear to have become established. No recent records.</td>
</tr>
<tr>
<td>(Sowerby)</td>
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<td>tella rubicunda); Dartnall 1969 (as Terebra-</td>
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<td></td>
<td>tella inconspicua).</td>
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<tr>
<td><strong>POLYCHAETA .. (worms)</strong></td>
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<tr>
<td>Hydroides norvegicus</td>
<td>European coasts</td>
<td>1885</td>
<td>H</td>
<td>Australia generally</td>
<td>Haswell 1884 (in Allen 1952).</td>
<td>May be a misidentification.</td>
</tr>
<tr>
<td>Gunnerus</td>
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<tr>
<td>Mercierella enigmatica</td>
<td>India</td>
<td>1932</td>
<td>H</td>
<td>NSW</td>
<td>Allen 1963.</td>
<td>Recorded from a wide variety of localities worldwide, including southern temperate waters.</td>
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<td></td>
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<td>? B</td>
<td>Southern Australia</td>
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<tr>
<td>Boccardia proboscidea</td>
<td>Japan or North-eastern Pacific</td>
<td>1977</td>
<td>B or H</td>
<td>VIC</td>
<td>Blake and Kudenev 1978 (in Carlton 1985);</td>
<td>Although thought to be a recent migrant, now widespread in VIC.</td>
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<td></td>
<td>Hartmann-Schröder 1981</td>
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<td></td>
<td>Hutchings and Turvey 1984.</td>
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<tr>
<td>Johnson</td>
<td>1912</td>
<td>U</td>
<td>WA</td>
<td></td>
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</tr>
<tr>
<td>Pseudopolydora paucibranchiata</td>
<td>Japan, New Zealand or</td>
<td>1978</td>
<td>B or H</td>
<td>NSW</td>
<td>Blake and Kudenev 1978; Blake and Kudenev 1978;</td>
<td>May occur naturally in Australia.</td>
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<tr>
<td>(Okuda)</td>
<td>northeastern Pacific</td>
<td></td>
<td></td>
<td></td>
<td>Carlton 1985;</td>
<td></td>
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<tr>
<td></td>
<td>1979</td>
<td>?</td>
<td>SA</td>
<td></td>
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<tr>
<td><strong>HYDROZOA .. (anemones)</strong></td>
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<tr>
<td>Bougainvillia ramosa</td>
<td>Northern hemisphere or earlier</td>
<td>1918</td>
<td>H</td>
<td>NSW</td>
<td>Briggs 1931; Allen 1953.</td>
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<tr>
<td>van Beneden</td>
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<tr>
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<tr>
<td><strong>BRYOZOA</strong> - (lace corals)</td>
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<tr>
<td><em>Dictyopora palmata</em> * van Beneden</td>
<td>Atlantic coast</td>
<td>1953</td>
<td>H</td>
<td>NSW</td>
<td>Allen 1963.</td>
<td></td>
</tr>
<tr>
<td><em>Conopora tubigerum</em> * Osburn</td>
<td>Atlantic coast (West Indies)</td>
<td>1953</td>
<td>H</td>
<td>QLD</td>
<td>Allen 1953.</td>
<td></td>
</tr>
<tr>
<td><em>Wateriopsis arcuata</em> * Banta</td>
<td>Mexico</td>
<td>(post 1860)</td>
<td>H</td>
<td>QLD, NSW SA, WA</td>
<td>Allen 1963. Ferguson Wood and Allen 1968; Womersley 1979 (as W. cascellata); Banta 1968a, b; Bruck 1866.</td>
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<tr>
<td><strong>RHODOPHYTA</strong> - (red seaweeds)</td>
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<tr>
<td><em>Polysiphonia brodiei</em> * (Dillwyn)</td>
<td>Northern Europe, Washington</td>
<td>1940</td>
<td>H</td>
<td>TAS, VIC</td>
<td>Womersley 1979</td>
<td></td>
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<tr>
<td><em>Polysiphonia paredes</em> * Holmberg</td>
<td>California or Japan</td>
<td>1973</td>
<td>H</td>
<td>SA</td>
<td>Womersley 1981.</td>
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<tr>
<td><em>Phaeophyta</em> - (brown seaweeds)</td>
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<tr>
<td><em>Arthrocrisia villosa</em> * (Hudson)</td>
<td>Temperate North Atlantic or Mediterranean</td>
<td>1961</td>
<td>&quot;by shipping&quot;</td>
<td>SA</td>
<td>Skinner and Womersley 1983.</td>
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<tr>
<td>Strictonema seriferus (Reinke)</td>
<td>North Atlantic or Mediterranean</td>
<td>1959</td>
<td>&quot;by shipping&quot;</td>
<td>VIC, SA, WA</td>
<td>Skinner and Womersley 1983</td>
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<tr>
<td>Strictonema attenuata (Greville)</td>
<td>North Atlantic, Mediterranean or New Zealand</td>
<td>1959</td>
<td>&quot;by shipping&quot;</td>
<td>TAS, WA</td>
<td>Skinner and Womersley 1983</td>
<td></td>
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<tr>
<td>Undaria pinnatifida (Harvey)</td>
<td>Japan</td>
<td>1997</td>
<td>B</td>
<td>TAS</td>
<td>Sandersen 1983</td>
<td>See text.</td>
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**DINOPHYCEAE (dinoflagellates)**

| Gynaxodinium extensum | Japan | 1990 | B | TAS | Hallegraeff and Summer 1986; Hallegraeff et al. 1990a, b | See text. |

**Key to probable means of introduction:**

- B = Ballast water
- D = Deliberate
- H = Hull fouling
- O = With oysters
- U = Uncertain

**Abbreviations:**

- NSW = New South Wales
- QLD = Queensland
- SA = South Australia
- TAS = Tasmania
- VIC = Victoria
- WA = Western Australia
general comments on relevant aspects of their biology and status, as appropriate. Species from this list which it is considered could have significant ecological impacts are discussed in more detail below.

**Decapod Crustaceans**

*The European shore crab* Carcinus maenas

*Carcinus maenas* is a brachyuran decapod belonging to the family Portunidae, and 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, often attributed to introductions (Stephenson 1972; Joska and Branch 1986). A description of this species, including its main distinguishing characters, appears in Joska and Branch (1986). It is also included in the keys of Stephenson (1972) to the Portunidae of the Indo-Pacific.

The first records of *C. maenas* in Australia date back to the turn of this century (Fulton and Grant 1900, 1901), when it was common in Port Phillip Bay, Victoria. It was thought to have been introduced to Australia via Port Phillip Bay sometime after 1856, and Fulton and Grant (1901) suggested that the vector for its introduction could have been the hull fouling communities of ships arriving from Europe, attracted by the gold rushes of the 1850s.

Another possible dispersal mechanism had earlier been noted by 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 to ballast water, which had only 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, NSW (Zeidler 1978), being common at Twofold Bay in southern NSW (Hutchings et al. 1986a).
Carcinus maenas was also recorded from South Australia and Western Australia by Zeidler (1978, 1988) and Rosenzweig (1984). Both of these authors state that these isolated colonies are unlikely to have resulted from natural dispersal of the species within Australia, but rather from separate recent introductions.

Rosenzweig (1984) suggests that the introduction vector could have been ships' fouling communities, as suggested by Fulton and Grant (1901). However, ballast water as a dispersal mechanism would seem equally plausible.

Overseas studies have revealed that the reproductive activity of this species is limited by low temperatures (Vermeij 1981) and exposure to wave action (Joska and Branch 1986). Unfortunately, the factors which may restrict its spread in Australia, such as the presence of predators or competitors, and its reproductive activity here, are unknown. Without some study of the biology of this species in Australia, it is difficult to predict its final geographical distribution. Attention to the continued spread of C. maenas in Australia, and study of it, would be wise for two reasons: (1) Fears expressed by Joska and Branch (1986) that the introduction of this large aggressive predator to South Africa could threaten the existence of a number of native species appear to be well founded. They may be equally applicable to the Australian situation in view of the problems C. maenas has caused the American shellfish industry, as reported by Joska and Branch (1986). (2) This species could possibly represent an untapped and potentially exploitable marine resource in Australia in that future opportunities may exist for aquaculture or fishing of this species.

The Japanese shrimp Palaemon macrodactylus

Although Williams et al. (1978, 1982) noted this palaemonid shrimp as an introduction to South Australia via ballast water, we have not been able to verify these records. The only substantiated Australian record appears in Buckworth (1979), who recorded P. macrodactylus from a fly ash dam near Vales Point Power Station, which is connected via Mannering Hole to Lake Macquarie, near Newcastle, NSW.

Carlton (1985) repeated the record of Williams et al. (1978) and also cited Holthuis (1980) as noting an introduction of P. macrodactylus to Australia. Holthuis (1980), however, simply states
"Now also found in Australia", and gives no further details, though it is likely that he was referring to Buckworth's (1979) record.

Buckworth (1979) does not discuss a dispersal mechanism for the introduction. Newman (1963), however, considered transport of this species to San Francisco Bay, USA, via oysters or ships' hull fouling, and rejected both possibilities as being unlikely for such a subtidal swimming organism. Newman (1963) proposed that the dispersal mechanism was possibly the seawater system of a ship (i.e., internal plumbing using seawater).

Carlton (1985) considered that the introduction of this shrimp, which was first known from the northwestern Pacific (Newman 1963; Holthuis 1980), to San Francisco Bay could have involved ballast water transport and notes that subsequent introductions to other areas of California may have been the result of accidental or deliberate releases by fishermen using the species for bait.

**Bivalve Molluscs**

*The Pacific oyster Crassostrea gigas*

The bulk of the information on the Pacific oyster outlined below has been extracted from a recent report on its current status in Australian waters by Holliday and Nell (1987).

Australia has an efficient and highly profitable (worth about A$35 million per year) intertidal oyster industry, based on the native Sydney rock oyster *Saccostrea commercialis* (Ostreidae), and centered on the coasts of NSW and southern Queensland.

The farming of the introduced Pacific or Japanese oyster *Crassostrea gigas*, which was introduced to Australia by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in the late 1940s and early 1950s, began in Tasmania in the early 1970s. This oyster is now also cultivated in South Australia, and present annual production is about 4 million dozen oysters valued at about A$10 million.

The Pacific oyster, which is native to Japan (Korringa 1976), was deliberately introduced to many countries in the northern hemisphere, in some cases to create an oyster culture industry and in others to replace an existing industry based on indigenous species affected by disease (Coleman 1986). It is also cultivated in South America and has been widely introduced to various countries in the South Pacific and the Indian Ocean.
In New Zealand, live Pacific oysters were first reported in 1971, but old shell specimens date back as far as 1958. Since 1978 New Zealand oyster farmers have been cultivating the Pacific oyster instead of the native rock oyster (*S. commercialis*), as the market price obtained for both species was similar, while the more rapid growth of the Pacific oyster meant that it could meet the local and export market size in a shorter period.

The Pacific oyster was introduced to Australia on the basis that cultivation of native oysters in the more southern states was marginal (Sumner 1972), and NSW production was unlikely to increase while cultivation was restricted to the Sydney rock oyster. NSW Fisheries officers strongly opposed the introduction and, in fact, an initial shipment which arrived from Japan was destroyed in 1940.

Introductions were, however, subsequently made during the period 1947 to 1970. The "Miyagi" strain is grown in New Zealand and Tasmania and is thought to be the strain presently spreading in Port Stephens and other areas of NSW.

Plantings were made in Oyster Bay, Western Australia (where they did not survive) and in Pittwater, Tasmania (Ferguson Wood 1948). Oysters from Pittwater were later transported to both Port Sorell, Tasmania, and Mallacoota, Victoria, and (unsuccessfully) to South Australia. Today, Pacific oysters form the basis of a significant industry in Tasmania.

After the first settlement of Pacific oysters in NSW was recorded in the Pambula River in 1967, an extensive survey of other NSW estuaries was begun. The spread continued along the NSW coastline to Port Stephens in 1973, the Richmond River at Ballina in 1975, and eventually as far as Moreton Bay in southern Queensland. Oyster farmers were notified of the spread and were educated to identify and destroy these oysters (Wolf and Medcof 1974; Medcof and Wolf 1975).

The Pacific oyster became well established in Port Stephens over the summers of 1984-85 and 1985-86, where it was largely confined to the inner estuary, the traditional growing area for the Sydney rock oyster (Holliday and Nell 1985).

Pacific oysters grow more rapidly than Sydney rock oysters and interfere with conventional stick culture by overgrowing the native oysters. The shells of Pacific oysters are usually thinner and open wider when feeding than those of the Sydney rock oyster and the former are, therefore, more susceptible to fish, crab and stingray predation. Its susceptibility to a major disease affecting the Sydney rock oyster in the northern estuaries of NSW (QX disease), however,
is as yet unknown, but it has been shown to be resistant to similar parasitic diseases overseas.

The future of the Pacific oyster in NSW will largely depend on its ability to spread and survive, and on efforts made by oyster farmers to minimize its occurrence. Its keeping quality could also present a problem if it were to be farmed and marketed using the traditional systems employed for the Sydney rock oyster (e.g., because of their shorter survival time out of water, Pacific oysters would have to be opened and refrigerated much sooner after depuration; this could disadvantage oyster farmers who do not have their own processing facilities close to the growing area).

The greatest difficulty facing NSW oyster farmers with the impending spread of the Pacific oyster is the potential problem associated with "overcatch" (the settlement of juvenile oysters on the established crop), which may greatly increase costly culling operations needed to remove unwanted "jockey" oysters.

In 1985, in an attempt to prevent the spread of the Pacific oyster throughout NSW and reduce its abundance in Port Stephens, the NSW Agriculture and Fisheries Department declared the Pacific oyster a noxious fish, making the cultivation and the presence of this oyster on leases an offense. Oyster farmers in NSW are obliged to make every reasonable effort to destroy any Pacific oysters on their leases, and all Pacific oysters on a lease must be destroyed before any Sydney rock oysters are removed. The shipment of oysters out of Port Stephens for further cultivation in other estuaries is now strictly controlled (Holliday and Nell 1987).

The New Zealand oyster Ostrea lutaria

Two distinct species of oyster, Ostrea angasi and O. lutaria, have often been confused in the literature causing problems in interpreting the evidence for the suggested introduction of the New Zealand species O. lutaria into Tasmania.

Dartnall (1969) records that O. angasi, which is also native to Australia, was the oyster transported from New Zealand to Australia. However, Powell (1979) lists O. angasi as one of the species that was often referred to as O. lutaria. Although Sumner (1974) has suggested that relict populations of O. lutaria may exist in Tasmania, our enquiries have failed to substantiate this.
Other mollusc species, including the bivalves Neilo australis and Paphirus largillierti and the gastropod Maoricolpus roseus, may have also been introduced to Tasmania together with shipments of these oysters from New Zealand (Dartnall 1969).

The Asian mussel Musculista senhousia

The Asian mussel Musculista senhousia (Mytilidae), which was originally described from China, is indigenous to eastern Asia and ranges naturally from the western Pacific coasts of Siberia and the Kurile Islands south to Singapore (Slack-Smith and Brearley 1987). Its introduction to Australasian waters within the last decade has been documented by Willan (1985a, b; 1987) and Slack-Smith and Brearley (1987).

Musculista senhousia adapts to a wide variety of habitats, being reported from the intertidal zone down to depths of 20m (Slack-Smith and Brearley 1987). On soft substrates, dense colonies may be formed when individuals secrete tough hair-like byssal threads for attachment. These become interwoven and trap sediment, forming "nests" or mats (Willan 1985b; Slack-Smith and Brearley 1987). 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 1987).

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, and this species is now well established in this estuary. The species has now also spread into the nearby international port of Fremantle, but no other records from Australia have been substantiated (Willan 1987).

Musculista senhousia has also been reported by Willan (1985a,b, 1987) from Auckland Harbour, New Zealand, where its establishment coincided with the period of its establishment in Western Australia.

The sudden isolated nature of these first records, far removed from the species' native shores, and the fact that they are both from major port areas, suggest that its occurrence is not the result of a natural expansion of the species' range. (Willan 1985b).

Other introductions of M. senhousia have apparently occurred overseas. It was first reported from the west coast of the USA in 1944
and has since become established there and is extending its range (Willan 1985b). *M. senhousia* is believed to have been brought into the USA with shipments of Japanese oysters (Slack-Smith and Brearley 1987).

The type of dispersal mechanism leading to the establishment of *M. senhousia* in Australia is not known, although Slack-Smith and Brearley (1987) have suggested transport among fouling organisms on ships' hulls or in water intake pipes and ducts, or alternatively as larvae in the ballast water of bulk cargo ships.

To resolve which of these is the true dispersal mechanism is perhaps not possible at present as we lack basic biological information on this species such as the length of its larval life (Slack-Smith and Brearley 1987).

Whatever the origin and mode of introduction of *M. senhousia* to Australia, its presence is cause for some anxiety. Mat building by this species has the capacity to radically alter the biota and movement of soft sediments. This "nesting" behavior is already occurring in the Swan estuary, with records of densities of individuals as high as 2,600 m\(^2\), which exceed those reported from its native shores (Slack-Smith and Brearley 1987).

*The New Zealand mussel* *Perna canaliculus*

May (1923) noted that *Perna canaliculus* was rare in Australia 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 its introduction, however, as specimens collected from Bridport, Tasmania, and dated 1876, are held at the Australian Museum (P. Colman, pers. comm.), while the importation of New Zealand oysters apparently did not occur until the mid 1880s (Dartnall 1969; Sumner 1972). Lucas (1980) notes that *P. canaliculus* may have been introduced, alternatively, through ships' fouling. In any event, this species 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.).

In recent years this species, which is cultured extensively in New Zealand, has been imported in large quantities to Australia, where it
arrives for sale freshly killed by chilling. Although representations were made by New Zealand trade authorities to import these mussels alive, the risks of the species becoming established in Australian waters were judged to be too great for Australian authorities to accede to this proposal.

**Algae**

**Dinoflagellates**

Apart from the entrainment of marine organisms, including planktonic algae, in ships' ballast water itself, Williams et al. (1982, 1988) have also pointed out that such organisms can also be transported in the sediments of ships' ballast water tanks. Most recently, Hallegraeff et al. (1988a) have highlighted the serious problems caused by toxic dinoflagellates, the spores of which could be contained in these sediments.

Dinoflagellates are microscopic one-celled algae which form an important component of the planktonic diet of shellfish, some species of which produce potent neurological toxins which can find their way through fish and shellfish to humans. Sometimes, these toxins can cause paralytic shellfish poisoning which, in extreme cases, can lead to death through respiratory paralysis.

With the exception of the organism causing ciguatera fish poisoning (Gillespie 1980), such toxic dinoflagellates were virtually unknown from Australian waters until recently. Hallegraeff and Sumner (1986), following a general plankton survey of Tasmanian coastal waters in 1985-86, reported "dense blooms (10,000 to 100,000 cells per liter) of the toxic dinoflagellate *Gymnodinium catenatum*, which has caused human illnesses in Mexico and Spain." This dinoflagellate appeared to be confined to the Huon and Derwent estuary systems, where a number of shellfish farms were in various stages of development. Unacceptably high toxin concentrations were detected in commercial mussels (*Mytilus edulis planulatus*) and oysters (*Crassostrea gigas*), and also in three species of scallops (Hallegraeff and Sumner 1986). Toxic shellfish were confined to the Huon estuary during March 1986, where five shellfish farms had to be temporarily closed, but then spread to the d'Entrecasteaux Channel region in May-June, where a further nine farms had to be closed (Hallegraeff and Summer 1986). Shellfish toxicity problems
were also later documented for the first time from inshore waters near Melbourne and Adelaide (Hallegraeff et al. 1988b).

Hallegraeff et al. (1988a) noted that: "On a global scale, both the number and intensity of toxic dinoflagellate blooms affecting fish and shellfish farms seem to be on the rise and their geographic extent seems to be spreading. To some degree, this may be simply attributed to our increased awareness of toxic species and increased utilization of coastal waters for aquaculture, but transport of these organisms by humans may also be contributing. Possible methods of spreading include the carry-over of cyst stages with the transport of shellfish stocks from one area to another, or the transport of dinoflagellates or their benthic resting spores (cysts) in the ballast holds of large cargo ships."

Gymnodinium catenatum, which was first noticed in southern Tasmania waters in 1980, produces a resistant resting spore which under favorable conditions can germinate and seed new dinoflagellate blooms in the water column. "Extensive surveys of Tasmanian waters and sediments have indicated that G. catenatum is confined to the Derwent and Huon estuaries near the main shipping port of Hobart as well as the adjacent woodchip harbor of Triabunna. Neither G. catenatum nor its resting spore has ever been seen in surveys of other Tasmanian or Australian waters. Previously this micro-algal species was known only from Mexico, Argentina, Spain and Japan (including Yatshusiro, which is a major port of origin of Japanese woodchip carriers)" (Hallegraeff et al. 1988a). It is difficult to prove conclusively that this dinoflagellate has been introduced by ballast water, as so far examination of the ballast water and sediments from Japanese woodchip vessels at Triabunna has not revealed any G. catenatum cysts. However, the sediments sampled from three of six ships tested were found to contain viable dinoflagellate spores, including those of another toxic species (Hallegraeff et al. 1988a).

**Macrocystis**

Although Williams et al. (1982) and Carlton (1985) made mention of the entrainment of planktonic algae in ships' ballast tanks, until very recently (e.g., Sanderson 1988) no consideration appears to have been given to the possibility of free floating macroalgae being introduced in ballast water. At this stage we do not know if ballast water is an important vector for such algae or not,
though future studies should consider this possibility. In any case, macroalgal spores are known to survive for very long periods in total darkness (up to 120 days) before germinating (Moss and Sheader 1973) and could potentially be transported via ballast water.

As in the case of some of the animals discussed above, transfer by shipping has long been used to explain the disjunct distributions 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 such fouling species, though the occurrence of fouling macroalgae, 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 deficiencies, however small, in increasingly sophisticated antifouling technology.

Another method by which macroalgae and other marine organisms could 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" (Foster and Willan 1979). Drilling rigs have been used to explain new records of marine organisms in South Africa (Joska and Branch 1986) and New Zealand (Foster and Willan 1979), and they could also be responsible for the transfer of such organisms around parts of the Australian coastline.

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

Recently another species of Phaeophyta has been reported as occurring in Tasmania (Sanderson 1988). This is the Japanese laminarian kelp Undaria pinnatifida, which has become established along about 4 km of rocky coastline near Rheban, about 10 km to the
south of Triabunna on the east coast of Tasmania. Clumps of plants up to 80 cm tall had colonized previously bare rocks in this area from near low water mark down to depths of 8 m. The numbers of these plants present were estimated to be in the tens of thousands.

In Japan, *Undaria* (known there as "wakame") is an important edible seaweed crop, and is also cultivated extensively to feed juvenile cultured abalone (Sanderson 1988). This species has also been introduced into Wellington Harbour, New Zealand (Hay and Lucken 1987), probably by Korean and Japanese squid fishing boats.

With regard to its introduction to Tasmania, Sanderson (1988) speculates that "fragments of plants or spores may have been released with ballast waters" from ships arriving to carry woodchips from Triabunna to Japan. As these plants form a thick canopy, Sanderson (1988) suggests that there could be competition for space and light with the native brown seaweeds *Phyllospora, Sargassum* and *Ecklonia*, which in turn could affect local fisheries for sea urchins and abalone which feed on these algae. More recently, Sanderson and Barrett (1989) have speculated that this alga "could infect the Australian coastline from Cape Leeuwin (WA) in the south west to Woolongong (NSW) in the south east", and that it "is set to become a conspicuous part of the subtidal marine flora of southern Australian waters".

**Discussion**

In Australia, the Australian National Parks and Wildlife Service regulates and controls the importation of all living marine organisms through the Wildlife Protection (Regulation of Exports and Imports) Act 1982.

Apart from deliberate introductions, and accidental ones known or thought to be associated with them (e.g., Dartnall 1969), 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 in this way, and other explanations have been put forward to explain these distributions. For example, several species of invertebrate animals and some plants have apparently been transported as fouling organisms on the bottoms of ships,
including the New Zealand barnacle *Elminius modestus* (Bishop 1951), the isopod crustacean *Cymodoce tuberculata* (Chilton 1910), and the alga *Arthrocladia villosia* (Skinner and Womersley 1983).

Certain processes of interchange, however, may have operated over longer periods than that during which the identification and documentation of the flora and fauna of a region may have occurred. Some organisms are such "seasoned travellers" (Woods 1974) that it is now very difficult to be sure of their country of origin. Rumors of deliberate "plantings" and other quarantine improprieties also abound in the literature, e.g., in Dartnall (1969, p. 53), Sumner (1974, p. 4), Medcof and Wolf (1975, p. 36) and Carlton (1985, p. 315).

In a previous paper (Pollard and Hutchings, this vol.), we noted that ballast water has frequently been suggested as a vector of introduced marine organisms, although it is difficult to prove. The hypothesis is not new. Carlton (1985) gives examples dating from 1908 where this mode of transport was invoked to explain the distributions of marine organisms. Carlton (1987) also suggests that 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 the occurrence of species with apparently disjunct distributions may be simply a reflection of limited collecting.

The first 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 examined and could survive oceanic transport.

Williams et al. (1982, 1988) reported on follow-up studies which confirmed and reinforced Medcof’s findings. They also showed that sediment which accumulates in ships' ballast tanks and is disposed of overboard could act as an additional dispersal mechanism and this was confirmed by Hutchings et al. (1986a, b).

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

Medcof (1975) and Williams et al. (1982, 1988) addressed the question of whether these animals survived their discharge. Overall, their data did indicate that it would be possible for marine animals to withstand the physical and chemical rigors associated with this mode of transport, but were not conclusive. However, as Williams et al. (1982) stated, "the amount and frequency with which water is
discharged makes it a prime candidate for the successful invasion of introduced species."

Williams et al. (1982) concluded that none of the animals identified from ballast water or sediment in their studies appeared very likely to be a threat as either a competitor, commensal, predator or parasite of Australian marine species. However, they did qualify this statement by making the point that the problem of nominating which particular species, when introduced into a new locality, could pose such a threat was a very difficult one. Furthermore, they indicated that many of the organisms not identified in their survey (such as juvenile polychaete worms and molluscs) did have the potential to become pests in Australia.

This study by Williams et al. (1982) increased awareness in the Australian scientific community of the potential problems associated with the discharge of ballast water into Australian ports and also recommended the future treatment of ballast water to reduce the likelihood of introducing further exotic species. Paxton and Hoese (1985) subsequently echoed this call for sterilization of ballast waters to ensure that harmful introductions do not occur. Willan (1987) has also suggested the need for more appropriate quarantine measures at ports.

In late 1989, the Bureau of Rural Resources (Federal Department of Primary Industries and Energy) initiated a Scientific Working Group on Ballast Water which has developed an extensive research program for which it is currently seeking funds. It is hoped that a series of research projects on the feasibility of treating ballast water and the distribution of toxic dinoflagellates within Australian ports, together with investigations of the effects of particular introductions on the marine environment, will be initiated shortly.

In addition, the Australian Quarantine and Inspection Service, in February 1990, introduced voluntary guidelines to shipping for the discharge of ballast water into Australian ports. At this stage these guidelines are designed to prevent the entry and spread of exotic organisms such as toxic dinoflagellates which can contaminate shellfish. Ships' masters are being asked to minimize sediment discharge when ballast water is being released, and to avoid taking on ballast water in ports where toxic dinoflagellate blooms are occurring. More details are available from the Australian Quarantine Service. The Australian Federal Department of Transport has also recently presented a paper on "Controls on Discharge of Ballast Water" at the meeting of the Marine Environment Protection
Committee of the International Maritime Organisation held in March 1990 in London.

These events indicate an increasing awareness by Australian authorities of the problems posed by the introduction of exotic marine organisms into Australia, and the need to investigate these introductions and to develop the necessary technology to minimize such introductions in the future.

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