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Actions to implement and complement the National System for the Prevention and Management of Introduced Marine Pests in Western Australia

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Executive Summary

Western Australia has a long (14,000 km) and varied coastline with high environmental values. With a relatively small population, marine pollution issues in WA are concentrated near Perth and in the major nodes of human activity in other parts of the State. However, even with the current resources boom, much of the Western Australian marine environment is relatively pristine.

Introduced marine pests are regarded as one of the critical environmental issues worldwide which can damage the marine environment, including that of Western Australia. Most introduced species cause no apparent harm. A small minority of introduced species become pests, but these few can cause substantial economic and ecological damage.

Despite the potentially serious nature of introduced marine pests, little is known about the status of introduced marine species, including marine pest species, in Western Australia. To help overcome this problem, in 2006 the Natural Heritage Trust program funded the WA Department of Fisheries to undertake a major examination of introduced marine species in Western Australia. The study was intended to provide information for use by environmental managers, including the various natural resource management groups in Western Australia, and to assist with the development of the National System got management of marine pest issues by the National Introduced Marine Pests Coordination Group (NIMPCG).

A number of projects were undertaken during the study. These were divided into two broad groupings: technical studies that developed scientific information on the status of introduced marine species, including marine pests, in Western Australia, and strategies to communicate the results to as broad an audience as possible.

As the first step, all available literature, unpublished reports, and anecdotal information was obtained and evaluated to develop a list marine species that have reported as being introduced into Western Australia. Records of 102 species were examined:

- 60 species are considered to have been introduced through human activity, including three on the list of Australian declared marine pests;
- 7 introduced species, including four natural introductions, have not been found recently and are not presently considered to be living in Western Australia;
- 26 species are regarded as cryptogenic or native; and
- 9 species, including two declared marine pests, are questionable or rejected.

The distribution of the 60 introduced species shows that most (37) are temperate species that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 introduced species occur in both the southern and northern halves of Western Australia. Because most of the introduced species are temperate species, southern marine areas have more introduced marine species than northern areas. The greatest concentration is in the southwest corner: 46 in Fremantle, Cockburn Sound and the lower Swan River; 25 in Albany and 24 in Bunbury. On the north coast, the largest number of introduced species is in Port Hedland (10 species).

As part of the study, the eastern Australian scallop *Scaeochlamys livida* is recorded from Cockburn Sound and Fremantle Harbour, Western Australia. It was first recorded in Cockburn Sound in the 1980s and has now become a permanent part of the molluscan fauna of both Fremantle Harbour and Cockburn Sound. This is only the second eastern Australian species to

be introduced into Western Australia (the other is the snail *Velacumantus australis*). The other 58 species have all been introduced from overseas.

One of the major components of the project was to trial the new national system for monitoring for introduced marine pests in a Western Australian port. Albany was chosen for the survey because of its diverse marine environment, range of possible vectors for introductions of marine species, and long history of interaction with European vessels. A wide variety of sampling methods were all used in two seasons (winter and spring): surface scrapes, grabs, visual census, small cores, large cores, traps, settlement plates, and plankton nets. A total of 875 flora and fauna samples were collected. Samples were sorted to major taxonomic groups and scanned for individuals that could possibly be one of the 52 target species; only possible target pest species were identified to species.

The only species recorded from Albany that were on the NIMPCG target list were the polychaete *Sabella spallanzanii* and the marine alga *Codium fragile* ssp. *tomentosoides* (now *C. fragile* ssp. *fragile*). *Sabella spallanzanii* was previously known from the area, but the single specimen of *C. fragile* ssp. *fragile* was a new record. Following the finding of *C. fragile* ssp. *fragile* in Princess Royal Harbour, an extensive survey specifically targeting this species was conducted in June 2008. No further specimens were found during the survey. The Port of Albany later collected thirteen additional individuals outside the initial survey area and their identity was confirmed as *C. fragile* ssp. *fragile*. In addition, two species (the marine algae *Grateloupia imbricata* and *Ulva fasciata*) were new records for the Albany marine area, bringing the total number of introduced species known from this region to 27. An evaluation of the monitoring manual was prepared and submitted to NIMPCG.

Dampier was the only major port not to have had a baseline survey, and NIMPCG had recommended that one be undertaken. The results of a four-year marine biodiversity survey of the Dampier Archipelago undertaken by a partnership of the Western Australian Museum and Woodside Energy Ltd were collated, and it was concluded that knowledge of the marine biodiversity of the Dampier area is better than any other area in Western Australia. The continuing work of environmental consultants in this area provides added comfort that there have been no introductions of pest species since the partnership results were published. A recommendation was made to NIMPCG that the extensive information from the Western Australian Museum/ Woodside partnership provides an outstanding baseline of marine biodiversity information and that it should be considered to have met the requirement for a baseline survey of Dampier. This recommendation was accepted by NIMPCG.

In October 2002 the dredge *Leonardo da Vinci* arrived in Geraldton for a major port enhancement program. It had sailed from Jamaica, West Indies, through warm seas during the entire voyage. An arrival inspection in Geraldton demonstrated the vessel stern and sea chests were fouled with a variety of non-indigenous marine species that could potentially be introduced to Geraldton, including pest species. The vessel was cleaned in water in Geraldton, with several steps taken to minimize the possibility of species being introduced. Surveys of key species of molluscs and crustaceans were undertaken in October 2003 and 2007. To date, none of these potential pest species have been found, except for *Amphibalanus reticulatus,* which had already been recorded north and south of Geraldton.

For some years, many of the illegal Indonesian fishing vessels apprehended off the north coast of Western Australia have been detained at Willie Creek, 38 km north of Broome until their cases have been heard in court. A survey was undertaken of the creek in February 2008 to determine whether two invasive mussel species (*Mytiliopsis sallei* and *Perna viridis*) have inadvertently been introduced into the creek by the impounded vessels. Neither species was found. Three species of barnacles were collected during the survey, including the cryptogenic *Amphibalanus cirratus* and the introduced *Megabalanus occator,* both of which have previously been recorded in WA. Vessels held at Willie Creek have been Type 1 or Type 2, which are considered to be low risk for the introduction of marine pests. There is no apparent requirement for a detailed survey of Willie Creek.

Fifteen ports in Western Australia were assessed on the potential for non-indigenous marine species to become introduced through ballast water and biofouling. The overall vessel-mediated incursion risk to Western Australian ports was calculated by summing the relative incursion threat posed by visits to each port (using 2006 port data). The relative threat value of these visits was determined by a set of uniformly applied criteria. These comprised:

- The number of vessels visiting the port;
- Their port of origin (domestic or international);
- The volume and source of ballast water discharged in each port;
- The dead weight tonnage (DWT); and
- The type and associated risk of vessels visiting each port.

Using the criteria outlined above the three ports at most risk of non-indigenous marine species introductions are:

- Dampier;
- Fremantle; and
- Port Hedland.

The rankings of each port in this study are consistent with an earlier study by NIMPCG; there have been no changes in the relative port risk profiles resulting from the current resources boom in Western Australia.

Commercial fisheries vessels are generally regarded as being high risk in introducing or translocating marine pest species. This segment analyses risks in WA managed fisheries introducing marine pests to the State or translocating them from one location to another within WA. A document outlining the issues was prepared and evaluated by an independent technical panel. This section provides the explanatory document and the assessment by the technical panel. The panel concluded there is little chance of commercial fishing boats introducing species into WA because few operate outside WA. However, if a species is introduced into WA through another mechanism, there is a significant chance of commercial fishing boats moving the species about within WA.

This is a similar document exploring the question of whether the national monitoring system should be expanded to include marine parks and fish habitat protection areas. The panel concluded that such an expansion is required.

The other major component of the marine pests project has been communicating the results to as wide a range of interested groups as possible. The key component here has been to write a handbook on introduced marine pests in Western Australia. The booklet *Introduced Marine Species in Western Australia* has been published. It is intended for a popular audience of NRM groups, marine managers, environmental groups, scientists, etc. The booklet outlines the issue of marine pests, the situation in Western Australia, and what we can do about it. It is illustrated with photographs that show a variety of species already found in WA and some of those that may be introduced through careless practices.

As part of the project a symposium on introduced marine pests was organised at the annual conference of the Australian Marine Sciences Association held in Melbourne in July 2007. This section presents the abstracts of the 25 papers presented in the symposium. Also presented are reports sent to a stakeholders group of more than 100 people and copies of articles published on the project.

The present report provides a solid basis of understanding of the current status of the marine pest issue in Western Australia and a platform on which mechanisms for preventing the arrival of additional marine pest species can be built.

Acknowledgements

The Department of Fisheries initiated a project *Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia* in October 2006. The was funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State government. The present document is the final report to the Natural Heritage Trust work undertaken on the project. We appreciate the considerable help of both Commonwealth and State representatives on the NHT project in facilitating our work on the project, including the staff of the State NRM office. In particular sincere thanks are offered to Martin Heller, Australian Government NRM Facilitator, and Barbara Pedersen of the WA Department of Planning and Infrastructure who were instrumental in facilitating the development of the project and were keenly interested in it.

During the project we worked very closely with Dr Stephanie Turner of the WA Department of Fisheries, and enjoyed the close rapport that was developed between her management role in the marine pest issue in Western Australia and our role of developing scientific information for use in management.

There was a steering committee that was instrumental in the early stages of the project in setting the parameters for the study. The committee consisted of: Martin Heller, Australian Government NRM Facilitator; Dr John Huisman, WA Herbarium; Rebecca James, Port of Fremantle; Diana Jones, Western Australian Museum; Steve Lewis, Port of Dampier; Warren Geeves, Commonwealth Dept of Environment and Heritage, Canberra; Barbara Pedersen, Dept of Planning and Infrastructure; Melissa Schubert, Commonwealth Dept of Agriculture, Fisheries and Forestry, Canberra; Brad Williamson, Port of Albany; Dr Stephanie Turner, Rob Tregonning, and Dr Fred Wells, WA Dept of Fisheries.

We also appreciate the background support of the National Introduced Marine Pests Coordination Group, based at the Department of Agriculture Fisheries and Forestry in Canberra.

This final report is presented as a series of related smaller projects undertaken during the course of the study. Acknowledgements are provided in each section for the people that helped with the individual sections. In particular we thank staff of the various port authorities in Western Australia and other Western Australian industries for facilitating many aspects of the project.

Contents

Introduction

Western Australia has a long and varied coastline of some 14,000 km spread over three major biogeographical regions. The north coast, from North West Cape to the Northern Territory border, is part of the vast Indo-West Pacific region that extends across the tropical Indian and Western Pacific Oceans (Wells 1980; Wilson and Allen 1987). Most of the species that live on the north coast of WA are widely distributed in the Indo-Pacific. The range of some extends from the east coast of South Africa to Hawaii. In Australia the many of the species reach the southern part of the Great Barrier Reef. The south coast of Western Australia, from Cape Leeuwin to the South Australian border, is part of the Southern Australian Warm Temperate Region. Most species have a wide distribution along the south coast to New South Wales or even southern Queensland. The marine biota of the north and south coasts of Western Australia is almost entirely separate; there are very few species that live in both areas. The west coast of WA, between Cape Leeuwin and North West Cape, is an area of biogeographical overlap, where the tropical and temperate biotas overlap. Clearly tropical species dominate in the northern parts of this range and temperate species in the south. There are also a small proportion (about 10%) of the shallow water benthic plants and animals that are endemic to Western Australia, meaning they only occur here. While these species can live in any part of the State, most are concentrated in the west coast overlap zone.

Not only does WA have a long coastline, but also its environmental values are high. The human population of Western Australia is relatively small, about 2.1 million people, two thirds of whom live in the Perth metropolitan area. Most of the remainder live in the southwest corner of the State. Issues of marine pollution are therefore concentrated near Perth and in the major nodes of human activity in other parts of the State. However, even with the current resources boom, much of the Western Australian marine environment is relatively pristine. WA waters have an abundant and diverse marine biota. While fisheries are small in terms of tonnage, they are distributed across the State and are economically valuable. At an average annual value of $ 300 million to the fishermen, the western rock lobster fishery is both the largest single species fishery in Australia and the largest rock lobster fishery in the world.

Introduced marine species are regarded as one of the critical environmental issues worldwide which can damage the marine environment (Padilla *et al.* 1996), including that of Western Australia. The major mechanisms (Carlton 1985) for introducing species are through:

- ballast water discharge;
- hull fouling; and
- deliberate introductions.

Most introduced species cause no apparent harm in marine ecosystems and, as far as we know, simply become additional species in the local environment. It is a minority of the species that become pests, but these few can cause substantial economic and ecological damage (Brenchley and Carlton 1983; Paesanti *et al.* 1991; Grosholz and Ruiz 1995; Blanchard 1997; Wyatt *et al.* 2005). The damage can include:

- disruption of ecosystem function;
- loss of biodiversity;
- losses to fisheries and aquaculture;
- fouling of pipelines and industrial equipment; and
- diseases in native species and humans.

For example, some species of dinoflagellates produce toxins. During blooms when the dinoflagellates are consumed by shellfish, the toxins accumulate to a point where they can cause serious illness or even death to humans (Hallegraeff *et al.* 1988; Campbell 1994; Walters 1996). A second example is the fouling caused by a species of mussel (*Dreissena polymorpha*) introduced into the Great Lakes of North America, which has now spread to 20 American states and Canadian provinces. It is estimated that this species alone will cost $ 5 billion over the next decade (Great Lakes Commission 2007). So while a minority of introduced species become pests, the damage done by those few pests can be very substantial.

During the 1990s and earlier in this decade the CSIRO Centre for Research into Introduced Marine Pests (CRIMP) conducted marine pest surveys of many of the harbours in Australia. The information is summarised on the *National Introduced Marine Pest Information System* website (NIMPIS 2002). The CRIMP and other surveys have provided the basis for the developing Australia-wide national system for marine managing marine pest issues. The system is being developed by the National Introduced Marine Pest Coordination Group. NIMPCG (2006a; 2006b) developed a detailed strategy for monitoring for marine pests.

In mid 2006, the Natural Heritage Trust program funded the WA Department of Fisheries to undertake a major examination of introduced marine species in Western Australia. The study was intended to provide information for use by environmental managers, including the various natural resource management groups in Western Australia, and to assist with the development of the National System by NIMPCG. This is the final report of the project.

A number of projects were undertaken during the study. These were divided into two broad groupings: technical studies that developed scientific information on the status of introduced marine species, including marine pests, in Western Australia, and strategies to communicate the results to as broad an audience as possible. The following sections present the results of both of these major components. Each section is presented as it was developed and is available separately as a computerised pdf file. This results in some duplication in the report but has the advantage of providing the full context for each component.

Part 1 Technical studies

This section was published as: Huisman, J.M., Jones, D.S., Wells, F.E., and Burton, T. 2008. Marine introductions into Western Australian waters. ***Records of the Western Australian Museum 25*****: 1-44.**

Introduced marine biota in Western Australian waters

Records of the Western Australian Museum **25**: 1–44 (2008).

Introduced marine biota in Western Australian waters

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Abstract – An annotated compendium is presented of 102 species of marine algae and animals that have been reported as introduced into Western Australian marine and estuarine waters, four of which are on the Australian national list of targeted marine pest species. For each species the authority, distribution (both in Western Australia and elsewhere), voucher specimen(s) and remarks are given. Sixty species are considered to have been introduced through human activity, including three on the list of Australian declared marine pests. The most invasive groups are: bryozoans (15 species), crustaceans (13 species) and molluscs (9 species). Seven of these introduced species, including four natural introductions, have not been found recently and are not presently considered to be living in Western Australia. Twenty-six species are regarded as cryptogenic or native. The records of nine species, including two declared marine pests, are questionable or rejected.

The distribution of the 60 introduced species shows that most (37) are temperate species that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 introduced species occur in both the southern and northern halves of Western Australia. Because most of the introduced species are temperate species, southern marine areas have more introduced marine species than northern areas. The greatest concentration is in the southwest corner: 46 in Fremantle, Cockburn Sound and the lower Swan River; 25 in Albany and 24 in Bunbury.

We conclude with a strong recommendation that continuing baseline taxonomic research and surveys of the Western Australian marine waters be regarded as an essential component of protecting and managing the State's valuable marine environment.

INTRODUCTION

The introduction of exotic species into the marine environment is a major threat to native biodiversity and ecosystem health (Padilla *et al.* 1996; Hass and Jones 2000). Three primary vectors for marine introductions are recognised – via ballast water discharge, hull fouling or deliberate introductions, such as through aquaculture (Carlton 1985) (species can also be accidentally introduced by being attached to deliberately introduced organisms such as oysters). While most introductions remain relatively passive and apparently co-exist with native species without detriment, many others have the ability to become pests, dominating and excluding local species and resulting in major shifts in ecosystem structure (Brenchley and Carlton 1983; Grosholz and Ruiz 1995). Local loss of biodiversity is an inevitable result of these pest intrusions (Paesanti *et al.* 1991; Blanchard 1995; Blanchard 1997; Wyatt *et al.* 2005). Some introduced species can directly impact human health, for example by toxin accumulation in shellfish due to toxic dinoflagellates (Hallegraeff *et al.* 1988). Consumption of contaminated shellfish may result in illness or death (Campbell 1994; Walters 1996).

Western Australia (WA) has, thus far, remained relatively free of marine pests. Jones (1992a) recorded 25 marine introductions into the State's waters, over half (15) detected since the 1970s and most of those introduced by shipping, either as fouling organisms or via ballast water. Furlani (1996) also recorded 25 introduced marine species in Western Australia. In 1999, this number was increased to 30 (Hass and Jones 1999). Those introductions that have been reported have generally remained innocuous, or have been largely restricted to artificial environments such as harbours. This parallels the situation in other Australian areas. A search of the *National Introduced Marine Pest Information System* website (NIMPIS 2002) reveals a list of 44 species introduced or possibly introduced into WA. Additional information presented here increases the number of known introduced species to 60. As yet there are no published data regarding adverse impacts of introduced species in Western Australia (Hass and Jones 1999), but several have been shown to have significant impacts in other areas, by competition for food and/or space. For example, no threats to Western Australian native species, fisheries or seagrass beds were identified through the introduction of *Sabella spallanzanii*, the European fan worm (Clapin and Evans 1995), although studies in Victoria have suggested that this species has the potential to compete with native filter feeders and change the structure of the benthic food web (Walters 1996). Adverse impacts may not occur until decades after the initial introduction and establishment (Courtney 1990) and it would, therefore, be extremely short-sighted to assume that Western Australia's relatively unaffected marine environment is somehow immune to infestation by pest species.

While the impact of introduced species in WA is as yet unknown, the likelihood of a pest outbreak is high, as the State includes many high traffic ports with a variety of habitats, ranging from tropical to temperate. Even a cursory review of the marine species known to be pests elsewhere will reveal that, for most, suitable conditions for their growth and possible survival can be found somewhere in the State (Department of Agriculture, Fisheries and Forestry 2006). Thus the risk of a pest incursion is high and on-going vigilance is important if WA is to remain relatively pest free. It is also pertinent to point out here that the incursion of marine pests is a two-way process. For example, the Australasian barnacle *Austrominius modestus* Darwin was introduced into Europe from Australia or New Zealand following the end of World War II, attached to the hulls of returning ships (Bishop, 1947). The species spread, becoming established on the British mainland coast and then extending to Europe (Bishop and Crisp 1957; Crisp 1958). Currently the species occurs from the Shetland Islands to Portugal and Maderia (Southward and Crisp 1963; Hiscock *et al.* 1978; O'Riordan and Ramsay 1999; Wirtz *et al.* 2006). Similarly the temperate Australian gastropod *Bedeva paivae* (Crosse, 1864) has colonised South Africa (Kilburn and Rippey 1982) and the south-western Australian green alga *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman and Boudouresque has become a major pest in the Mediterranean (Verlaque *et al.* 2003). The vector by which these introductions occurred is not known, especially in areas where native fauna is not well documented.

Several factors can hamper marine pest surveys. Obvious impediments include the marine environment itself, as most introductions remain hidden from sight, their presence often only revealed by snorkelling or SCUBA diving. Perhaps of greater significance, however, is the difficulty in accurately identifying introduced species and assessing their impact. For almost all introduced species it is virtually impossible to ascertain the 'event' that led to the introduction, and many are not observed until they are well established and essentially impossible to eradicate. Accurate identification is essential, primarily to ensure that introduced species are not missed, but equally to ensure that native species are not inadvertently recorded as introductions, as there are many undescribed native species. For example, some species generally considered to be cosmopolitan may be undocumented introductions or, conversely, non-introduced native species (Chapman and Carlton 1991; Poore 1996).

The large number of ships, private yachts, and illegal foreign fishers means that there is a considerable current potential for additional marine species to be introduced into WA. The current resource boom is concentrated in the Pilbara, but includes all parts of Western Australia. The planned increase in shipping movements means there will be increased threats of species being introduced into WA. There have already been several incidents that give cause for alarm. In October 2002, the cutter suction dredge *Leonardo da Vinci* arrived in Geraldton almost directly from the Caribbean and had a number of foreign species, including potential pest species, in its sea chests or attached to its hull. Prompt action was taken by authorities to minimise the chances of an introduction. A resurvey is planned to see if any species have been introduced. A second incident occurred in late 2006, when the dredge *Volvox Australia* arrived at the port of Dampier fouled with the Asian green mussel, *Perna viridis*. It was denied entry and went to Singapore for cleaning in drydock before being allowed to return to WA. More recently a barge arrived in Dampier and on inspection was found to have an extensively fouled hull. It was immediately ordered to go out to the 200 m depth contour and be cleaned before returning to port; on return to the coast the ship was reinspected and allowed to enter Port Hedland.

In managing incidents such as these, it is critical that we understand what species have been introduced into Western Australia and where they occur. This paper develops the required information.

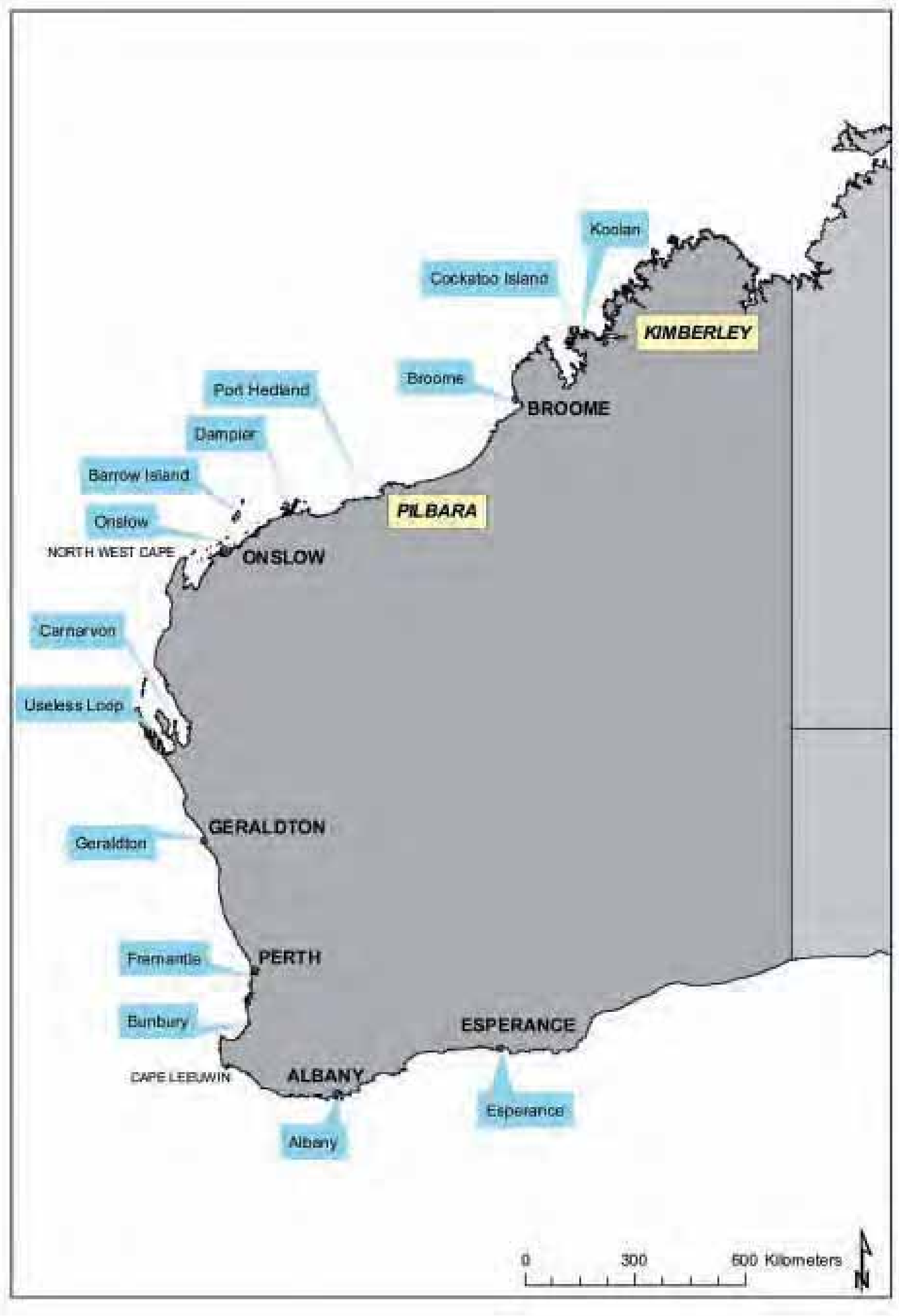

Figure 1 Map of the major areas of Western Australia where introduced marine species have been reported.

MATERIALS AND METHODS

This paper presents a list of species reported or believed to have been introduced into Western Australian waters. The records have been drawn from a variety of sources, including the scientific literature, several unpublished surveys of WA ports and unpublished information. Figure 1 shows the major marine areas in Western Australia where introduced species have been recorded. Table 1 shows the major surveys of Western Australian ports. We have listed all species previously documented as 'introduced' in the State. In addition, several species included herein are newly recorded; these meet at least some of the criteria used by Chapman and Carlton (1994, see below) for recognition of introduced species. Cryptogenic species (i.e., those potentially introduced but their origins presently obscure due to their widespread distribution) are listed only if they are known to exhibit pest tendencies elsewhere.

Listed for each species are the authority and distribution (both Western Australian and elsewhere) incorporating published records and whether there are voucher specimen(s) in the WA Museum, WA Herbarium or other institutions. Occasionally no vouchers were available to support the records and these species should be viewed critically. Where several works are cited, it is likely that the earliest published will represent the original record, with those following generally not providing new records but repeating the original. A remarks section includes an assessment of any questionable records and an evaluation of the pest potential of the species. Finally, several tables indicating the present status of the species are given.

Abbreviations for voucher specimens are: WAM = Western Australian Museum; PERTH = Western Australian Herbarium; AD = Adelaide Herbarium; MUCV = Monash University Botany Department Herbarium; QM = Queensland Museum; AM = Australian Museum; MV = Museum of Victoria.

Assessing native or introduced status

Several species listed herein represent new (or recent) records for Western Australia. These may simply have been overlooked previously, but their proximity to harbours suggests potential introductions. They have been assessed against the list of criteria provided by Chapman and Carlton (1994) to objectively identify marine introductions, including:

1. Previously unknown locally (herein interpreted as no published records and no specimens in the WA Museum or Herbarium)
2. Post introduction range extension
3. Human mechanism of introduction
4. Association with known introductions
5. Association with artificial or altered environments
6. Discontinuous or restricted regional distribution
7. Disjunct global distribution
8. Insufficient life history adaptations for global dispersal
9. Exotic evolutionary origin

These criteria are particularly useful when assessing recent introductions, but the status of species introduced some time ago and since naturalized cannot be determined without additional study, typically involving DNA sequencing methods to assess relationships between the local population and potential source populations. Voucher collections in museums and herbaria can also assist in determining a species' status, but these are often not available and historically record-keeping was generally not as detailed or consistent as it presently is. Compounding these difficulties is the high likelihood that populations of many widespread species arose from multiple introductions over time. In such cases, when a species is known to be widely distributed but its origin (or native range) cannot be determined, the species is regarded as 'cryptogenic'. A cryptogenic species may or may not be introduced, but current methods do not allow a definitive assessment. A species that is cryptogenic in one location, however, may subsequently be introduced to another.

DISCUSSION

A total of 102 species are discussed in the present paper, enabling a more accurate assessment of the status of introduced marine species in Western

Table 1 Major surveys for introduced marine species in Western Australia.

Location	Reference	Identifications
Esperance	Campbell (2003b)	WA Museum
Albany	CRIMP (1997b)	CRIMP
Bunbury	CRIMP (1997a)	CRIMP
Fremantle	CRIMP (2000)	Various; WA Museum identified vouchers
Geraldton	Campbell (2003a)	WA Museum
Dampier	Wells *et al.* (2003); Jones (2004)	WA Museum surveys accepted by NIMCPG in lieu of broad survey; numerous specialists identified the material.
Port Hedland	CRIMP (1999)	CRIMP

Table 2 Targeted pest species in Western Australia (4 spp.)

Dinoflagellates
Alexandrium minutum
Alexandrium tamarense[1]

Polychaetes
Sabella spallanzanii

Molluscs
Musculista senhousia

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[1] Requires confirmation by genetic studies.

Australia. Only four species are on the Australian national list of targeted marine pest species (Table 2). Two are dinoflagellates, *Alexandrium tamarense* and *A. minutum,* although the record of *A. tamarense* is yet to be positively confirmed by genetic analyses (Hallegraeff 2007; pers. comm.). The other targeted marine pest species are the polychaetes *Sabella spallanzanii* and the bivalve mollusc *Musculista senhousia.* Table 3 lists 60 marine species that have been introduced and and are presently established in Western Australia. They represent a wide range of plant and animal taxa. The groups with the most introduced species are bryozoans (15), crustaceans (13) and molluscs (9). Seven species have been reliably reported as introduced to Western Australia (i.e., with vouchers) but have not been collected or observed recently and are not presently known to occur in the State (Table 4). Four of these are natural introductions (Macpherson 1953; Wells and Kilburn 1986). Twenty-six species are considered to be cryptogenic or native (Table 5). The records of nine species are questionable or have been excluded (Table 6).

Altogether, 60 species are classified as being introduced and currently living in Western

Table 3 Marine species introduced and presently established in Western Australia (60 spp.)

Dinoflagellates (1 sp.)
Alexandrium minutum

Algae (4 spp.)
Elachista orbicularis
Grateloupia imbricata
Pseudocodium de-vriesii
Stictyosiphon soriferus

Bryozoans (15 spp.)
Amathia distans
Amathia vidovici
Bowerbankia gracilis
Bugula flabellata
Bugula neritina
Bugula stolonifera
Conopeum seurati
Cryptosula pallasiana
Savignyella lafontii
Schizoporella errata
Schizoporella unicornis
Tricellaria occidentalis
Watersipora arcuata
Watersipora subtorquata
Zoobotryon verticillatum

Crustaceans (13 spp.)
Amphibalanus amphitrite
Amphibalanus reticulatus
Cirolana harfordi
Paracerceis sculpta
Paradella dianae
Sphaeroma serratum
Megabalanus ajax
Megabalanus rosa
Megabalanus tintinnabulum
Monocorophium acherusicum
Monocorophium insidiosum
Monocorophium sextonae
Tesseropora rosea

Hydroids (6 spp.)
Antennella secundaria[2]
Ectopleura crocea
Eudendrum carneum
Halecium delicatulum
Obelia dichotoma
Sarsia eximia

Molluscs (9 spp.)
Velacumantus australis
Godiva quadricolor
Musculista senhousia
Mytilus edulis planulatus
Okenia pellucida
Ostrea edulis
Polycera hedgpethi
Scaeochlamys livida
Theora lubrica

Polychaetes (4 spp.)
Alitta succinea
Boccardia proboscidea
Ficopomatus enigmatica
Sabella spallanzanii

Ascidians (5 spp.)
Ascidiella aspersa
Botryllus schlosseri
Ciona intestinalis
Styela clava
Styela plicata

Fish (3 spp.)
Acentrogobius pflaumi
Sparidentex hasta
Tridentiger trigonocephalus

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[2] considered by NIMPIS (2002) to be cryptogenic in parts of WA but introduced to the Pilbara region.

Table 4 Marine species introduced but not presently found in Western Australia (7 spp.)

Crustaceans
Carcinus maenas
Pyromaia tuberculata

Molluscs
Bullia annulata (natural introduction)
Crassostrea gigas
Cymatium cutaceum africanum (natural introduction)
Haliotis spadicea (natural introduction)
Nassarius kraussianus (natural introduction)

Table 5 Species considered to be cryptogenic or native (26 spp.)

Dinoflagellates
Alexandrium tamarense[3]

Algae
Acanthophora spicifera
Acrosymphyton taylorii
Caulerpa taxifolia
Cottoniella fusiformis
Endarachne binghamiae
Eucheuma denticulatum
Hypnea musciformis
Ulva fasciata
Ulva taeniata

Bryozoans
Aetea anguina
Beania mirabilis
Synnotum aegyptiacum
Tricellaria inopinata

Hydroids
Aglaophenia parvula
Antennella secundaria[4]
Eudendrium capillare
Gymnangium gracilicaule
Obelia bispinosa
Obelia longissima[5]
Plumularia setacea
Plumularia warreni

Molluscs
Nassarius burchardi
Spisula trigonella

Polychaetes
Hydroides elegans[6]

Ascidians
Botrylloides leachi

Table 6 Questionable and excluded records (9 spp.)

Dinoflagellates
Alexandrium catenella
Gymnodinium catenatum

Algae
Striaria attenuata

Crustaceans
Amphibalanus improvisus

Molluscs
Haliotis diversicolor
Haliotis hargravesi
Teredo navilis

Polychaetes
Polydora ciliata
Pseudopolydora paucibranchiata

Australia. All of these species occur in marine areas associated with harbours. A majority (34 species) have been recorded only in harbours. Twenty-six species occur both in harbours and on nearby open coasts, including estuaries such as the mouth of Peel Inlet. This strongly suggests species are being introduced through major nodes of human activity, followed by some spread to nearby areas. However, it should be noted that surveys for introduced species have been concentrated in harbours and the records from adjacent open shores are incidental. A targeted survey would be required to determine how widespread introduced species have become outside harbours. The most diverse groups on open coasts are bryozoans (7 species) and barnacles (5 species). The bryozoans were all recorded in Shark Bay by Wyatt *et al.* (2005), and the barnacles from the various papers of DSJ.

A second major finding of Table 7 is that most of the marine species introduced into Western Australia are cooler water, temperate species (37 species) that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 introduced species occur in both the southern and northern halves of Western Australia. The preponderance of temperate species is in agreement with most published work on introduced species. It must be noted that the Port of Dampier, which has considerable shipping activity, has not been surveyed in detail, although the associated Dampier Archipelago, which includes a broad variety of marine habitats, has been the subject of several intensive marine biodiversity surveys (Wells and Walker 2003; Jones 2004a). Because most of the introduced species are temperate, it follows that southern marine areas have more introduced marine species than northern areas. The greatest concentration is in the southwest corner of Western Australia: Fremantle (including Cockburn Sound and the lower Swan River) has 46 introduced

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[3] Requires confirmation by genetic studies.

[4] considered by NIMPIS (2002) to be cryptogenic in parts of WA but introduced to the Pilbara region.

[5] according to sections of NIMPIS (2002), this species is not recorded from Australia, but elsewhere on the site is listed as cryptogenic

[6] Regarded as a possible introduction by NIMPIS (2002).

species and is the port with the largest number of vessel movements. Albany (25), Bunbury (24) and Esperance (15) are all smaller ports with fewer vessel movements and fewer introduced marine species. In addition to the high vessel activity in the Fremantle marine area, there is also considerable habitat diversity (both natural and artificial), which provides a variety of niches for introduced species to occupy. In this regard, the Albany area also has a wide variety of habitats in close proximity (Wells 1990), so the large number of introduced species might be expected. Esperance has a much lower habitat diversity (Kendrick *et al.* 2005), so fewer species would be expected in that area. Bunbury stands out in this regard. The marine area is small and habitat diversity is low, so it would be expected to have relatively few introduced species. Instead, at 24, the number of introductions is high. A separate analysis is currently being undertaken of the numbers of vessel movements and where the vessels have come from.

It is impossible to know when most of the species were introduced into Western Australia. Lamarck (1819) described *Mytilus edulis planulatus* from King George Sound. If the species is in fact introduced as we believe, it arrived with the very first European boats to visit the south coast and eastern Australia. That *M. edulis* is introduced has already been suggested by Hewitt (2003). Morton *et al.* (2003) reported the European oyster *Ostrea edulis* (Linnaeus, 1758) from Oyster Harbour, Albany. This species was also probably an early arrival. The first record of an introduced species in Western Australia appears to be the barnacle *Amphibalanus amphitrite* (Darwin, 1854), which was recorded from Broome, north-western Australia by the Swedish Mjöberg Expedition (1910–1913; in Broch 1916), although it was known previously from the east coast (Darwin 1854). Subsequently, the ascidian *Botryllus schlosseri* (Pallas, 1766) was recorded by Hartmeyer and Michaelsen (1928). These were followed by the polychaetes *Alitta succinea* (Leuckart, 1847) and *Ficopomatus enigmatica* (Fauvel, 1923) by Monro (1938). Kott (1952) reported the ascidian *Styela plicata* (Lesueur, 1823). There were two species recorded in the late 1970s and 11 in the 1980s. The great majority were reported in the 1990s and earlier this decade, many as a result of surveys undertaken by the CSIRO's *Centre for Research on Introduced Marine Pests* (CRIMP) and other surveys. However, many of these species may have been in Western Australia well before the first literature record. For example, the polychaete *Sabella spalanzanii* was first reported by Clapin and Evans (1995). Subsequent examination of the WA Museum collections demonstrated that the first specimen was collected in Albany in 1965 but it was not identified at that time.

The NIMPIS (2002) database can be searched by state or territory. A search of the database for introduced species lists the following numbers: Victoria (57); New South Wales (55); Tasmania (45); Western Australia (44); South Australia (43); Queensland (26); and the Northern Territory (9). While the data are out of date, identifications were often not done by specialists in the various groups, and are not backed by voucher specimens, they do suggest that on a nationwide basis there tend to be more introduced marine species on the temperate south coast than in the tropical northern waters, a point discussed by Hutchings *et al.* (2002). With about a third of Australia's coastline, Western Australia ranks fourth of the six states in the number of introduced marine species, just one species ahead of South Australia. We recognise 60 species as being introduced and 26 as cryptogenic in the entire state of Western Australia. Hewitt *et al.* (2004) report 99 species as introduced to Port Phillip Bay, Victoria, alone, and an additional 61 cryptogenic species in the bay. However, it should be recognised that the number of known introduced species is probably inflated by the detailed studies that have been conducted. There is cause for comfort in the relatively low number of species introduced into Western Australia given the 14,000km of coastline and wide range of temperatures, spanning the full range of tropical and temperate habitats. However, it should be remembered that there have been recent incursions of the black striped mussel *Mytilopsis sallei* on illegal Indonesian fishing boats in Broome and Port Hedland and the Asian green mussel *Perna viridis* into Dampier. Whatever the current situation, there is still a great need for continued vigilance.

One aspect arising from this project, for which we have co-opted the term "the taxonomic impediment" (Taylor 1983), warrants further comment. It is recognized that the identification of introduced species is a difficult process that requires specialist taxonomic knowledge and historic faunistic and floristic data (Hass and Jones 2000). A common thread running through much of the literature regarding marine introductions is the lack of baseline studies and the difficulty in accurately identifying specimens. For example, the CRIMP survey of Fremantle Port (CRIMP 2000) recorded 44 species of red algae (Rhodophyta), of which 28 were essentially unidentified (Red sp. 1, etc.) and a further four are identified to genus only. Granted the study was targeted primarily at introduced and pest species, but how then does one recognise new introductions if the biota is not identified? A consequence of this inability to identify the vast majority of species is that the survey has no value as a baseline for further work. Also, if a species is not identified, there is no basis for knowing whether or not it is introduced. If

Table 7 Distribution of introduced marine species in Western Australia. (Note: Fremantle includes Cottesloe, Cockburn Sound, Garden I., Swan R. and Rockingham)

	Open coast					Marine areas													
Species	South	Southwest	Gascoyne	Pilbara	Kimberley	Esperance	Albany	Bunbury	Fremantle	Geraldton	Useless Loop	Carnarvon	Onslow	Barrow I.	Dampier	Port Hedland	Broome	Cockatoo I.	Koolan I.
Algae (4 spp.)																			
Elachista orbicularis		X					X												
Grateloupia imbricata									X										
Pseudocodium de-vriesii									X										
Stictyosiphon soriferus							X												
Dinoflagellates (1 sp.)																			
Alexandrium minutum		X						X	X										
Bryozoans (15 spp.)																			
Amathia distans																X			
Amathia vidovici																X			
Bowerbankia gracilis																X			
Bugula flabellata							X	X	X										
Bugula neritina			X			X	X	X	X	X					X	X			
Bugula stolonifera			X			X	X	X								X			
Conopeum seurati			X			X													
Cryptosula pallasiana							X	X	X										
Savignyella lafontii			X											X		X			
Schizoporella errata			X			X	X	X	X	X									
Schizoporella unicornis						X	X	X	X										
Tricellaria occidentalis									X					X					
Watersipora arcuata						X	X	X	X	X									
Watersipora subtorquata			X				X	X	X	X									
Zoobotryon verticillatum			X													X			
Crustaceans (13 spp.)																			
Amphibalanus amphitrite	X	X	X	X	X	X	X	X	X	X		X			X	X	X		
Amphibalanus reticulatus		X		X					X	X				X	X	X			
Cirolana harfordi									X										
Paracerceis sculpta		X	X			X		X	X										
Paradella dianae								X	X										
Sphaeroma serratum		X				X			X										
Megabalanus ajax			X	X	X						X			X	X		X		
Megabalanus rosa			X	X					X					X	X	X		X	
Megabalanus tintinnabulum	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	
Monocorophium acherusicum								X	X										
Monocorophium insidiosum									X										
Monocorophium sextonae								X											
Tesseropora rosea							X		X										
Hydroids (6 spp.)																			
Antenella secundaria		X	X	X	X		X	X	X							X			
Ectopleura crocea		X							X										
Eudendrium carneum		X					X	X	X										
Halecium delicatulum	X	X	X				X	X	X										
Obelia dichotoma			X				X	X											
Sarsia eximia		X	X				X												
Molluscs (9 spp.)																			
Velacumantus australis									X										
Godiva quadricolor									X										
Musculista senhousia									X										
Mytilus edulis planulatus	X	X					X	X	X										
Okenia pellucida									X										
Ostrea edulis							X												

Table 7 (cont.)

	Open coast					Marine areas													
Species	South	Southwest	Gascoyne	Pilbara	Kimberley	Esperance	Albany	Bunbury	Fremantle	Geraldton	Useless Loop	Carnarvon	Onslow	Barrow I.	Dampier	Port Hedland	Broome	Cockatoo I.	Koolan I.
Polycera hedgpethi							X		X										
Scaeochlamys livida									X										
Theora lubrica									X										
Polychaetes (4 spp.)																			
Alitta succinea									X										
Boccardia proboscidea									X										
Ficopomatus enigmatica		X							X										
Sabella spallanzanii						X	X	X	X										
Ascidians (5 spp.)																			
Ascidiella aspersa						X	X	X	X										
Botryllus schlosseri			X	X		X	X		X										
Ciona intestinalis						X	X	X	X										
Styela plicata			X	X		X		X	X										
Styela clava							X		X										
Fish (3 spp.)																			
Acentrogobius pflaumii									X										
Sparidentex hasta									X										
Tridentiger trigonocephalus								X	X										
Totals (60 spp.)	4	14	18	8	4	15	25	24	46	7	2	2	1	6	6	12	3	2	0

voucher specimens are deposited in the State Museum or Herbarium, future studies by taxonomists are possible, but unfortunately specimen deposition has often been neglected.

In the past, a number of surveys of Australian ports have been conducted. The specimens collected were treated in different ways by a variety of contractors who conducted the work, often without the aid of taxonomists. Few collections were deposited in Australian museums or herbaria, so recorded distributions could not be verified by vouchered specimens. As part of the National System for the Prevention and Management of Introduced Marine Pests in Australia, funding was provided by the Natural Heritage Trust for the Port Survey Integration project (2005–2006), to firstly trace these collections and secondly relocate them to the relevant state museums and herbaria, where they could be housed, curated and made available for scientific study. Very few vouchers had been kept of marine algae. For fauna, 50,735 specimen lots were retrieved and deposited, including 15,967 in the Western Australian Museum. The material ranged from unsorted lots in varying states of preservation to material identified to species. Specimens representative of introduced marine faunal pest, introduced and cryptogenic (likely introduced) species, which had been identified in each surveyed port, were verified by state museums dependent on the taxonomic expertise available. Fifteen introduced species and 17 cryptogenics were identified from the Western Australian material. These records are accessible nationally via the OZCAM website (Online Zoological Collections of Australian Museums). It is interesting to note that only one specific taxonomic group, the barnacles, had all the specimens identified to species in every port collection by a taxonomic expert (DSJ, an author of the present paper). Although this makes the barnacle data set a potent national asset, it also emphasises the severe lack of taxonomic expertise in Australia and the problems facing us in the identification of introduced pests, which in the port surveys were often identified by contractors with varying skill levels.

A more positive example is the marine biological survey of the waters of the Dampier Archipelago conducted by the WA Museum from 1998 to 2002 (Jones 2004a). Although this survey excluded the Port of Dampier, five species of introduced barnacles were recorded in the area, including port areas (Jones 2004b). Overall >4500 marine animal and plant species collected by the survey were identified to species by expert taxonomists world-wide, vouchered and deposited in the collections of the Western Australian Museum and the Western

Australian Herbarium. This material, collected from 120 geo-positioned stations, is a valuable baseline for future work including surveys for introduced species in the area (Jones 2004a, b). Although diving was not undertaken in the port operational areas, intertidal collecting was done, and we believe the results obtained are representative of the Dampier region.

Unfortunately, capable marine taxonomists in Western Australia are few in number and poorly supported. For some ecologically important marine organisms (e.g. hard corals, soft corals, polychaetes, etc.) and groups with known fouling organisms (e.g. ascidians, bryozoans, hydroids, etc.) specimens need to be sent to interstate or overseas experts, as there are none in Western Australia. This lack of expertise severely hampers both the baseline assessment of the Western Australian marine biota and the assessment of potential introductions. There can be no substitute for taxonomic expertise and experience. It would be folly to expect that species recognition and assessment of invasive status can be undertaken without input from experienced taxonomists. Furthermore, it is imperative that voucher specimens be retained. These permanent collections permit reassessment of records and allow for update of names following taxonomic revisions. Unvouchered records are of limited value and can only be assessed in light of the level of expertise of the identifier, for the most part a fairly nebulous gauge of a record’s worth. Voucher specimens remove all doubt, particularly where future studies may show there are sibling species or presently undescribed native species.

We conclude with a strong recommendation, that continuing baseline taxonomic research and surveys of the Western Australian marine waters be regarded as an essential component of protecting and managing the State’s valuable marine environment.

SPECIES LIST

Algae (Chlorophyta, Heterokontophyta, Rhodophyta)

Preamble

The Western Australian marine benthic flora includes numerous species that are widely distributed, particularly so in tropical areas where many of the taxa have a broad Indo-West Pacific distribution. These species could be regarded as cryptogenic (i.e., potentially introduced but their origins presently obscure due to their widespread distribution), but there seems little value in including them in this compendium. Womersley (2003: 499), faced with a similar situation in the southern Australian marine flora, commented “There are numerous species in all three phyla which are regarded as widely dispersed species rather than adventive (i.e., introduced). These include some species (such as *Polysiphonia brodiei*) which may be adventive, but they have known to be present for a long time and are known from several localities.” While we have not included the majority of these widespread species, we have, however, incorporated cryptogenic species that are known introductions or pest species in other areas.

CHLOROPHYTA

Class Ulvophyceae (Green Algae)

Order Bryopsidales

Family Caulerpaceae

Caulerpa taxifolia (Vahl) C.Agardh, 1817

Western Australian records and vouchers

Known from the Abrolhos Islands (PERTH 03985369) and north into tropical WA (PERTH 07117620).

Distribution elsewhere

Widespread in tropical seas. The invasive strain is thought to have originally come from southern Queensland and has been introduced to New South Wales and South Australia (in addition to overseas locations such as the Mediterranean and California) (Jousson *et al.* 2000; Cheshire *et al.* 2002; Millar 2002; Schaffelke *et al.* 2002). Subtle genetic differences between these populations suggest that several independent introductions have occurred.

Remarks

This species has been recorded from tropical Western Australia, but it is unlikely to be the invasive strain of *C. taxifolia*. Molecular testing is required to positively identify the invasive strain. No unusually prolific infestations of *C. taxifolia* have been reported and the species has not been seen outside of its expected tropical distribution.

Family Pseudocodiaceae

Pseudocodium devriesii Weber-van Bosse, 1896

Western Australian records and vouchers

Known only from Cottesloe and off Rous Head, Fremantle (PERTH 07259948; 07259697).

Distribution elsewhere

Known from East London, South Africa eastward to Mozambique; Madagascar (Coppejans *et al.* 2005).

Remarks

This species appears to be restricted to the Rous Head and Cottesloe area, where it forms small clusters in sand associated with rocks. It was first observed in 2000 and its proximity to Fremantle harbour suggests it is probably an introduction. DNA sequence analyses (Verbruggen, pers. comm., 2006) have demonstrated its conspecificity with specimens from South Africa. The population does not appear to be spreading but any expansion should be monitored closely.

Order Ulvales

Family Ulvaceae

Ulva taeniata (Setchell) Setchell and Gardner, 1920

Western Australian records and vouchers

Fremantle, Swan Estuary (Womersley 1984: 149; Phillips 1988: 450, as *U. stenophylla*; MUCV 1578, 1579).

Distribution elsewhere

Pacific coast of North America; Hawaiian Islands; Australia; New Zealand.

Remarks

Ulva is represented by two widespread species that occur sporadically (*U. taeniata*) or commonly (*U. fasciata*) in the Perth region. Very little is known of the relationships of these species with overseas populations. *Ulva taeniata* was recorded by Womersley (1984) for the Perth region and subsequently listed by Womersley (2003) as a 'probable adventive species'. Phillips (1988: 450) referred the Womersley (1984) record to *U. stenophylla* and the true identity of the Western Australian entity requires more detailed (probably molecular) comparisons with overseas populations. Whatever the outcome, the species will still be regarded as introduced or cryptogenic, as the native distributon of both species is the Pacific coast of North America.

Ulva fasciata Delile, 1813

Western Australian records and vouchers

Swan River Estuary (Phillips, 1988: 436; PERTH). Cryptogenic on the lower west coast of WA (NIMPIS, 2002).

Distribution elsewhere

Widespread in tropical to temperate seas.

Remarks

See remarks under *U. taeniata*.

Heterokontophyta

Class Phaeophyceae (Brown Algae)

Order Chordariales

Family Elachistaceae

Elachista orbicularis (Ohta) Skinner, 1983

Western Australian records and vouchers

King George Sound (PERTH 04156404); Rottnest I. (Womersley, 1987: 78; PERTH 04156382).

Distribution elsewhere

Native to Japan; introduced to southern Australia (Rottnest I. and Albany, WA; Port Noarlunga to Port Elliot, SA, and Garie Beach, NSW) (Womersley 1987).

Remarks

This species forms dark brown tufts on *Ecklonia radiata*. It is common in the Perth region and was thought to be an introduction from Japan (Womersley 1987). Given its small size and seemingly negligible effect on the host, *Elachista orbicularis* is unlikely to become a pest species.

Order Dictyosiphonales

Family Striariaceae

Striaria attenuata Greville, 1828

Western Australian records and vouchers

Not present; no vouchers.

Distribution elsewhere

Adelaide, SA, Tas., and Pambula, NSW; temperate N. Atlantic; southern New Zealand; Japan (Womersley 1987).

Remarks

Jones (1992, table 4) tabulated several species of marine introductions, including this brown alga, citing Skinner and Womersley (1983). Western Australian records of the species are not mentioned in that publication or in Womersley's subsequent *Marine Benthic Flora of Southern Australia* (1987), and the species does not appear to occur in WA.

Stictyosiphon soriferus (Reinke) Rosenvinge, 1935

Western Australian records and vouchers

Albany (Skinner and Womersley, 1983; Womersley, 1987: 314; AD A51388).

Distribution elsewhere

North Atlantic; Mediterranean; introduced in southern Australia (Albany to Port Phillip Bay, Vic. in harbours) (Womersley 1987).

Remarks

Thought to be an introduction from the North Atlantic (Womersley 1987: 314), as in southern Australia it is predominantly restricted to harbours. The status of the species in Albany is presently unknown, as it was not mentioned in the CRIMP (1997b) survey of the Port of Albany and has not been the subject of a targeted search.

Order Scytosiphonales

Family Scytosiphonaceae

Endarachne binghamiae J.Agardh, 1896

Western Australian records and vouchers

Cottesloe, on intertidal rock (Huisman *et al.* 2006), Rottnest I. (PERTH 07573286; 07573278).

Distribution elsewhere

Widespread in temperate and tropical seas.

Remarks

This species is only recently recorded for WA, from an area close to Fremantle Harbour. It has since also been observed at Rottnest Island. Given its widespread distribution elsewhere, the origins of the Perth specimens of *Endarachne* will be difficult to assess. Moreover, the superficially similar *Petalonia fascia* is well known as a winter annual in the Perth region, which might have led to earlier populations of *Endarachne* being overlooked. Since it has not displayed pest tendencies in other areas and is restricted to intertidal habitats, *E. binghamiae* is unlikely to become a problem species in WA.

Rhodophyta
(Red Algae)

Class Florideophyceae

Order Ceramiales

Family Delesseriaceae

Cottoniella fusiformis Børgesen, 1930
(also reported as *C. filamentosa* var. *fusiformis*).

Western Australian records and vouchers

Houtman Abrolhos and Dampier Archipelago (as *C. filamentosa*; Huisman, 1997, 2000; Huisman and Borowitzka, 2003; PERTH: MURU DAR 1276).

Distribution elsewhere

Widespread in warmer waters.

Remarks

Recorded as adventive by Womersley (2003: 500) based on South Australian records from eastern Gulf St. Vincent. This species is known in WA from many locations. It has a broad distribution in warmer waters and its presence in WA is not unexpected.

Family Rhodomelaceae

Acanthophora spicifera (Vahl) Børgesen, 1910

Western Australian records and vouchers

Dawesville (PERTH 07573294); Houtman Abrolhos north (Huisman, 2000; PERTH – MURU DAR 1508).

Distribution elsewhere

Widespread in tropical and warm temperate seas.

Remarks

A widespread species in many tropical areas, including the warmer waters of WA, *A. spicifera* was introduced to the Hawaiian Islands and has become a major pest species, virtually dominating many intertidal and shallow subtidal reef flats. It is generally only encountered sporadically in WA. However, a recent bloom (2007) of *A. spicifera* has occurred at Dawesville, which is of great interest as it is outside the usual range of the species, and the population is very dense (Hosja, pers. comm.). Specimens from the Dawesville population are presently being analysed to assess their relationships with those from northern WA and also with Hawaiian populations.

Order Gigartinales

Family Acrosymphytaceae

Acrosymphyton taylorii Abbott, 1962

Western Australian records and vouchers

Rottnest I.; Houtman Abrolhos (Huisman 2000; PERTH 06559050; 06559077).

Distribution elsewhere

Widespread in warmer waters of the Indo-West Pacific; Hawaiian Islands (Millar and Kraft, 1984; Huisman, 2000).

Remarks

Recorded as adventive by Womersley (2003: 500) based on a South Australian record. This species is known in WA from Rottnest Island and some localities further north (e.g. Houtman Abrolhos Islands). It has a broad distribution in warmer waters of the Indo-Pacific and its presence in WA is not unexpected. *Acrosymphyton taylori* is known only from the conspicuous gametophyte phase of the life history, the tetrasporophyte presumably cryptic and presently unknown. Gametophytes are usually spring-summer annuals. As such, *A. taylori* is similar to several other seasonal red algae found in WA, none of which are regarded as pests.

Family Hypneaceae

Hypnea musciformis (Wulfen) Lamouroux, 1813

Western Australian records and vouchers

Point Peron (PERTH 07573545; 07573553).

Distribution elsewhere

Widespread in warmer seas (Guiry and Guiry 2007).

Remarks

Specimens compatible with descriptions of this species are occasionally common in the Perth region. This species forms blooms in the Hawaiian Islands, probably as a response to increased nutrients. As yet, *H. musciformis* has not been problematic in WA. DNA sequence analyses are being undertaken to assess the relationships between local and overseas specimens.

Family Solieriaceae

Eucheuma denticulatum (Burman) Collins and Hervey, 1917

Western Australian records and vouchers

From the Houtman Abrolhos (rarely), and northward of the North West Cape region (Huisman, 2000; Huisman and Borowitzka, 2003; PERTH 07235445; 06706541).

Distribution elsewhere

Widespread in the Indo-Pacific.

Remarks

A widespread species in the Indo-Pacific and found in several locations in tropical WA. This species was intentionally introduced to the Hawaiian Islands and has become a major pest. WA populations have not shown similar tendencies.

Order Halymeniales

Family Halymeniaceae

Grateloupia imbricata Holmes, 1896

Western Australian records and vouchers

Cottesloe (Huisman *et al.,* 2006; PERTH 07573316).

Distribution elsewhere

Native to Japan, introduced to the Mediterranean (Verlaque *et al.* 2005).

Remarks

At present known in WA only from a rocky groyne in Cottesloe (Huisman *et al.* 2006), DNA sequence analyses (De Clerck, pers. comm.) have indicated that the local material is closely related to populations of this species in Japan and the Mediterranean (the latter considered an introduction, Verlaque *et al.* 2005). Further studies of the extent of this species in WA are required.

Dinophyta

(Dinoflagellates)

Class Dinophyceae

Order Gonyaulacales

Family Gonyaulaceae

Alexandrium catenella (Whedon and Kofoid 1936) Balech, 1985

Western Australian records and vouchers

Listed as occurring in WA in the Schedule of 'Known exotic species in Australian waters' (CRIMP 1997b, 2000); in ballast water of ship arriving at Port Hedland (Hallegraeff and Bolch 1992).

Distribution elsewhere

Widespread in many temperate seas; cryptogenic in south-eastern Australia (NIMPIS 2002).

Remarks

Viable cysts of this species were collected and germinated from the ballast tanks of a ship arriving in Port Hedland (Hallegraeff and Bolch 1991, 1992), but it is not known if local populations were established as a result. The species has never been collected directly from WA waters (Hallegraeff 2007; pers. comm.). NIMPIS (2002) indicates only a south-eastern Australian distribution.

Alexandrium minutum (Halim, 1960) Balech, 1989

Western Australian records and vouchers

Bunbury (CRIMP 1997a, as 'cf.'); Bunbury and Geographe Bay, Mandurah, Peel Inlet, Cockburn Sound, Swan River (Hallegraeff and Hosja 1993; NIMPIS 2002).

Distribution elsewhere

Cryptogenic in the Mediterranean, Spain, New Zealand, east coast of USA, south east Asia and parts of south-east Australia, introduced to Tas., parts of SA and southwestern WA (Chang and McClean 1997; Giacobbe *et al.* 1996; NIMPIS 2002).

Remarks

This and the following species are recorded sporadically in WA waters, either as the swimming, flagellated stage or as benthic cysts. In other areas of the world, these species form dense toxic blooms in shallow lagoons and brackish marine embayments that may be accompanied by mortality of fish and shellfish (Sorokin *et al.* 1996) and in outbreaks of paralytic shellfish poisoning (PSP) (Anderson *et al.* 1983). No blooms have been reported in WA. Monitoring is routinely undertaken of commercial mussel and oyster farming areas in WA.

Alexandrium tamarense **(Lebour) Balech, 1985**

Western Australian records and vouchers

Bunbury (CRIMP 1997a, as 'cf.'); Fremantle (CRIMP 2000). NIMPIS (2002) lists this species as being possibly introduced into the south coast and lower west coast of WA.

Distribution elsewhere

Native range unknown, cryptogenic almost worldwide in temperate coastal waters (Turpin *et al.* 1978; Anderson *et al.* 1983; Schrey *et al.* 1984; Ogata *et al.* 1987; Anderson *et al.* 1994; Sorokin *et al.* 1996; Adachi *et al.* 1999), including southern Australia (Parry *et al.* 1997; Cohen *et al.* 2001; Aquenol 2001; Ruiz Sebastian *et al.* 2005).

Remarks

Alexandrium tamarense – like cells were found in the preserved Fremantle port survey collections, but obviously these could not be cultured, and cysts from Fremantle were also never successfully germinated (Hallegraeff 2007; pers. comm.). Thus this record remains to be confirmed genetically. *Alexandrium tamarense* is linked with paralytic shellfish poisoning (PSP) (Giacobbe *et al.* 1996; Chang and McClean 1997).

Order Gymnodiniales

Family Gymnodiniaceae

Gymnodinium catenatum **Graham, 1943**
(now *G. microreticulatum*)

Western Australian records and vouchers

Albany (CRIMP 1997b); Bunbury (CRIMP 1997a).

Distribution elsewhere

Native range unknown, cryptogenic in cool temperate to tropical/subtropical seas virtually worldwide (Matsuyama *et al.* 1999), including parts of southern Australia. Introduced to Tasmania (Hallegraeff and Bolch 1991; Hallegraeff *et al.* 1997; McMinn *et al.* 1997; Lovejoy *et al.* 1998; Bolch *et al.* 1999; Bolch and Reynolds 2002).

Remarks

Gymnodinium catenatum cysts were reported in high concentrations from several locations in Albany and Bunbury by CRIMP (1997a, b), but the original identification was of "*Gymnodinium catenatum* – like cysts" (Hallegraeff 2007; pers. comm., including emphasis). This taxon was subsequently described as the new, non-toxic species *Gymnodinium microreticulatum* (Bolch *et al.* 1999). *Gymnodinium catenatum* has never been seen in WA waters (Hallegraeff 2007; pers. comm.).

Bryozoa (Bryozoans)

Class Gymnolaemata

Order Cheilostomatida

Family Aeteidae

Aetea anguina **Linnaeus, 1758**

Western Australian records and vouchers

Shark Bay (Wyatt *et al.* 2005).

Distribution elsewhere

Widely distributed throughout most seas, apparently only absent from polar regions, common in European seas (Osburn 1950; Ryland 1965; Ryland and Hayward 1977); in southern Australia from Port Phillip Bay, Vic. (Black 1971; Vigeland 1971; Bock 1982; Hewitt *et al.* 2004).

Remarks

A common but inconspicuous member of the fouling fauna, usually found growing over the surface of algae, other invertebrates, rocks, shells, wooden structures and almost any submerged object (Ryland 1965; Ryland and Hayward 1977; Bock 1982).

Family Beaniidae

Beania mirabilis **Johnston, 1840**

Western Australian records and vouchers

Port Hedland (WAM 30558).

Distribution elsewhere

Widespread in warm and warm temperate seas (Osburn 1950; Ryland and Hayward 1977; Winston 1982).

Remarks

An inconspicuous species that grows on a variety of surfaces but is probably often overlooked (Ryland and Hayward 1977; Winston 1982).

Family Bugulidae

Bugula flabellata (Thompson in Gray, 1848)

Western Australian records and vouchers

Albany (CRIMP 1997b; WAM 30985); Bunbury (CRIMP 1997a; WAM 30530; 32085); Fremantle and Cockburn Sound (CRIMP 2000; WAM 30812; 32846). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Possibly native to Atlantic and Mediterranean coasts. Widely distributed in warm and temperate seas (Ryland 1965; Ryland and Hayward 1977; Gordon 1986; Gordon and Mawatari 1992); in Australia from Port Adelaide, SA (Allen 1953; Brock 1985), Port Phillip Bay, Vic. (Keough and Ross 1999; Cohen *et al*. 2001; Hewitt *et al*. 2004) and Eden to Port Stephens, NSW (Allen and Wood 1950).

Remarks

Found almost invariably attached to other bryozoans. Occurs commonly on rocky shores near low water mark and among the epibenthos of inshore waters (Ryland and Hayward 1977); mainly found on stones, shells etc, occasionally on harbour structures, from low water mark and coastal waters (Ryland 1965).

Bugula neritina (Linnaeus, 1758)

Western Australian records and vouchers

Esperance (Western Australian Museum, 2002; Campbell 2003b; WAM 30570; 30572); Albany (CRIMP 1997b; WAM 30959; 30968); Bunbury (WAM 4973; 4974); (CRIMP 1997a; WAM 32071; 32080); Fremantle (CRIMP 2000; WAM 4987); Cockburn Sound (WAM 30813); Shark Bay (Wyatt *et al*. 2005); Geraldton (WA Museum, 2001; Campbell, 2003a); Port Hedland (CRIMP 1999; DALSE 2004); Dampier (Mackie *et. al*. 2006). Introduced into all areas of WA (NIMPIS 2002).

Distribution elsewhere

Widely distributed throughout most seas worldwide, except in cold polar and subarctic/subantarctic regions (Osburn 1950; Ryland 1965; Ryland and Hayward 1977; Winston 1982; Gordon 1986; Keough 1989; Gordon and Mawatari 1992); in Australia from most areas (Keough and Ross 1999) including Port Phillip Bay, Geelong, Portland, Vic. (Black 1971; Vigeland 1971; Parry *et al*. 1997; Currie *et al*. 1998; Cohen *et al*. 2001; Hewitt *et al*. 2004); Port Adelaide, SA (Brock, 1985); Port Hacking, Port Jackson, Port Kembla, NSW (Allen and Wood 1950; Vail and Wass 1981; Moran and Grant 1993); and Launceston, Tas. (Aquenol 2001). Genetic analysis suggests a common source for globally widespread introductions (Mackie *et. al*. 2006).

Remarks

Found worldwide in warm water ports and harbours, this is a serious and common fouling organism that grows on a wide variety of substrata (Ryland 1965; Ryland and Hayward 1977; Bock 1982; Winston 1982).

Bugula stolonifera Ryland, 1960

Western Australian records and vouchers

Esperance (Western Australian Museum, 2002; Campbell 2003b; WAM 30582; 30583); Albany (WAM 30983; 30984); Bunbury (WAM 30974; 32105); Shark Bay (Wyatt *et al*. 2005); Port Hedland (WAM 30634; CRIMP 1999; WAM 32176; 32187).

Distribution elsewhere

Mediterranean Sea, Adriatic Sea, southern Britain, Ireland, Ghana, Massachusetts to Florida, Gulf of Mexico, Brazil, Panama Canal; New Zealand, South Australia (Ryland 1965; Ryland and Hayward 1977; Winston 1982; Gordon 1986; Gordon and Mawatari 1992); in Australia known from Port Adelaide, SA (Brock 1985) and Port Phillip Bay, Vic. (Hewitt *et al*. 2004).

Remarks

This is a common fouling species, mainly found in ports and harbours on submerged structures where colonies are commonly associated with *B. neritina* (Ryland 1965; Ryland and Hayward 1977). It is less tolerant of warm temperatures than that species (Winston 1982).

Family Candidae

Tricellaria inopinata Hondt and Occhipinti Ambrogi, 1985

Western Australian records and vouchers

Port Hedland (WAM 30555).

Distribution elsewhere

Origin: Probably Pacific, known to be invasive in New Zealand and Europe (Dyrynda *et al.* 2001); cryptogenic in southern Australia (Zibrowius 1991; Aquenol 2001 citing a pers. comm. from P. Bock).

Remarks

Bock (cited in Aquenol 2001) indicates that this is a cosmopolitan species that has only recently been distinguished from several closely related taxa, and that many of the records of *T. occidentalis* may represent *T. inopinata*. Further work is required to establish the distributions of these species in Australia.

Tricellaria occidentalis (Trask, 1857)

Western Australian records and vouchers

Fremantle (CRIMP 2000; WAM 32702; 30814); Barrow I. (Wells and Huisman 2004; Western Australian Museum 2005); (WAM 8520; no location given).

Distribution elsewhere

Known from British Columbia to California, Japan, China, New Zealand, Venice, Italy (Osburn 1950; Gordon 1986); in Australia from SA and Port Phillip Bay, Vic. (Gordon and Mawatari 1992; Hewitt *et al.* 2004).

Remarks

See under *T. inopinata*.

Family Cryptosulidae

Cryptosula pallasiana (Moll, 1803)

Western Australian records and vouchers

Albany (CRIMP 1997b; WAM 30994; 30996; 32029); Bunbury (CRIMP 1997a; WAM 30528; 32102; 32359); Fremantle (CRIMP 2000; WAM 30804; 32803). South coast and lower west coast (NIMPIS 2002).

Distribution elsewhere

Widespread around the world, particularly in ports, harbours and estuaries (Ryland 1965; Hayward and Ryland 1979; Winston 1982; Gordon 1989; Gordon and Mawatari 1992); in Australia from the south coast (Bock 1982), including Port Adelaide, SA (Brock 1985) and Port Phillip Bay and Western Port, Vic. (Keough and Ross 1999; Hewitt *et al.* 2004); Sydney Harbour, NSW (Keough and Ross 1999).

Remarks

This is a common and well-known component of the fouling fauna that can be found encrusting on virtually all solid surfaces in the intertidal or shallow subtidal, including boat hulls (Ryland 1965; Hayward and Ryland 1979; Bock 1982; Gordon 1989; Gordon and Mawatari 1992); its distribution may be related to proximity to shipping lanes (Winston 1982).

Family Electridae

Conopeum seurati (Canu, 1928)

Western Australian records and vouchers

Esperance (Western Australian Museum 2002; Campbell 2003b; WAM 30568); Shark Bay (Wyatt *et al.* 2005).

Distribution elsewhere

Estuarine habitats in Britain, northern Europe, Mediterranean, New Zealand, Northeast Pacific, Florida (Ryland and Hayward 1977; Winston 1982; Gordon 1986; Gordon and Mawatari 1992); elsewhere in Australia from Port Phillip Bay, Vic. (Hewitt *et al.* 2004).

Remarks

This species is tolerant of extreme fluctuations in salinity and temperature (Ryland and Hayward 1977; Gordon and Mawatari 1992).

Family Epistomiidae

Synnotum aegyptiacum (Audouin, 1826)

Western Australian records and vouchers

Port Hedland (WAM 30551).

Distribution elsewhere

Widespread in warm waters, including Indonesia, Timor, Singapore, Japan, Indian Ocean, Red Sea, Mediterranean Sea, Brazil, Florida, California (Osburn 1950; Gordon 1984); in Australia from Vic. and NSW (Gordon 1984).

Family Savignyellidae

Savignyella lafontii (Audouin, 1826)

Western Australian records and vouchers

Shark Bay (Wyatt *et al.* 2005); Barrow I. (Wells and Huisman 2004; Western Australian Museum 2005); Port Hedland (WAM 30556; 32310).

Distribution elsewhere

Widely distributed in warmer waters (Osburn 1952; Winston 1982; Wyatt *et al.* 2005).

Remarks

This species is usually found associated with algae, sponges, *Zoobotryon* and hydroids; its delicate colonies are not usually obvious until examined microscopically (Winston 1982).

Family Schizoporellidae

Schizoporella errata (Waters, 1878)

Western Australian records and vouchers

Esperance (Western Australian Museum 2002; Campbell 2003b; WAM 30566; 30573); Albany (WAM 30541; 30535; 30547); Bunbury (WAM 30533); Fremantle Harbour (CRIMP 2000; WAM 33011); Geraldton (WA Museum 2001; Campbell 2003a); Shark Bay (Wyatt *et al.* 2005).

Distribution elsewhere

Widespread in warm temperate to subtropical seas (Ryland 1965; Hayward and Ryland 1979; Gordon and Mawatari 1992); in Australia known from Port Adelaide, SA (Brock 1985); Port Phillip Bay, Vic. (Hewitt *et al.* 2004).

Remarks

A well known fouling species, mostly found in shallow water in ports and harbours (Ryland 1965; Hayward and Ryland 1979).

Schizoporella unicornis (Johnston, 1847)

Western Australian records and vouchers

Esperance (Western Australian Museum, 2002; Campbell, 2003b; WAM 30567; 30571); Albany (CRIMP 1997b; WAM 32633); Bunbury (CRIMP 1997a; WAM 30532; 30534; 32104); WA (Pollard and Hutchings 1990b); Fremantle Harbour (Allen 1953). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Cryptogenic in Japan and colder waters of the eastern Atlantic; introduced to the northeast Pacific (including the Hawaiian Is), west Atlantic (Osburn 1952; Ryland 1965; Sutherland 1978; Hayward and Ryland 1979; Winston 1982; Hurlbut 1991); and eastern and soutwestern Australia (e.g., Port Adelaide, SA, Port Phillip Bay, Vic., Port Hacking and Port Jackson, NSW, Great Barrier Reef, Qld.) (Allen 1953; Vail and Wass 1981; Brock 1985; Pollard and Hutchings 1990b; Hewitt *et al.* 2004).

Remarks

A principal fouling species, recorded widely but perhaps often erroneously as there is some confusion with *Schizoporella errata* (Ryland 1965; Hayward and Ryland 1979; Winston 1982). There is some evidence that this species arrived in Sydney on two Japanese vessels captured during the war (Allen 1953).

Family Watersiporidae

Watersipora arcuata Banta, 1969

Western Australian records and vouchers

Esperance (Western Australian Museum 2002; Campbell 2003b; WAM 30569); Albany (CRIMP 1997b); Bunbury (CRIMP 1997a; WAM 32082; 32091); Fremantle Harbour (CRIMP 2000; WAM 32836; Mackie *et al.* 2006); Geraldton (WA Museum 2001; Campbell 2003a); WA (Pollard and Hutchings 1990b). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Widely distributed in warmer seas (Banta 1969; Winston 1982; Gordon 1989; Gordon and Mawatari 1992); in Australia recorded from several locations in southern Australia (Bock 1982), including Port Adelaide, SA (Brock 1985), Port Phillip Bay, Vic. (Hewitt *et al.* 2004), Port Hacking, Port Jackson and Port Kembla, NSW (Vail and Wass 1981; Moran and Grant 1993) and Qld. (Pollard and Hutchings 1990b).

Remarks

This is a common and well-known fouling organism that can grow rapidly on almost any surface, including copper anti-fouling paint (Winston 1982; Bock 1982; Gordon 1989; Gordon and Mawatari 1992).

Watersipora subtorquata (d'Orbigny, 1852)

Western Australian records and vouchers

Albany (WAM 30539); Bunbury (CRIMP 1997a; WAM 30527); Fremantle (CRIMP 2000; Mackie *et. al.* 2006); Geraldton (WA Museum, 2001; Campbell 2003a); Shark Bay (Wyatt *et al.* 2005).

Distribution elsewhere

Brazil, West Indies, Bermuda, California, Cape Verde Islands, Japan, Torres Strait, Mediterranean, Great Barrier Reef, New Zealand (Gordon 1989; Zibrowius 1991; Gordon and Mawatari 1992); in Australia from the Great Barrier Reef, Qld. (Gordon and Mawatari 1992); Port Phillip Bay and Portland, Vic. (Parry *et al.* 1997; Currie *et al.* 1998; Keough and Ross 1999; Hewitt *et al.* 2004); Port Lincoln and Adelaide, SA (Keough and Ross 1999); and Launceston, Tas. (Aquenol 2001).

Remarks
Grows on a wide variety of substrata. Exact distribution uncertain because of taxonomic difficulties (Gordon and Mawatari 1992; Mackie *et. al.* 2006).

Order Ctenostomatida

Family Vesiculariidae

Amathia distans Busk, 1886

Western Australian records and vouchers
Port Hedland (CRIMP 1999; WAM 30559; 32445; DALSE 2004). Lower west coast and Pilbara of WA (NIMPIS 2002).

Distribution elsewhere
Apparently native to the warmer waters of the west Atlantic; cryptogenic in the east Atlantic and introduced widely, including France, the Mediterranean and Red Seas, the Atlantic coast of America from North Carolina to Brazil, Puget Sound Washington, Southern California, South Atlantic, Java, Indonesia, New Zealand, and various locations around Australia (Osburn 1953; Winston 1982; Gordon and Mawatari 1992).

Remarks
Amathia distans forms pale-brownish transparent colonies growing on other bryozoans, algae or more usually under sandstone boulders, on oyster valves and polychaete tubes (Gordon and Mawatari 1992). This species is not considered a pest in Australia and its potential impact on the environment is regarded as low (CRIMP 1999).

Amathia vidovici Heller, 1867

Western Australian records and vouchers
Port Hedland (WAM 30559; WAM 30629).

Distribution elsewhere
Recorded from the Western Atlantic, from Massachusetts to Gulf of Mexico, the Caribbean, the Pacific from southern California to the Galapagos, the Mediterranean, Adriatic, East Atlantic and Indian Ocean (Osburn 1953; Winston 1982).

Bowerbankia gracilis Leidy, 1855

Western Australian records and vouchers
Port Hedland (WAM 30552).

Distribution elsewhere
Widely distributed around the world, mostly in shallow water (Osburn 1953; Ryland 1965; Winston 1982; Gordon 1986; Gordon and Mawatari 1992), in Australia from Port Adelaide, SA (Brock 1985).

Remarks
This species occurs in brackish as well as marine waters and grows on a wide variety of surfaces (Ryland 1965; Winston 1982), its colonies appearing as a characteristic fine grey ‘fur’ just visible to the naked eye (Gordon and Mawatari 1992).

Zoobotryon verticillatum della Chiaje, 1828

Western Australian records and vouchers
Port Hedland (WAM 30550; 32461); Shark Bay (Wyatt *et al.* 2005).

Distribution elsewhere
Widely distributed in warm waters, including the Mediterranean and Adriatic where it is common in many of the major ports (Osburn 1953; Ryland 1965; Winston 1982; Gordon and Mawatari,1992); in Australia from several locations in southern Australia (Bock 1982) including Port Adelaide, SA (Brock 1985); Port Phillip Bay, Vic. (Hewitt *et al.* 2004); Port Hacking and Port Jackson, NSW (Vail and Wass 1981).

Remarks
A common fouling species of warmer waters, typically found in ports and harbours growing on any submerged object (Ryland 1965; Bock 1982).

Arthropoda

Class Malacostraca (Amphipods, Isopods and Crabs)

Order Isopoda (Isopods)

Family Cirolanidae

Cirolana harfordi (Lockington, 1877)

Western Australian records and vouchers
Swan River (Bruce 1986; Poore and Storey 1999; Furlani 1996); Fremantle Harbour (Hass and Jones 2000). Introduced into the lower west coast of WA (NIMPIS 2002).

Distribution elsewhere
First described from California, distributed in western North America from British Columbia to Baja California, subsequently recorded from Japan, eastern Russia and Malaysia (Johnson 1976; Poore and Storey 1999); in Australia from Port Phillip Bay, Lorne, and Bass Strait, Vic. (Bruce 1986; Hutchings

et al., 1987; Currie *et al.*, 1998; Cohen *et al.*, 2001; Hewitt *et al.*, 2004) and Waverton, NSW (Bruce, 1986). Australian records mainly limited to ports.

Remarks

Initially discovered in the Swan River in 1980 (Bruce, 1986) and subsequently in Fremantle Harbour in 1991 (Hass and Jones, 2000). Collected under rocks and amongst mussels, from ship hulls (Bruce, 1986); this is a voracious scavenger that has the potential to be a pest species by reaching high population densities (Johnson, 1976; Furlani, 1996).

Family Sphaeromatidae

Paracerceis sculpta (Holmes, 1904)

Western Australian records and vouchers

Esperance (Western Australian Museum, 2002; Campbell, 2003b; WAM 34505; 34506); Bunbury, Mandurah, Fremantle, Port Denison, 1996 (Hass and Jones, 2000); Bunbury (WAM 23303; CRIMP; WAM 34508 – 34511; 35140 – 35187); Fremantle (CRIMP; WAM 35839; 35846). Lower west coast of WA (NIMPIS, 2002).

Distribution elsewhere

Originally described from California, and since recorded elsewhere in tropical Pacific and Atlantic (Brazil, Mexico, Hawaiian Is.); possibly introduced to the Mediterranean (Zibrowius, 1991); in Australia from Port Phillip Bay, Vic. (Hewitt *et al.*, 2004); Townsville, Qld. (Harrison and Holdich, 1982b; Hutchings *et al.*, 1987; Pollard and Hutchings, 1990b; Furlani, 1996; Poore and Storey, 1999; Hewitt and Campbell, 2001).

Remarks

Like other sphaeromatids, females and juveniles are almost impossible to identify without accompanying males. This species is so rarely recorded in Australia that nothing is known of its biology here (Poore and Storey, 1999).

Paradella dianae (Menzies, 1962)

Western Australian records and vouchers

Bunbury (WAM 23302; WAM 16781; 23302); Swan River (Harrison and Holdich, 1982a; Pollard and Hutchings, 1990b; Zibrowius, 1991; Furlani, 1996); Fremantle Harbour, Bunbury Harbour (Hass and Knott, 1998). Other vouchers QM W7938, QM W3746. South coast and lower west coast of WA (NIMPIS, 2002).

Distribution elsewhere

Originally described from Baja California and subsequently reported from California, the Marshall Islands, Queensland, the Arabian Sea, Brazil and Puerto Rico, recorded in the Mediterranean for the first time from Alexandria, Egypt (Zibrowius, 1991); in Australia from Townsville and North Stradbroke Island, Qld. (Harrison and Holdich, 1982a; Hutchings *et al.*, 1987; Furlani, 1996).

Remarks

First discovered in the Swan River in 1980 (Harrison and Holdich, 1982a), subsequently in Fremantle and Bunbury Harbours in 1994/95 (Hass and Knott, 1998). Grows amongst barnacles, bryozoans and rock oysters on rocks and artificial structures, appears to be tolerant of a wide variety of ecological conditions (Harrison and Holdich, 1982a).

Sphaeroma serratum Fabricius, 1787

Western Australian records and vouchers

Esperance (Western Australian Museum, 2002; Campbell, 2003b; WAM 36953); Swan River (Holdich and Harrison, 1983; Hutchings *et al.*, 1987; Pollard and Hutchings, 1990b; Hass and Knott, 1998; Furlani, 1996); Jurien Bay (Hass, 2007).

Distribution elsewhere

Widespread (Pollard and Hutchings, 1990b).

Remarks

First discovered in the Swan River in 1980 (Holdich and Harrison, 1983), subsequently rediscovered in 1994/95 (Hass and Knott, 1998) and then in Jurien Bay in 2006 (Hass, 2007).

Order Amphipoda (Amphipods)

Family Corophiidae

Monocorophium acherusicum (Costa, 1857)

Western Australian records and vouchers

Bunbury, Swan River (Poore and Storey, 1999). Lower west coast of WA (NIMPIS, 2002).

Distribution elsewhere

Native to the northeast Atlantic and Mediterranean region, cryptogenic on both coasts of North America, introduced to various localites in the southwestern Atlantic, Indian and western Pacific oceans (Hurley, 1954; Barnard, 1970); in Australia from the southeast and southwest, e.g., Port Jackson, Port Kembla and Botany Bay, NSW; eastern Tasmania (Poore and Storey, 1999); Gippsland Lakes, Mallacoota, Western Port and Port Phillip Bay, Vic. (Fearn-Wannan, 1968; Cohen *et al.*, 2001; Hewitt *et al.*, 2004).

Remarks

This species is commonly found in association with ships, buoys and around wharf structures (Fearn-Wannan 1968), its distribution tracing some major shipping routes (Hurley 1954).

Monocorophium insidiosum (Crawford, 1937)

Western Australian records and vouchers

Swan River (Poore and Storey 1999). Lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Widely distributed, especially in harbours (Barnard 1970; Alonso de Pina 1997); in Australia from Port Kembla, NSW, Port Phillip Bay and Western Port, Vic., and Port MacDonnell, SA (Poore and Storey 1999; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

An estuarine species, occurring intertidally and subtidally on mud sediments or among algae and seagrasses. Most Australian records are from harbours or estuaries (Poore and Storey 1999).

Monocorophium sextonae (Crawford, 1937)

Western Australian records and vouchers

Bunbury Harbour (Poore and Storey 1999). Lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Northeast Atlantic (England, Scotland, Ireland, France, The Netherlands, the Mediterranean, Portugal) and New Zealand (Hurley 1954; Costello 1993) in Australia from Jervis Bay, NSW; Port Phillip Bay, Point Henry, Queenscliff, and Western Port, Vic.; Georges Bay and Launceston, Tas. (Poore and Storey 1999; Aquenol 2001; Hewitt *et al.* 2004).

Remarks

Monocorophium sextonae is a tube dwelling amphipod, found on kelp holdfasts, sponges and artificial substrata (Costello 1993). Hurley (1954) suggested that the species had possibly been introduced to Europe from New Zealand. Its natural distribution is uncertain and it may be native to Australia and New Zealand (Poore and Storey 1999).

Order Decapoda (Crabs)

Family Portunidae

Carcinus maenas (Linnaeus, 1758)

Western Australian records and vouchers

Swan River, 1965 (Zeidler 1978; Furlani 1996; Hass and Jones 2000; WAM 14833). WA (Pollard and Hutchings 1990b). Voucher specimen(s): Presumably AM P36248-9, P36089. NIMPIS (2002) has a blank area indicated on the lower west coast of WA.

Distribution elsewhere

Originally from Europe, although now widespread elsewhere; in Australia from Port River – West Lakes, SA, Port Phillip Bay, Vic. to Sydney, NSW, and Tas. (Fulton and Grant 1900, 1901; Allen 1953; Zeidler 1978; Rozenweig 1984; Hutchings *et al.* 1986, 1987, 1989; Pollard and Hutchings 1990b; Furlani 1996; Currie *et al.* 1998; Ahyong 2005; Cohen *et al.* 2001; Aquenol 2001; Hewitt *et al.* 2004).

Remarks

In 1965 the European shore crab, *Carcinus maenas*, was recorded from the Swan River Estuary, WA. No populations appear to have established (CRIMP 1997b: 7) and the species is presently known from only one specimen in WA (Hass and Jones 2000). This introduced species, however, has become established in the south-eastern states of Australia, where it out competes native species (Fulton and Grant 1901; Zeidler 1978, 1988; Furlani 1996; Walters 1996; Ahyong 2005). The method of introduction of *C. maenas* into Western Australia is not known, but the species is suspected to have been introduced into Australia from Europe, on the hulls of the ships which brought the first settlers (Fulton and Grant 1901).

Family Inachoididae

Pyromaia tuberculata (Lockington, 1877)

Western Australian records and vouchers

Cockburn Sound (Morgan 1990; Furlani 1996; Poore and Storey 1999; Hass and Jones 2000; WAM 19338). Lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Native to west coast of the Americas ranging from San Francisco Bay, California to Utria Bay, Colombia; widely distributed in the temperate and sub-tropical Pacific and South Atlantic, Brazil, Japan, New Zealand (Morgan 1990; Poore and Storey 1999); in Australia from Port Phillip Bay, Vic. (Hass and Jones 2000; Furlani 1996; Poore and Storey 1999; Hewitt *et al.* 2004).

Remarks

In Western Australia, the American spider crab, *Pyromaia tuberculata*, was introduced to Cockburn

Sound in 1978 via ballast water (Morgan 1990). This species is now also recorded as an introduction in Port Phillip Bay, Vic. (Walters 1996), but in WA it is only known by the specimen reported by Morgan in 1990.

Class Maxillopoda

Subclass Cirripedia (Barnacles)

Order Sessilia

Family Balanidae

Amphibalanus amphitrite (Darwin, 1854)

Western Australian records and vouchers

As *Balanus amphitrite*: Garden I. (Lewis 1981); from Esperance area to Dampier Archipelago (Jones 1987a, 1987b, 1990a, 1990b, 1999a, 2002, 2004b, 2005; Jones and Hewitt 2001; WAM 668; 778, 10092; 6926; 12141); Port Hedland (CRIMP 1999; DALSE 2004) and Broome and Kimberley area (Jones 1991, 1992b, 2004b; WAM 20944; 21166-21168).

Distribution elsewhere

Indian Ocean to southwestern Pacific; regarded as an introduced species in New Zealand (Foster 1978) and Australia (Jones 1992a). Cosmopolitan in tropical and warm temperate seas (Jones 1990a).

Remarks

A cosmopolitan, cryptogenic species, occurring in tropical, subtropical and temperate seas. In Australia it is recorded from the waters of WA, SA, Vic., NSW, Qld. and the NT. The species occurs intertidally to a depth of 9m, in quiet bays and estuaries protected from rough surf. It attaches to a variety of animate (e.g. decapod crustaceans, molluscs) and inanimate (e.g. rocks, buoys, cables) substrata and is an important fouling species of boats and marine installations.

Amphibalanus improvisus (Darwin, 1854)

Western Australian records and vouchers

As *Balanus improvisus*: Southwestern Australia (Bishop 1951; Hutchings *et al.* 1987; Jones 1992a; Furlani 1996; no vouchers available).

Distribution elsewhere

Atlantic coasts of North America; North Atlantic; Europe; W Africa to Cape of Good Hope; Mediterranean; Black Sea; Red Sea; Baltic Sea; southern Australia (Pollard and Hutchings 1990b); Japan; NW coast of USA (Washington to San Francisco); Ecuador.

Remarks

The Australian record is historical and the species has not been recollected (Jones 1992a). Bishop (1951) suggested that the Atlantic brackish-water species *Balanus improvisus* had become established in "one of the southern Australian ports" during the 1940s. However, from fouling studies of submerged surfaces on the eastern Australian coast, Allen (1953) could not substantiate this claim and there are no subsequent records of this species occurring in Australian waters. There are no specimens lodged in any of the Australian state museums (pers. obs., DSJ). If the species is found in Australia in the future, it would be through a new introduction.

Amphibalanus reticulatus (Utinomi, 1967)

Western Australian records and vouchers

As *Balanus reticulatus*: Cockburn Sound (WAM 33156; 33157); Swan Estuary, Nedlands (WAM 32451); Yanchep (Jones 1990b; WAM 17826); *Leonardo Da Vinci* Geraldton Port (Jones 2002a; WAM 34004; 34007); Barrow I. (Jones 2005); Dampier Archipelago (WAM 27238); Burrup Peninsula (WAM 27336; 27339); Cape Preston (WAM 27355); Dampier (WAM 27354; 25750); Cape Lambert, Port Hedland (Jones, unpublished data); Cocos-Keeling Islands (WAM 29046); Christmas Island (WAM 33372; 33373).

Distribution elsewhere

Cosmopolitan in tropical waters and a circumtropical fouling species (Jones 1990a).

Remarks

This circumtropical fouler was first recorded in Australian waters on fouling panels at the North Barnard Islands, Qld. (Lewis 1979, as *B. amphitrite*; 1981b). First records in WA were from Yanchep Marina (Jones 1990a, 1991; Jones *et al.* 1990) and, more recently, the species has been recorded from the Dampier Archipelago (Jones 2004b) and Barrow Island (Jones 2005). The means of introduction of *A. reticulatus* into Australian waters is unknown, but Utinomi (1967) has suggested that the widespread distribution of this Japanese species is via ship transport.

Megabalanus ajax (Darwin, 1854)

Western Australian records and vouchers

Shark Bay (WAM 32490; 32496); Muiron Is. (Jones and Hewitt 1996; WAM 22345); Barrow I. (Jones 2005); Dampier Archipelago (Jones 2004b; WAM 22345-22347); Broome (WAM 32495).

Distribution elsewhere

Widespread in the Indo-west Pacific.

Remarks

Megabalanus ajax attaches mainly to corals (e.g. *Millipora complanata* Lamarck) but also occasionally occurs as a fouler of ships hulls (Jones 1992b, 2004b, 2005). The species has been recorded from Queensland as well as from WA. The possible vector for the introduction of this species to WA waters is shipping.

Megabalanus rosa (Pilsbry, 1916)

Western Australian records and vouchers

Garden I. (WAM 33163; 33165; 33189); Shark Bay (WAM 15848; 15855); Barrow I. (Jones 2005); Dampier Archipelago (WAM 27205; 27241; 27292); Port Hedland (WAM 15847); Cockatoo I. (AM P 20075). WA central and north-west coast (Jones *et al.* 1990; Jones 1992a). Introduced into the entire west and Pilbara coasts of WA (NIMPIS 2002).

Distribution elsewhere

Japan; China; Taiwan (Pollard and Hutchings 1990b); Australia (Allen 1953); in Australia from lower east coast, NSW (Jones *et al.* 1990; Jones 1992a).

Remarks

Allen (1953) recorded the Japanese fouler *Megabalanus rosa*, together with *M. volcano* and *Amphibalanus albicostatus*, on aircraft carriers and other vessels returning to Australia after service in Korean and Japanese waters. However, it is not known where these vessels docked and Allen (1953) did not record these species as establishing on the Australian coastline. The appearance of the species in WA waters appears to be relatively recent, the first specimens being collected in 1981 (Jones 1992a). *Megabalanus rosa* is now established on the central and the north-western coast of WA (Garden Island; Shark Bay, Barrow Island, the Dampier Archipelago, Port Hedland and Cockatoo Island), as well as on the lower east coast of Australia (Woolongong, Port Botany and Port Kembla in NSW) (Hass and Jones 2000; Jones 2000b, 2001a, 2001b, 2004b, 2005; Jones *et al.* 1990). These are all areas that receive international shipping and, therefore, ship fouling is the most probable transport mechanism for this species.

Megabalanus tintinnabulum (Linnaeus, 1758)

Western Australian records and vouchers

Esperance (WAM 32482); Albany (WAM 16098); Rockingham (WAM 16132); Cockburn Sound (Jones 1992a; WAM 12188); Fremantle (Jones 1999a; WAM 25240); Cottesloe (WAM 3919); Port Gregory (WAM 12153); Dongara (WAM 14546); Geraldton (WAM 33766); Shark Bay (WAM 7484); Carnarvon (WAM 23789); Pt Cloates, Ningaloo Reef (WAM 13265); North West Cape (WAM 12159); Warroora Station, Ningaloo Reef (WAM 16139); Coral Bay (WAM 16214); Exmouth Gulf (WAM 21180); Muiron Islands (Jones and Hewitt 1996; WAM 22287); Onslow (WAM 7556); Barrow I. (Jones 1992a; Jones 2005; WAM 14242); Montebello Islands (Jones and Berry 2000; WAM 23404); Dampier (Jones 1992a; WAM 12151); Roebourne (WAM 21178); Cape Lambert (WAM 21184); Port Hedland (CRIMP 1999); Broome (WAM 12210); Port Walcott (WAM 14433); Cockatoo I. (Jones 1992a); Yampi Sound, Kimberley (WAM 16093); Mary Anne Passage (WAM 12191); Kimberley (Jones and Hewitt 1997; WAM 22978); King Sound, Derby (WAM 32674); Bonaparte Archipelago (WAM 16138); Buccaneer Archipelago (WAM 21013); Cocos – Keeling Islands (WAM 33133); Flying Fish Cove, Christmas Island (WAM 20038). NIMPIS (2002) states the species is introduced into Australia but shows it as cryptogenic throughout WA.

Distribution elsewhere

Cosmopolitan – Atlantic Ocean, West Africa from Mediterranean to Cape of Good Hope, East Mediterranean, Madagascar, Arabian Sea, Bay of Bengal, Indian Ocean, Thailand, Formosa, Sagami Bay, Japan, Malay Archipelago, East Indian Archipelago, New Zealand, Palau Island (Jones 1990b). In Australia from Bass Strait, Vic., lower east coast of NSW, north east coast of Qld. and Port Essington, NT (Jones *et al.* 1990; Furlani 1996).

Remarks

Megabalanus tintinnabulum is a cosmopolitan fouling species, first recorded in WA waters in 1949 (Jones 1990a, 1991, 1992a). The species is now known from southwestern to northwestern waters of WA (Hass and Jones 2000; Jones 1990a, 1990b; 1991, 1992b, 1999a, 2000, 2001a, 2004b, 2005; Jones and Hewitt 1997, 2001; Jones *et al.* 1990). Jones (1990) suggested that the species is an introduction via shipping, since most WA collection localities are in the vicinity of ports or areas that receive international shipping (e.g. Kwinana, Fremantle, Carnarvon, Barrow Island, Thevenard Island, Dampier, Cape Lambert, Cockatoo Island). Although early reports of *M. tintinnabulum* occurring on the eastern Australian coast may be erroneous (Allen 1953; Jones 1990a, 1991), records of the species have been confirmed from Bass Strait, Vic., and the lower, mid and north-eastern coasts and northern coast of Australia (Jones 1999b; Jones unpublished data; Jones *et al.* 1990).

Family Tetraclitidae

Tesseropora rosea (Krauss, 1848)

Western Australian records and vouchers
Albany (WAM 18955); Cottesloe Beach (WAM 17763); Fremantle; Cockburn Sound (WAM 15963); Garden I. (Jones 1990c; WAM 536-86).

Distribution elsewhere
South Africa; Australasia – Australia, Lord Howe I., Kermadecs; in Australia, from eastern Australia between 19° and 38°S, Mallacoota, Inverloch, Vic. (Jones 1990a).

Remarks
Tesseropora rosea is a common intertidal species on the eastern Australian seaboard. Originally described from one specimen collected at Algoa Bay, South Africa (Krauss 1848), the species was subsequently recorded from NSW and Queensland (Darwin 1854), where it is abundant in exposed coastal areas in the intertidal (Jones *et al.* 1990). The species was not known from western areas of the continent until 1948 (Jones 1990a). In 1986, three live specimens were collected on intertidal granitic rock at Cottesloe and the species has also been found at Fremantle, Garden Island and Cockburn Sound and, more recently, Albany. The isolated occurences of this species, in the vicinity of active ports (Fremantle and Albany), led to the suggestion that the species had been introduced from eastern Australia via shipping. Since *T. rosea* is not known as a hull fouler, ballast water transport was implicated as the dispersal agent for the introduction of the species into the waters of Western Australia (Jones 1990c).

Cnidaria

Class Hydrozoa (Hydroids)

Order Anthomedusae

Family Corynidae

Sarsia eximia (Allman, 1859) = *Sarsia radiata* von Lendenfeld, 1885

Western Australian records and vouchers
Albany (WAM 30538); Houtman Abrolhos Is. (Watson 1996; Watson 1997); Shark Bay (Wyatt *et al.* 2005). NIMPIS (2002) shows this species as a known introduction to the south coast but cryptogenic on the lower west coast of WA.

Distribution elsewhere
Widespread, regarded as cryptogenic in the North Atlantic from North America to Europe and from Iceland to France; Mediterranean; west coast of North America, Brazil, Valparaiso and the NW Pacific, New Zealand (Schuchert 1996); in Australia cosmopolitan and cryptogenic in Sydney Harbour, NSW, and numerous locations in Vic. (e.g., Bass Strait, Westernport Bay, Popes Eye Reef, as *Sarsia radiata*, Watson 1978, 1994, 1997, 1999); Port Phillip Bay, Vic. (Hewitt *et al.* 2004), introduced to Tas. (NIMPIS 2000).

Family Eudendriidae

Eudendrium carneum Clarke, 1882

Western Australian records and vouchers
Perth to Albany (Watson 1996); Bunbury (CRIMP, WAM 30531).

Distribution elsewhere
Circumtropical (Boero and Bouillon 1993); California; Ecuador; Mexico; California; north west Atlantic (Fraser 1948).

Eudendrium cf. *capillare* Alder, 1856

Western Australian records and vouchers
Albany (WAM 30544).

Distribution elsewhere
Cosmopolitan (Fraser 1948; Boero and Bouillon 1993); in Australia from Qld. (Pennycuick 1959); Port Phillip Bay, Vic. (Ralph 1966).

Family Tubulariidae

Ectopleura crocea (Agassiz, 1862)

[including *Tubularia crocea and Tubularia ralphi* (Bale, 1884)].

Western Australian records and vouchers
Dunsborough (WAM 945); Cockburn Sound (WAM); Fremantle (Bock 1982; Watson 1999; CRIMP 2000). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere
Native to Atlantic coast of North America, introduced to the Pacific coast of North America, Europe, Mediterranean, Japan, parts of Asia, Australia and New Zealand (Fraser 1948; Schuchert 1996; Watson 1999); in Australia from the east and south-east [e.g., Qld. (Pennycuick 1959); Port Phillip Bay, Vic. (Ralph 1966; Black 1971; Watson 1980; Hewitt *et al.* 2004); Sydney Harbour, Port Kembla, NSW (Watson 1980, 1999); Launceston, Tas. (Aquenol 2001)].

Remarks
This species forms colonies to 12 cm high composed of hundreds of greenish-white stems growing from a matted hydrorhiza (Watson 1999). It is a common fouling organism on the Victorian coast. This species was recorded on numerous occasions as *Tubularia ralphii* (Bale, 1884), the synonymy tentatively suggested by Schuchert (1996) and Watson (1999).

Order Leptomedusae

Family Aglaopheniidae

Aglaophenia parvula Bale, 1882

Western Australian records and vouchers
Albany (WAM 30543).

Distribution elsewhere
Bass Strait, Vic. (Watson, 1994).

Remarks
Associated with sponges and ascidians (Watson 1994). The WA record of this cryptogenic species is based on a specimen in the WA Museum and requires verification.

Gymnangium gracilicaule (Jäderholm, 1903)

Western Australian records and vouchers
Houtman Abrolhos Is. (Watson 1996; Watson 1997); Port Hedland (CRIMP 1999; WAM 30557).

Distribution elsewhere
Widely distributed in the tropical and subtropical Indian Ocean and Indo-West Pacific (Watson, 1997).

Family Campanulariidae

Obelia dichotoma (Linnaeus, 1758) (=*Obelia australis*)

Western Australian records and vouchers
Albany (WAM 30546); Bunbury (WAM 30524); Shark Bay (Wyatt *et al.* 2005). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere
Widespread in tropical and temperate waters of the Atlantic, Pacific, and Indian oceans (Fraser 1948; Calder 1991; Boero and Bouillon 1993; Brinckmann-Voss 1996); in Australia from Qld. (Pennycuick 1959), Tas. and Bass Strait (Ralph 1957, Watson 1994, both as *O. australis*), Port Phillip Bay and Western Port, Vic. (Watson 1999) and Eden to Port Stephens, NSW (Allen and Wood 1950, as *O. australis*).

Remarks
Extremely opportunistic species growing in a wide variety of habitats including algal and invertebrate substrata, present in southern Australia at least since the 1880s (Watson 1999).

Obelia longissima (Pallas, 1766)

Western Australian records and vouchers
Port Hedland (CRIMP 1999?; DALSE 2004).

Distribution elsewhere
Widespread (Fraser 1948; Ralph 1957; Boero and Bouillon 1993).

Remarks
According to comments on the NIMPIS web site (2002, under *Obelia dichotoma*: similar species), this species is not recorded for Australia, but, confusingly, elsewhere on the site it is listed as cryptogenic. The species is mentioned in the DALSE (2004) report as being recorded from Port Hedland by the CRIMP survey. In the CRIMP report, however, while the impacts of *O. longissima* are discussed (CRIMP 1999: 9), the species is not actually listed. Clarification of the Port Hedland record is clearly desirable.

Family Haleciidae

Halecium delicatulum Coughtrey, 1876

Western Australian records and vouchers
Albany (WAM 30536; 30545; 30549; 30546); Bunbury (WAM 30524); Houtman Abrolhos Is.; Perth to Albany (Watson 1996, 1997; WAM 30536; 30545; 30549). NIMPIS (2002) states that this species is introduced, but the map shows it occurring as cryptogenic on the south and lower west coasts.

Distribution elsewhere
Circumglobal tropical to Antarctic waters (Ralph 1958; Watson 1997); in Australia from numerous southern and eastern localities, e.g., Port Stephens, Port Jackson, and Coogee, NSW (Bale 1888; Ritchie 1911; Hodgson 1950; Bruny I., Tas. (Briggs 1914; Watson 1975); Port Phillip Bay, Western Port, and Bass Strait Vic. (Ralph 1966; Black 1971; Watson 1994; 1999; Hewitt *et al.* 2004); Qld. (Pennycuick 1959); Pearson Island, SA (Watson 1973).

Remarks
This is a common southern Australian species colonising many invertebrate and algal substrata (Watson 1997).

Family Halopterididae

Antennella secundaria (Gmelin, 1791)

Western Australian records and vouchers
Cape Peron (WAM 2541); Perth to Albany, Houtman Abrolhos Is., Shark Bay to Exmouth (Watson 1996, 1997); Port Hedland (CRIMP 1999; WAM 30554; DALSE 2004). Introduced to the Pilbara and cryptogenic in the Kimberley and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere
Cosmopolitan in temperate and tropical seas (Boero and Bouillon 1993; Watson 1997, 1999, 2000); in Australia from several southern and eastern localities, e.g., Qld. (Pennycuik 1959); Port Phillip Bay, Western Port, and Bass Strait, Vic. (Watson 1994, 1999; Hewitt *et al.* 2004); Pearson Island, SA (Watson 1973).

Remarks
Grows in thick masses on algal and invertebrate substrata in sheltered ocean waters, often amongst sponges and red algae (Bock 1982; Watson 1994).

Family Plumulariidae

Plumularia setacea (Linnaeus, 1758)

Western Australian records and vouchers
Cervantes (WAM 2650; 2629); Perth to Albany (Watson 1996); Jurien Bay (WAM 2632). NIMPIS (2002) states this is a known introduced species, but shows it as being cryptogenic on the south coast of WA.

Distribution elsewhere
Near cosmopolitan in subtropical and temperate seas (Fraser 1948; Boero and Bouillon 1993; Watson 1999, 2000); in Australia recorded from various southern and eastern localities, e.g., Port Phillip Bay and Bass Strait, Vic. (Bale 1888; Watson 1994, 1999); Tas. (Hodgson 1950); Qld. (Pennycuick 1959); Jervis Bay, NSW (Ritchie 1911).

Remarks
Generally found in sheltered, shallow waters, associated with algae, old shells and other invertebrates (Hodgson 1950; Bock 1982; Watson 1994), this species is reportedly intolerant of reduced salinity (Watson 1999).

Plumularia warreni Stetchow, 1919

Western Australian records and vouchers
Port Hedland (CRIMP 1999; WAM 30553).

Distribution elsewhere
South Africa, Madagascar, southwestern Indian Ocean (Gravier 1970; Gravier-Bonnet and Bourmaud 2006) and possibly Darwin (Watson pers. comm.).

Remarks
This species is listed for Port Hedland by CRIMP (1999) but without comment. The voucher specimen in WAM is listed as *Plumularia* cf. *warreni* and the identification requires confirmation (Watson 2007, pers. comm.).

MOLLUSCA (Molluscs)

Class Gastropoda (Gastropods)

Family Batillariidae

Velacumantus australis (Quoy and Gaimard, 1834)

Western Australian records and vouchers
Sandflats in lower Swan River and at Woodman Point, Cockburn Sound (Ewers 1967; Wells and Bryce 1986).

Distribution elsewhere
Queensland to South Australia; also Tasmania (Wells and Bryce 1986); northern NSW to southern Qld.

Remarks
Wells and Bryce (1986) state the WA records "May be the result of human introduction of the species" but there have been no further studies. The fossil record shows *V. australis* was previously more widespread across southern Australia but its range has since become more restricted. The record as an introduced species is tentatively accepted here.

Cotton (1984) also recorded *V. australis* from Albany, a record used by Ewers (1967) and Roberts and Wells (1980). However, the specimen was later determined to be a subfossil, and there are no records of living specimens from Albany (Wells 1984).

Family Cymatiidae

Cymatium cutaceum africanum (A. Adams, 1854)

Western Australian records and vouchers
Augusta (Wells and Kilburn 1986; WAM 54-82).

Distribution elsewhere
South Africa (Wells and Kilburn 1986).

Remarks
A single specimen of this species was collected at

Augusta by W. Anson on 27 or 28 January 1979. The species may well have arrived naturally in Western Australia as Augusta is not a major shipping area. This was apparently an isolated individual, and despite searching of the area no known populations exist in Augusta. In its natural range, this species lives among solitary ascidians offshore, under rocks at low tide or on sand near ascidians (Wells and Kilburn 1986).

Family Facelinidae

Godiva quadricolor (Barnard, 1927)

Western Australian records and vouchers

Found in Cockburn Sound and Fremantle in 1980, 1983 and 1997 (Willan 1987b; WAM 339-86; 26849). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Native to South Africa, from the Cape of Good Hope to Port Alfred (Willan 1987b), introduced to Port Jackson, NSW (Macnae 1954, as *Hervia quadricolor*).

Remarks

The specimen was collected by C. Bryce at the southern end of Cockburn Sound on 10 January 1984 and photographed. Detailed notes on the find were reported by Willan (1987b) and subsequently repeated by Furlani (1996). An experienced amateur photographer, G. Saueracker also saw specimens in the Fremantle to Cockburn Sound area at about the same time (Willan, 1987b). The species is also recorded by Fisheries WA (2000) and NIMPIS (2002).

Family Goniodorididae

Okenia pellucida Burn, 1967

Western Australian records and vouchers

Fremantle (Willan and Coleman 1984, no vouchers in WAM).

Distribution elsewhere

Widespread (see remarks); native range unknown but possibly includes Sydney, NSW (Willan and Coleman 1984).

Remarks

Rudman (2004) reported that this species, which was described from Sydney, is widespread, and has been reported from Hawaii, Japan, Palmyra Atoll, Malaysia, and the United Arab Emirates, in addition to Australia (NSW, Qld., WA). The species lives and feeds on the bryozoan *Zoobotryon verticillatum*. This is a common fouling species that is believed to be moved readily by shipping activities.

Family Haliotidae

Haliotis spadicea Donovan, 1808

Western Australian records and vouchers

Cowaramup Bay, south of Cape Naturaliste, 1952, referring to *H. sanguinea* (Macpherson 1953; MV F12987).

Distribution elsewhere

Native to South Africa (Macpherson 1953).

Remarks

Like the three species reported from Augusta by Wells and Kilburn (1986), this is a record of a South African species that may have arrived in Western Australia naturally. No populations have been subsequently recorded and the identification of the specimen needs to be checked.

Haliotis diversicolor Reeve, 1846

Western Australian records and vouchers

Not present; no vouchers.

Distribution elsewhere

Japan and China.

Remarks

Geiger (2000) and Geiger and Poppe (2000) show localities of North West Cape and Albany, but this is in error because the extensive collections in WAM do not record a single specimen of this species from WA.

Haliotis hargravesi (Cox, 1869)

Western Australian records and vouchers

Not present; no vouchers.

Distribution elsewhere

Northern NSW to southern Qld.

Remarks

Geiger and Poppe (2000) show a locality of Carnarvon with a question mark. This locality is incorrect because the extensive abalone holdings in WAM do not record a single specimen of this species in WA

Family Nassariidae

Bullia annulata Lamarck, 1816

Western Australian records and vouchers
Augusta (Wells and Kilburn 1986; WAM 52-82; Furlani 1996).

Distribution elsewhere
South Africa (Wells and Kilburn 1986; Furlani 1996).

Remarks
A single specimen of this species was collected at Flinders Bay, Augusta, by W. Anson on an unknown date. The species may well have arrived naturally in Western Australia as Augusta is not a major shipping area. This was apparently an isolated individual, and despite searching of the area no known populations exist in Augusta.

Nassarius burchardi (Dunker in Philippi, 1849)

Western Australian records and vouchers
Southern Qld. to Fremantle, WA; Swan River, 1965 (Chalmer *et al.* 1976; Slack-Smith and Brearley 1987). There are numerous specimens in WAM from a variety of WA locations.

Distribution elsewhere
Southern Australia.

Remarks
This species was first recorded in the Swan River in 1965 (Wilson and Kendrick 1968; Chalmer *et al.* 1976; Slack-Smith and Brearley 1987). However, it was simply an extension of the species into the estuary, and not an introduction. The species has been reported from a wide range of localities from across southern WA to the Swan River by Wells (1984), Wells and Bryce (1986) and Wilson (1994). The ecology of *N. burchardi* was investigated by Kowarsky (1969) and Smith (1975).

Nassarius kraussianus (Dunker, 1846)

Western Australian records and vouchers
Augusta (Wells and Kilburn 1986; WAM 51-82; 2670-83; 2670-83; 51-82).

Distribution elsewhere
South Africa (Wells and Kilburn 1986).

Remarks
Two shells of this species were collected at Augusta by Wendy Anson in January 1974 and by Glad Hansen at Flinders Bay, Augusta, on 2 July 1972. The species may well have arrived naturally in Western Australia as Augusta is not a major shipping area. These were apparently isolated individuals, and despite searching of the area no known populations exist in Augusta.

Family Polyceridae

Polycera hedgpethi Marcus, 1964

Western Australian records and vouchers
Quaranup, Princess Royal Harbour (Wells and Bryce 1993; Furlani 1996; NIMPIS 2002); Rockingham (WAM 29806). Lower west coast of WA (NIMPIS 2002).

Distribution elsewhere
California; Caribbean; Mediterranean; South Africa; New Zealand; Japan; Iberian Peninsula (Gosliner 1982; Pollard and Hutchings 1990b; Gofas and Zenetos 2003); in Australia from NSW, Vic., SA (Hutchings *et al.* 1987; Furlani 1996), e.g., Port Phillip Bay and Mallacoota, Vic. (Willan and Coleman 1984; Hewitt *et al.* 2004) and Port Hacking, NSW (Willan and Coleman 1984).

Remarks
This species was thought to be an introduction from California, where it was originally described. However, the natural range is obscure (Wilson 2006). Specimens were known from New Zealand prior to the original species description (Miller 2001) and the species was recorded in Australia only nine years later. In Western Australia the species was originally recorded from jetty pilings at Quaranup, Princess Royal Harbour at Albany in February 1980 (Wells and Bryce 1993: 76). Wilson (2006: 138) stated that no further specimens have been recorded from that locality or for the entire State (based on a pers. comm. C. Whisson and C. Bryce of the WA Museum), but the species has subsequently been collected from Rockingham in 2005 (WAM 29806).

Class Bivalvia (Bivalves)

Order Myoida

Family Teredinidae (Shipworms)

Western Australian records and vouchers
Various, see Brearley *et al.* (2003) for vouchers.

Distribution elsewhere
Variable.

Remarks
Shipworms get their common name from their habit of boring into the wood of early ships, but they are actually bivalve molluscs. They also burrow into mangroves, with some species

occurring in live wood, others in dead wood and some in both. The species also colonise dead logs. This habitat has resulted in many species of shipworms occupying widespread ranges and being introduced into a variety of different coastal areas, but it is very difficult to determine what the original distribution was for each species. Turner (1966, 1971a, 1971b) and Marshall and Turner (1974) provide information on species occurring in Australia, including Western Australia. Brearley *et al.* (2003) studied the distribution of five species of teredinids and one pholad in mangroves at the Burrup Peninsula near Dampier, and provide a table showing the locations where 28 species have been recorded in Australia. *Teredo navalis* Linnaeus, 1758 is shown by NIMPIS (2002) to occur from the south coast to Kalbarri. However, despite all of these studies, we do not know what species were native to WA and which have been introduced. Until further information is obtained, the record is excluded.

Order Mytiloida

Family Mytilidae

Musculista senhousia (Benson in Cantor, 1842)

Western Australian records and vouchers

This species was first found at Chidley Point in the Swan River estuary in 1983. Subsequent sampling in 1984 revealed that it was as far upstream as the Canning Bridge and Perth Water. It has also been recorded in Fremantle (Slack-Smith and Brearley 1987; Willan 1985a, 1985b, 1987a; Hutchings *et al.* 1987; Pollard and Hutchings 1990b; Furlani 1996; Wilson 1998; Fisheries WA 2000; CRIMP 2000; WAM 10748, 12718, 14305, 16462, 16910). Lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Native to Pacific coast of Asia. This is an invasive species that has been recorded in a wide variety of areas, including the Mediterranean, USA, India, and New Zealand. In Australia it occurs in Port Phillip Bay, Vic., Devonport, Launceston and the Tamar River, Tas., St Kilda, SA (Willan 1985a, 1985b, 1987a; Hutchings *et al.* 1987; Pollard and Hutchings 1990b; Coleman 1993; Furlani 1996; Aquenol 2001; Hewitt *et al.* 2004; NIMPIS 2002).

Remarks

Although the species was common in the lower Swan River in the 1980s, recent attempts to find specimens for DNA analysis have not recorded any individuals. A survey to determine the present distribution of *M. senhousia* is planned for late 2007.

Mytilus edulis planulatus Lamarck, 1819

Western Australian records and vouchers

WA as far north as Cockburn Sound (see remarks below). Numerous specimens in the WAM, including N4017, N4172, 514-40, all from Albany; 141-66 Wilson Inlet; 77-63 Bunbury; N1650 Garden Island.

Distribution elsewhere

Western Europe, Mediterranean.

Remarks

The taxonomy of this species is confused. It is used for aquaculture in the Albany harbours, Warnbro Sound and Cockburn Sound, WA, under the name *M. edulis*. Shepherd and Thomas (1989) state that blue mussels were collected in King George Sound by François Péron on the French corvette Géographe and were later described as *Mytilus planulatus* Lamarck, which is now considered to be a subspecies of *M. edulis*.

Furlani (1996) and NIMPIS (2002) use the name *M. galloprovincialis* Lamarck and give an inferred distribution throughout Western Australia as far north as North West Cape. In fact, blue mussels are found in protected bays and estuaries only as far north as Cockburn Sound (Wells 1984). Furlani (1996) and NIMPIS (2002) state that the two species are inseparable on shell characteristics but can be separated genetically (Geller *et al.* 1993). More recently, Coghlan and Gosling (2007) investigated the two species in Ireland and showed that they co-occur, with a large proportion of the populations (greater than 33%) being hybrids. There were more *M. galloprovincialis* on open shores than in protected bays. Such genetic work has not been undertaken in Western Australia.

In a volume on Quaternary molluscs of South Australia, Ludbrook (1984) describes *M. edulis planulatus* living in SA. However, in other chapters she reports the mussels *Brachidontes* cf. *suberosus* (Singleton) from the Pleistocene and *Brachidontes erosus* (Lamarck 1819) and *B. rostratus* (Dunker 1857) from the Holocene of SA, but not *M. edulis planulatus*. The origins of the Australian form of this species remain uncertain. It may also be an introduction dating to the 16th century (Hewitt 2003).

Order Ostreoida

Family Ostreidae

Crassostrea gigas (Thunberg, 1793)

Western Australian records and vouchers

Not present, although the species is recorded for WA localities in several publications, e.g., Albany, 1947 (Thomson 1952; Fisheries WA 2000); specific location not specified (Coleman and Hickman 1986); WA (Pollard and Hutchings 1990b). No vouchers. NIMPIS (2002) originally had this species as introduced to the south coast of WA, but currently shows a blank in this area.

Distribution elsewhere

Native to the north-west Pacific, introduced widely in temperate to tropical seas for aquaculture (Dinamani 1971; Zibrowius 1991; Gofas and Zenetos 2003); in Australia introduced to several locations, e.g., southern and northern Tas. (Thomson 1952, 1954; Aquenol 2001), Port Phillip Bay, Vic. (Hewitt *et al.* 2004), Mallacoota Inlet, Vic., Anderson Inlet, NSW (Coleman and Hickman 1986).

Remarks

Also known as the Pacific oyster, this species was introduced for aquaculture into Tasmania and Oyster Harbour, Western Australia in 1947. However, the specimens were shipped from Japan by boat and took too long to arrive in Australia. Mortality was very high, and the experiment was unsuccessful. A subsequent attempt was made successfully to ship broodstock by air to Tasmania. The species has since spread to Vic., NSW and SA. It is unusual in being considered to be both a pest species and a valuable species for aquaculture. The history of the introduction is detailed in a number of reports (Thomson 1952, 1959; Sumner 1972, 1974; Medcof and Wolf 1975; Coleman 1986; Coleman and Hickman 1986; Hutchings *et al.* 1987; Furlani 1996; Fisheries WA 2000). Victoria has banned its use as an aquaculture species since 1996 (T. O'Hara, pers. comm.).

Thomson (1959) clearly states the attempt to introduce the species into Oyster Harbour was unsuccessful. In a study of the molluscs of the Albany area, Roberts and Wells (1980) did not record *C. gigas.* A similar study of the Esperance area also failed to disclose any material (Wells *et al.*, 2005). Furlani (1996) reports the deliberate introduction of *C. gigas* into Oyster Harbour but fails to mention that the introduction was not successful. She records the species on the basis of a dead shell taken from Cockburn Sound, and provides a presumed distribution of the species from the entire coastline between Onslow, WA, through to northern NSW. However, *C. gigas* is occasionally imported into WA for restaurants, and it is possible that was the source of the Cockburn Sound shell. The original NIMPIS database included this distribution (e.g., see list of 'known exotic species in Australian waters' in CRIMP 2000: 17), but following approaches to the Centre for Research into Introduced Marine Pests, it has been removed. There are no verified records of the species in WA.

Ostrea edulis (Linnaeus, 1758)

Western Australian records and vouchers

Oyster Harbour, Albany (Morton *et al.* 2003).

Distribution elsewhere

Native to Western Europe.

Remarks

Morton *et al.* (2003) discuss this species in detail. While there had been literature uses of the name *Ostrea edulis* for southern localities, recent authors used the name *O. angasi* (Sowerby, 1871). This is the species for which Oyster Harbour was named by Vancouver in 1798. Morton *et al.* (2003) examined DNA sequences of ten individuals from Oyster Harbour; seven were *O. angasi* and three were *O. edulis.* Once the species were determined genetically, differences in the species were found in the shells. The authors speculate that *O. edulis* could have been introduced into Australia either accidentally or unofficially, but do not report on when this may have occurred.

Family Pectinidae

Scaeochlamys livida (Lamarck, 1819)

Western Australian records and vouchers

Fremantle Harbour and Cockburn Sound (CRIMP 2000, as *Chlamys livida*; WAM S14964).

Distribution elsewhere

Eastern Australia.

Remarks

This scallop species was recorded in the CRIMP (2000) survey of Fremantle Harbour and Cockburn Sound. It did not attract attention in the survey because it is introduced from eastern Australia and not overseas. Morrison and Wells (2008) provide full details on the species in Fremantle Harbour and Cockburn Sound. It first appeared about 1985 and is now well established.

Order Veneroida

Family Mactridae

Spisula trigonella (Lamarck, 1818)

Western Australian records and vouchers

Shark Bay, Swan River, Garden Island, Peel Inlet, Nornalup Inlet (Wilson and Kendrick 1968); Swan River (Chalmer *et al.* 1976). Numerous specimens in WAM including WAM 581-67; 582-67; 580-67.

Distribution elsewhere

Eastern Australia, widespread in Qld., NSW, Tas., Vic., and SA (Wilson and Kendrick 1968).

Remarks

This species appeared suddenly in the Swan Estuary about 1964, as documented by Wilson and Kendrick (1968). Chalmer *et al.* (1976) reported that by the mid 1970s it had become a conspicuous inhabitant of the lower and middle Swan Estuary. They also reported that marine records are rare in WA. However, the species appears to be native to the state, and has been recorded from a number of southwestern estuaries (Wells 1984).

Family Semelidae

Theora lubrica Gould, 1861

Western Australian records and vouchers

Bunbury (CRIMP 1997a); Rockingham, Swan River (Chalmer *et al.* 1976; Slack-Smith and Brearley 1987; Hutchings *et al.* 1987; Pollard and Hutchings 1990b; Furlani 1996). Voucher from Lucky Bay, ca. 600 m north of Pt Waylen, Swan estuary. Lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Pacific coast of Asia, California, New Zealand (Chalmer *et al.* 1976; Pollard and Hutchings 1990b), in Australia introduced to Port Phillip Bay, Vic. (Coleman 1993; Furlani 1996, as *Theora fragilis*; Hewitt *et al.* 2004) and Launceston, Tas. (Aquenol 2001).

Remarks

Coleman (1993) records *Musculista senhousia* and *Theora lubrica* from Corio Bay, Port of Geelong, where *T. lubrica* is an abundant species. Both were introduced from the east coast of Asia. *Theora lubrica* arrived at least in the early 1970s and was identified as *T. fragilis* A. Adams (Poore and Rainer 1974; Hutchings *et al.* 1987; Pollard and Hutchings 1990b). The taxonomy of this species appears to be confused. Furlani (1996) and NIMPIS (2002) use *T. lubrica,* but state that *T. fragilis* may be an earlier, valid name.

The WA material, based on a single record, needs confirmation of the identification.

Annelida

Class Polychaeta (Polychaetes)

Order Phyllodocida

Family Nereididae

Alitta succinea (Leuckart, 1847)

= *Neanthes oxypoda* Marenzeller, 1879, *Nereis oxypoda* Marenzeller, 1879, *Neanthes succinea* Hartman, 1938

Western Australian records and vouchers

Swan River, 1938 as *Neanthes oxypoda* (Monroe, 1938); Swan River, 1946 as *Nereis oxypoda* (Thomson, 1946); Swan River as *Neanthes succinea* (Wilson, 1984). Lower west coast and south coast of WA (NIMPIS 2002). No vouchers in WAM.

Distribution elsewhere

Widely distributed in both hemispheres (Wilson 1988); in Australia from Yarra River, Maribyrnong River, and Port Phillip Bay, Vic. (Wilson 1984; Cohen *et al.* 2001; Hewitt *et al.* 2004) and (as *Neanthes oxypoda*): Port Hacking, Hawkesbury River, Lake Macquarie, NSW (Hutchings and Murray 1984; Wilson 1999).

Remarks

All Australian records of this species are from estuaries associated with or adjacent to major shipping harbours (Wilson 1999). According to Wilson (1984), published records of *Neanthes oxypoda* from Australia, China and Japan confuse two distinct forms, with material from China and Japan probably being an undescribed species. More recent records are likely to be the result of introductions by humans, both intentional and accidental (Wilson 1988).

Order Sabellida

Family Sabellidae

Sabella spallanzanii (Gmelin, 1791)

Western Australian records and vouchers

Esperance (Clapin pers. comm., cited in CRIMP, 2000; WAM 4612; Campbell 2003b; WAM 4617; 4618); Albany (CRIMP 1997b; WAM 4048); Bunbury (WAM 4054; 4056; CRIMP 1997a; WAM 7283; 7285); Cockburn Sound, Fremantle (Clapin and Evans 1995; CRIMP 2000; WAM 4613; 4053). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Native to the Mediterranean and Atlantic east coast to English Channel, introduced to South-East Asia, Rio de Janeiro and various localities in temperate Australia (West Lakes, North Haven, and Port River, SA, Port Phillip Bay, Vic., Devonport, Tas., and Twofold Bay, NSW) (Carey and Watson 1992; Clapin and Evans 1995; Furlani 1996; Currie *et al.* 1998, 2000; CRIMP 2000; Cohen *et al.* 2001; Pollard and Rankin 2003; Hewitt *et al.* 2004).

Remarks

Also known as the European fan worm, this species was first noted in south-west Western Australia in 1994–5 (Clapin and Evans 1995), but specimens from Albany in the WA Museum date from 1965, 1978 and 1979. The species was first observed in Cockburn Sound in 1994.

Myxicola infundibulum (Renier, 1804)

Western Australian records and vouchers

NIMPIS (2002) states the species is introduced to Australia but shows it as cryptogenic on the south coast and lower west coast of WA. No vouchers in WAM.

Distribution elsewhere

In Australia, from Port Phillip Bay, Port of Melbourne, Geelong and Portland, Vic. (Black 1971; Knox and Cameron 1971; Parry *et al.* 1997; Currie *et al.* 1998; Cohen *et al.* 2001; Hewitt *et al.* 2004); Hong Kong (Paxton and Chou 2000).

Remarks

The identity of Australian records currently known as *Myxicola infundibulum* are currently being investigated by E. Dane and R. Wilson at Museum Victoria (T. O'Hara, pers. comm.).

Family Serpulidae

Hydroides elegans Haswell, 1883

[also reported as *Hydroides norvegica* Gunnerus]

Western Australian records and vouchers

Cockburn Sound, 1978 (Lewis 1982). No vouchers in WAM.

Distribution elsewhere

Native distribution unknown, but appears to be of tropical/subtropical origin. Also known in the Mediterranean, Hawaii, Hong Kong, China, New Zealand and various locations in Australia, e.g., Port Phillip Bay, Vic., Port Jackson, NSW, and Qld. (Allen 1953; Wisely 1958; Hurlbut 1991; Zibrowius 1991; Paxton and Chou 2000; Hewitt *et al.* 2004).

Remarks

Often incorrectly identified in early Australian records as *Hydroides norvegica* (NIMPIS 2002) which *H. elegans* was considered synonymous with. Recognition of morphological differences between the two species (Zibrowius 1991) has shown *H. norvegicus* to be restricted to the Atlantic and Mediterranean, with *H. elegans* a widespread fouling species common in temperate southern Australia (Lewis *et al.* 2006). This species is regarded as a considerable fouling nuisance (Lewis *et al.* 2006).

Ficopomatus enigmatica (Fauvel, 1923)

Western Australian records and vouchers

Peel – Harvey Estuary (WAM 86); Swan River (Monroe 1938; Allen 1953; Hove and Weerdenburg 1978; Hutchings and Murray 1984; Hutchings *et al.* 1987; Pollard and Hutchings 1990b).

Distribution elsewhere

Native distribution unknown, but appears to be of subtropical or temperate origin. Also known in the Mediterranean, U.K., France, Spain, India, Egypt, Tunisia, Black Sea, Japan, North and South America and various locations in Australia (SA, Port Phillip Bay, Vic., Sydney, NSW, Qld.) (Monroe 1938; Allen 1953; Hove and Weerdenburg 1978; Hutchings and Murray 1984; Hutchings *et al.* 1987; Pollard and Hutchings 1990b; Zibrowius 1991; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

Prevously known as *Mercierella enigmatica* Fauvel. Hove and Weerdenburg (1978) state that many records in the literature are based on incorrectly identified material. Tolerant of salinity fluctuations (Allen 1953).

Order Spionida

Family Spionidae

Boccardia proboscidea Hartman, 1940

Western Australian records and vouchers

Fremantle (Hartmann-Schröder 1982; Hutchings *et al.* 1987; Pollard and Hutchings 1990b; Furlani 1996). Lower west coast of WA (NIMPIS 2002). No vouchers in WAM.

Distribution elsewhere

Native to Japan or north-eastern Pacific; also found in Chile, Panama and locations in temperate Australia, e.g., Eyre Peninsula, SA, Port Phillip Bay and several locations to Portland, Vic., and Lake Macquarie, NSW (Blake and Kudenov 1978; Hartmann-Schröder 1982; Carlton 1985; Hutchings *et al.* 1987; Hartmann-Schröder 1989; Pollard and Hutchings 1990b; Furlani 1996; Wilson 1999; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

This species was first noted in Fremantle Harbour in 1975 and was probably introduced through ballast water or hull fouling (Hartmann-Schröder 1982).

Polydora ciliata Johnston, 1938

Western Australian records and vouchers

Fremantle, Cockburn Sound (Day 1975; Hutchings *et al.* 1987; Pollard and Hutchings 1990b; WAM 128).

Distribution elsewhere

Native to the Atlantic, Mediterranean, also found in the Indo-West Pacific, introduced to Newcastle, NSW (Haswell 1885; Day 1975; Pollard and Hutchings 1990b). NIMPIS (2002) shows this species as a known introduction to the Pilbara but cryptogenic on the lower west coast.

Remarks

Possibly a misidentification, the single Western Australian specimen (collected in 1972) was identified only from the anterior half as the posterior half was missing (Day 1975). Hutchings *et al.* (1987) echoes these sentiments and Furlani (1996) treats this as an unconfirmed record.

Pseudopolydora paucibranchiata (Okudu, 1937)

Western Australian records and vouchers

WA, 1979 (Hutchings *et al.* 1987 citing Hartman-Schroder 1981 WA (Pollard and Hutchings 1990b). No vouchers in WAM

Distribution elsewhere

Native to the north-west Pacific; introduced to west coast of USA, France, New Zealand (Blake and Kudenov 1978); in Australia recorded from the south-east, e.g., Botany Bay, Port Hacking, Jervis Bay, Merimbula, NSW, Port Phillip Bay, Westernport Bay, Vic., Porter Bay, Torrens Island, Port Lincoln, SA (Dorsey 1982; Hutchings and Turvey 1984; Hutchings and Murray 1984; Carlton 1985; Pollard and Hutchings 1990b; Wilson 1999; Hewitt *et al.* 2004).

Remarks

This species is only presumed to occur in WA according to Furlani (1996) and is not recorded for the state by NIMPIS (2002).

Chordata

Class Ascideacea (Ascidians)

Order Phlebobranchia

Family Ascidiidae

Ascidiella aspersa (Mueller, 1776)

Western Australian records and vouchers

Esperance (WAM 30936); Albany (Kott, 1985; CRIMP 1997b); Bunbury (CRIMP 1997a); Fremantle (CRIMP 2000) Bunbury; Pt Walter, Swan R. (George and George 1979; Kott 1985; Furlani 1996); Swan River (CRIMP; WAM 30507). South coast and lower west coast and Pilbara of WA (NIMPIS 2002).

Distribution elsewhere

Native to the Mediterranean, introduced to the eastern Atlantic and east coast of USA, New Zealand and temperate Australian waters (various isolated estuaries and bays from the Swan River, W.A., to SA, Tas. and Vic.) (Black 1971; George and George 1979; Kott 1985; Furlani 1996; Currie *et al.* 1998; Keough and Ross 1999; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

First seen in Albany in 1952 and subsequently in the Swan River in 1962. Found on rocks and other surfaces in the inter-tidal zone to depths of 50 m or more (George and George 1979).

Family Cionidae

Ciona intestinalis (Linnaeus, 1767)

Western Australian records and vouchers

Esperance (Western Australian Museum 2002; Campbell 2003b; McDonald 2004; WAM 30565); Albany (WAM 744-83); Bunbury (CRIMP 1997a); Canning R.; Albany, Fremantle, Swan R. (Kott 1985, 1990; Furlani 1996; CRIMP 1997b, 2000; WAM 30765). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Native to the North Atlantic, introduced to North and South America; Hong Kong; China Sea; Indonesia; New Zealand; most harbours throughout the world and ports throughout Australia (Port Adelaide and Adelaide outer harbour, SA, Portland and Port Phillip Bay, Vic., Derwent Estuary, Tas., Port Jackson and Newcastle, NSW, Rockhampton, Qld) (Herdman 1899; Van Name 1945; Allen and Wood 1950; Black 1971; Kott 1990, 1997; Furlani 1996; Currie *et al.* 1998; Keough and Ross 1999; CRIMP 2000; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

Kott (1997) suggests that *C. intestinalis* appears to be declining in many of the locations in which it was once common, and the report of this species in Bandy Creek Harbour, Esperance, is the first to be published for almost ten years (McDonald 2004: 869). The species was recorded for Fremantle by CRIMP (2000). *Ciona intestinalis* is known to rapidly cover the substratum, smothering the existing species (Lambert and Lambert 1998, cited in McDonald 2004). Surveys of the Bandy Creek harbour following severe local flooding and sedimentation in early 2007 indicate that this might have eradicated the population in that small harbour (Travers, pers. comm.)

Order Stolidobranchia

Family Styelidae

Botrylloides leachi (Savigny, 1816)

Western Australian records and vouchers

Esperance (Western Australian Museum, 2002; Campbell, 2003b; WAM 30564); Albany (CRIMP, 1997b; WAM 16463); Bunbury (CRIMP, 1997a); Shark Bay (Wyatt *et al.* 2005); Barrow I. (Western Australian Museum 2005; WAM 29711); Geraldton, Fremantle, Rottnest I., Cockburn Sound, Bunbury, Busselton, Albany-Princess Royal Harbour (all collected in 1905) (Hartmeyer and Michaelsen 1928); Geraldton, Cockburn Sound, Bunbury, Albany, Dampier Archipelago, Rowley Shoals, Port Gregory, Houtman Abrolhos, Cockburn Sound (Kott 1985). North Mole, Fremantle (WAM 9583; 9584). Introduced into all areas of WA (NIMPIS 2002).

Distribution elsewhere

Northeastern Atlantic, Europe, British Isles, North Sea, western Mediterranean, Adriatic Sea, Black Sea, Indonesia, western Indian Ocean, Red Sea, South Africa, New Zealand, Australia wide (Herdman 1899; Kott 1985; Furlani 1996; Cohen *et al.* 2001; Aquenol 2001; Hewitt *et al.* 2004).

Botryllus schlosseri (Pallas, 1766)

Western Australian records and vouchers

Esperance (WAM 30562); Albany, Cockburn Sound, Swan River, Shark Bay, Rowley Shoals (Hartmeyer and Michaelsen 1928; Kott 1985; Sabbadin and Graziani 1967; Furlani 1996). WAM 945-6.83, 963.83, 929.83, 938.83. Introduced into all areas of WA (NIMPIS 2002).

Distribution elsewhere

Native to the north-east Atlantic to Mediterranean, Adriatic Sea and Black Sea; introduced to North America, Hong Kong, Japan, New Zealand, and Australia-wide with the apparent exception of NSW (Kott 1985; Furlani 1996; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Styela plicata (Lesueur, 1823)

Western Australian records and vouchers

Bunbury (CRIMP 1997a); Monte Bello Is., Swan River, Canning River, Cockburn Sound, Bunbury (Kott 1952, 1985; Hutchings *et al.* 1987; Pollard and Hutchings 1990b; Furlani 1996). Shark Bay (Wyatt *et al.* 2005); Esperance (Western Australian Museum 2002; Campbell 2003b; WAM 30561). West coast and Pilbara of WA (NIMPIS 2002).

Distribution elsewhere

Native range unknown, cryptogenic in various widespread locations in the Mediterrranean and warmer parts the Pacific, Indian and Atlantic Oceans, introduced to Atlantic South America and probably Australia-wide (Allen and Wood 1950; Kott 1952, 1985; Hutchings *et al.* 1986, 1987, 1989; Pollard and Hutchings 1990b; Furlani 1996; Currie *et al.* 1998; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

First local specimens came from Cockburn Sound in 1928.

Styela clava (Herdman, 1881)

Western Australian records and vouchers

Albany, Cockburn Sound (Kott 1985). No vouchers in WAM.

Distribution elsewhere

Native to the northwest Pacific: Japan, Korea, Northern China, and Siberia; spread to parts of northwestern Europe, North America. In Australia from northern Tas., southern NSW, and Port Phillip Bay, Vic. (Kott 1985; Pollard and Hutchings 1990b; Currie *et al.* 1998; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

This species was recorded for WA by Kott (1985) but a western distribution is not indicated by NIMPIS (2002).

Class Actinopterygii (Fish)

Order Perciformes

Family Gobiidae

Acentrogobius pflaumii (Bleeker, 1853)

Western Australian records and vouchers

Swan River; Cockburn Sound (B. Hutchins, pers comm.).

Distribution elsewhere

Native to the north-west Pacific: Japan, Korea, China, Philippines; introduced to New Zealand; in Australia from Port Phillip Bay, Vic. (Lockett and Gomon 1999, 2001; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

In Port Phillip Bay, this species is common on soft sediments around pier pylons in water deeper than 5 m (Lockett and Gomon 1999, 2001).

Tridentiger trigonocephalus (Gill, 1858)

Western Australian records and vouchers

Bunbury (CRIMP 1997a; WAM 32763); Swan River, Fremantle Harbour, Cockburn Sound (Chubb *et al.* 1979; Bodeker 1985; Paxton and Hoese 1985; Pollard and Hutchings 1990a; Gomon *et al.* 1994; Lockett and Gomon 1999, 2001; CRIMP 2000). Swan River (WAM 26037; 27679; 27690); Cockburn Sound (WAM 25945). South coast and lower west coast of WA (NIMPIS 2002).

Distribution elsewhere

Native to north-west Pacific (Japan, China, Korea), introduced to California and parts of Australia, e.g., Sydney Harbour and Port Kembla, NSW; Port Phillip Bay, Vic. (Friese 1973; Hoese 1973; Bodeker 1985; Paxton and Hoese 1985; Hutchings *et al.* 1987; Pollard and Hutchings 1990a; Gomon *et al.* 1994; Furlani 1996; Lockett and Gomon 1999, 2001; Cohen *et al.* 2001; Hewitt *et al.* 2004).

Remarks

In eastern Australia (Sydney Harbour and Port Phillip Bay), this species occurs among seagrass and is associated with a variety of substrata; it is common around commercial port regions (Pollard and Hutchings 1990a; Lockett and Gomon 2001).

Family Sparidae

Sparidentex hasta Valenciennes, 1830

Western Australian records and vouchers

Swan River, 1985 (Bodeker 1985; Harvey and Beard 1985; Anon. 1985; Hutchings *et al.* 1987; Pollard and Hutchings 1990a; WAM 28437).

Distribution elsewhere

Arabian Sea, west coast of India, Persian Gulf (Pollard and Hutchings 1990a).

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Colonisation of Fremantle Harbour and Cockburn Sound, Western Australia by the eastern Australian scallop Scaeochlamys livida (Lamarck, 1819)

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Abstract

The eastern Australian scallop *Scaeochlamys livida* (Lamarck, 1819) is recorded from Cockburn Sound and Fremantle Harbour, Western Australia. It was first recorded in Cockburn Sound in the 1980s and has now become a permanent part of the molluscan fauna of both Fremantle Harbour and Cockburn Sound.

Introduction

Worldwide, the introduction of exotic species is one of the major threats to biodiversity (Carlton and Geller 1993). In the marine environment there are three primary mechanisms by which species introductions have occurred: through the discharge of ballast water into ports or the arrival of fouling species on the hulls of ships (both of which are inadvertent) or deliberate introductions, such as through aquaculture (Carlton 1985). Like other places in the world, many exotic species have been introduced into Western Australia (NIMPIS 2002), a number of which are molluscs. The Pacific oyster, *Crassostrea gigas* (Thunberg, 1793), was introduced for aquaculture in Oyster Harbour, Albany, in 1947 but did not survive. However the species survived in Tasmania (Thomson, 1952, 1959) and has since spread to New South Wales, Victoria and South Australia in southeastern Australia (Hewitt *et al.* 2004). The black mussel is raised commercially at Albany and in Cockburn Sound as *Mytilus edulis* Linnaeus, 1758, but the taxonomic status and origins of this species are uncertain. It may actually be *M. galloprovincialis* (Lamarck, 1819). Another mussel, *Musculista senhousia* (Benson, 1842), has established large populations in Cockburn Sound and the Swan River estuary (Slack-Smith and Brearley 1987). *Theora fragilis* (A. Adams, 1856) has been reported in the Swan River (Chalmer *et al.* 1976). Three species of nudibranchs have also been recorded: *Godiva quadricolor* (Barnard, 1927) in Cockburn Sound (Willan 1987); *Polycera hedgpethi* (Marcus, 1964) at Albany and Augusta (Willan and Coleman 1984; Wells and Bryce 1993) and *Okenia pellucida* Burn, 1967 at Fremantle (Willan and Coleman 1984). The three species have been introduced from very different sources. *Godiva quadricolor* is a South African species that has also been introduced to Sydney (Willan 1987). *Polycera hedgpethi* was thought to be an introduction from California, where it was originally described. However, the natural range is obscure and it has also invaded a several other Australian ports (Wilson 2006). Similarly, the natural range of *O. pellucida* is unknown; it was described from Sydney (Rudman 2004). The

European oyster *Ostrea edulis* (Linnaeus, 1758) was recently recorded from Albany based on analyses of genotypes (Morton *et al.* 2003). Beechey and Willan (2007) have reported the Asian columbellid snail *Mitrella bicincta* (Gould, 1860) from Cottesloe as well as from New South Wales.

All of the above introductions into Western Australia have been from outside Australia. There is a growing awareness that species can also be moved from one part of Australia to another. We report such an introduction here, establishment of the eastern Australian scallop *Scaeochlamys livida* (Lamarck, 1819) into Fremantle Harbour and Cockburn Sound, Western Australia.

Materials and Methods

Staff of the Western Australian Museum (WAM) identified voucher specimens for the CRIMP (2000) survey for introduced species in Cockburn Sound. As part of this exercise, one of us (HM) identified a species of scallop as *Scaeochlamys livida.* WAM reference collections were searched for additional specimens. Contact was also made with long-term members of the Western Australian Shell Club to obtain further information regarding records of *S. livida* from Cockburn Sound or other areas in south Western Australia. Shells only were examined in this study.

Results

Previous surveys of the area

From 1958 to 1960, the marine group of the Western Australian Naturalists' Club conducted a detailed survey of marine benthic invertebrates of Cockburn Sound (Wilson *et al.* 1978), with the sound being divided into 178 numbered grid squares. Samples were taken from the centre of each block by diving, dredging or shore collecting. Incidental collecting was undertaken after 1960. *Mimachlamys asperrima* (Lamarck, 1819) was recorded in 29 blocks in the 1958-1960 survey. Many records were based on live scallops, and the species was listed as abundant at several stations. The species was also collected at four of the post-1960 stations (Wilson *et al.* 1978). Specimens from this survey and other Naturalist Club material later formed the initial mollusc collection in the Western Australian Museum. Surveys of the molluscs of the Swan River were undertaken in the late 1960s and early 1970s (Chalmer *et al.* 1976), and Wells (1984) collated WAM information on molluscs in southwestern Australian estuaries, including the Swan. All of these studies, and Wells and Bryce (1986), listed *M. asperrima,* but *Scaeochlamys livida* (Figure 1a; b) was never collected in any of the above studies.

Lamprell and Whitehead (1992) list the range of *S. livida* as from northern Western Australia to central New South Wales. Raines and Poppe (2006) also show *S. livida* in north Western Australia. However, there are no records from northern Western Australia in the WAM collections; the only records in WAM are from New South Wales and Queensland. Northwestern Australian specimens in WAM previously attributed to *S. livida* are currently being described as a new species (H. Dijkstra, pers. comm. to HM).

Western Australian material of *Scaeochlamys livida* examined

Woodmans Point, Cockburn Sound, 28 Aug 1985 (Frank Turnbull Collection TC 1428); between the shipyards and Alcoa, southwestern Cockburn Sound, 10 Dec 1989 (WAM S33048); mussel farm near the Kwinana Grain terminal, 1992 (WAM S33049); 7 m, barge wreck, Rous Head, 2004 (WAM S 14964); Woodmans Point, 1991, 1991 & 2000 (WAM S33050; S33053;

S33051); Rottnest Island, H. Morrison Coll., 2002; Whitfords, H. Morrison Coll., 2002; naval base, southwest Garden Island, March 2005 (MuseumVictoria F131574; F131583; F131591; F131599; F132050; F132060; F132064; F132086; C.Y. O'Connor Beach, Fremantle, Jan 2007 (WAM S33043); BHP Jetty, southern Cockburn Sound, 11 Feb 2007 (WAM S33045).

Comparison of *Scaeochlamys livida* with *Mimachlamys asperrima*

Scaeochlamys livida lives in essentially the same habitat as *M. asperrima,* attached to rocks and jetty pilings in shallow waters in areas such as Fremantle Harbour and Cockburn Sound. Both species are commonly overgrown with a bright red sponge. The CRIMP (2000) report listed *S. livida* as occurring at four stations, and *M. asperrima* as being at four different stations (Figure 2). The CRIMP report also listed another unidentified species of *Chlamys.* However, the identifications of *M. asperrima* and the unidentified *Chlamys were* done by students at Murdoch University and cannot be verified as the material has been discarded; no *M. asperrima* were present in the material identified at WAM. This emphasises the need for maintaining voucher specimens against which identifications can be checked by future researchers. There are no other scallops in the local area with which *S. livida* and *M. asperrima* could be confused. For these reasons, the two species are compared here.

Scaeochlamys livida (Figure 1 a,b): Up to 7 cm high; slightly inequilateral, left valve more convex; auricles unequal; byssal gape pronounced; colourful (often brown or purple, or orange, yellow, or white), internal colours lighter but similar; 10-12 very strong, low, flattened radial ribs on left side with flat, translucent scales, much stronger near shell margin, up to 8 mm long, 4 mm wide. Interstices between ribs each with 4-5 fine radial lines. Right valve with 20-25 ribs, but lower than on left valve.

Scaeochlamys squamata (Gmelin, 1791) is a similar western Pacific species that ranges from southern Japan to Indonesia (Raines and Poppe 2006). *Scaeochlamys squamata* (Figure 1c) differs from *S. livida* in it has fewer primary ribs (five to seven instead of 10-12), with smaller, narrower scales which are confined to the centre of the ribs.

Mimachlamys asperrima (Figure 1 d) is similar in size, but reaches 9 cm. It also has variable colour patterns, often brown or purple. The key differences between this species and *S. livida* are the ribs, which are fewer, larger and stronger in *S. livida,* and have much more pronounced scales. The radial ribs of *M. asperrima* are much lower and are not as distinct; they tend to occur as a series of three ribs close together with the central rib largest and all three having fine scales less than 1 mm high.

Discussion

Data from the WAM collections and anecdotal sources indicate that *S. livida* was first recorded in Cockburn Sound about 1985 and was not there during the late 1950s. Numerous records since then indicate that it is now a permanent resident in Cockburn Sound and Fremantle Harbour.

There is an active movement of ships between the eastern states, particularly between Sydney, and Fremantle, suggesting the invasion of *S. livida* into the Cockburn Sound was due to shipping, with the scallop either attached to the hull or as veligers in ballast water. It is likely that scallops can be transported through either medium. In normal weather conditions a vessel can move from Sydney to Fremantle in five days (G. Valenti, Fremantle Port Authority, pers. comm.). In the early years most introductions resulted from species fouling on the hulls of ships. The post World War II change in ballasting from dry to wet increased introductions significantly during the 1970s and 1980s (Culver and Kuris 1999; Carlton and Geller 1993). Thus *S. livida* may have been able to reach Cockburn in ballast water with veligers settling from the discharged ballast water settling on suitable habitat and establishing a viable population.

Acknowledgements

Henk Dijkstra of the Zoological Museum, Amsterdam, confirmed the identification of *S. livida*. We thank Shirley Slack-Smith and Glad Hansen of the Western Australian Museum, Karen Gowlett-Holmes of CSIRO Marine Research, Dr Rob Hilliard of URS Australia Pty Ltd, and Gino Valenti of Fremantle Ports Authority for discussions on this project; John Campton, Derek Mead-Hunter and Andrew Cummings for collecting data from Cockburn Sound; Brian Cleaver for specimens from Rottnest Island, City Beach and Whitfords; Clay Bryce and Simone Pfuetzner for photography; Gareth Parry for doing the map; and Dr Tim O'Hara and Joanna Browne for access to the Museum Victoria collections and information. Dr Stephanie Turner and Mike Travers of the WA Department of Fisheries commented on a draft manuscript.

Figure 1. Exterior view of right valves. A. *Scaeochlamys livida* (Lamarck, 1819) Fremantle Harbour, Western Australia (WAM S 14964); B. *S. livida,* Stradbroke Island, Queensland (Hugh Morrison Collection); C. *S. squamata* (Gmelin, 1791) Minabe, Wakyama, Japan (Hugh Morrison Collection); and D. *Mimachlamys asperrima* (Lamarck, 1819) Woodmans Point, Cockburn Sound, Western Australia (WAM S 14965).

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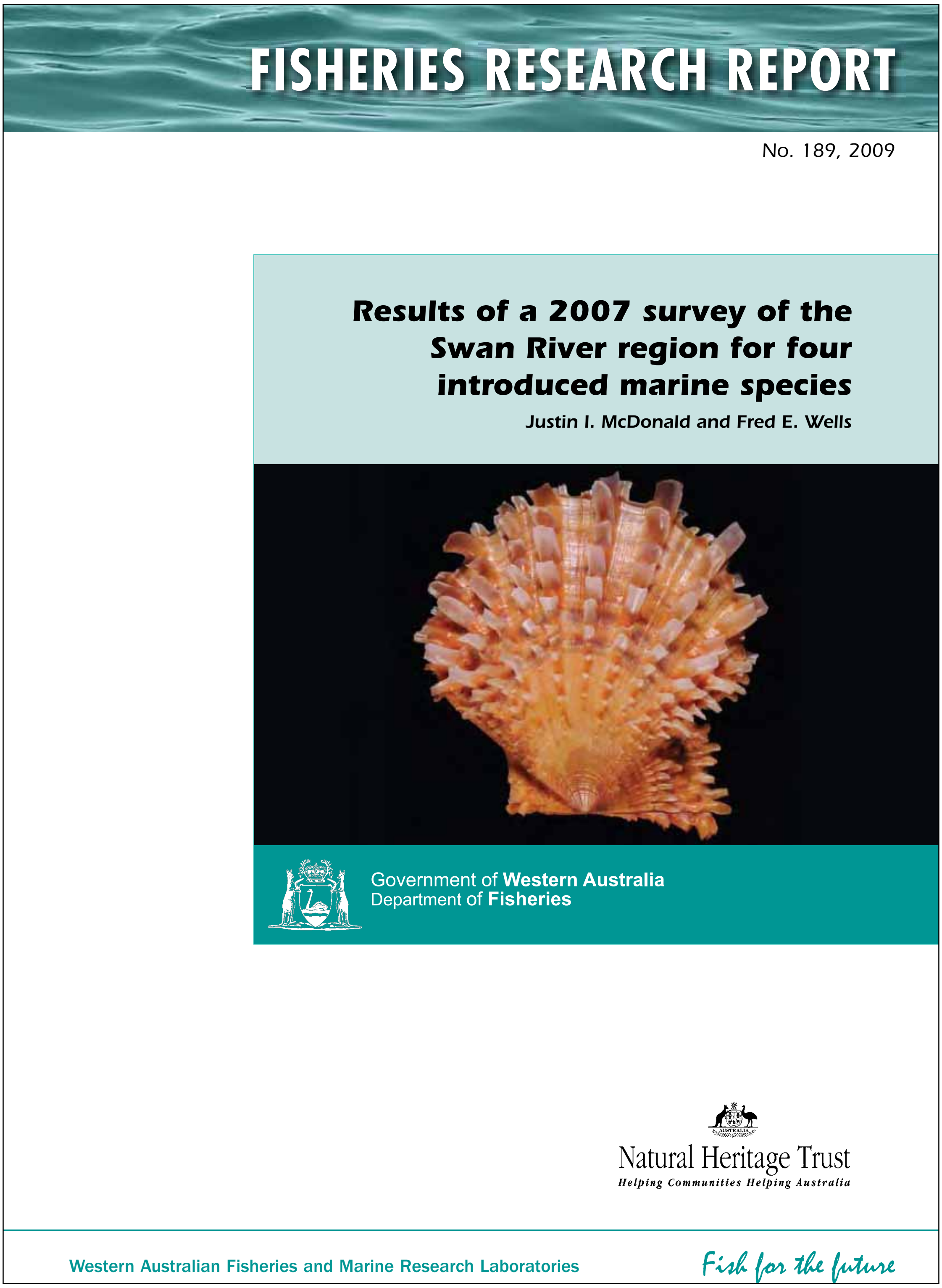

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Results of a 2007 survey of the Swan River region for four introduced marine species

Justin I. McDonald and Fred E. Wells

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Contents

Results of a 2007 survey of the Swan River region for four introduced marine species

Justin I. McDonald and Fred E. Wells

Executive summary

A survey of the Swan River region for four non-indigenous marine species was conducted in 2007: the European shore crab *Carcinus maenas*, the Asian bag mussel *Musculista senhousia*, the European fan worm *Sabella spallanzanii,* and the scallop *Scaeochlamys livida*. The first three of these species are global in their distribution and on the 'top-ten world's worst invaders listing; the last species is introduced from the eastern states of Australia.

In this survey divers on SCUBA examined 43 sites for each of the listed species. Despite previous records of *Carcinus maenas* and *Musculista senhousia* in this region the diver visual surveys found no evidence of either species. The European fan worm, despite anecdotal reports that it had died out in the Swan region, has actually increased its geographic spread, though the densities of this species in the more open waters of Cockburn Sound are much reduced from those reported in the early 1990's. The scallop *Scaeochlamys livida* has well-established populations in Cockburn Sound and the Swan River. There is some speculation that this species may have displaced the 'native scallop' *Mimachlamys asperrimus*.

There are currently 46 known non-indigenous species in the Cockburn Sound and Fremantle Harbour area. These species have the capacity to be translocated within the Swan River region quite easily; furthermore they have the capacity to be translocated to iconic areas such as Rottnest Island. As such, a study into the potential of these species to be translocated is needed.

1.0 Introduction

Non-indigenous species (NIS) are a global problem, and are ranked second only to habitat change and habitat loss in reducing global biodiversity (Crooks and Soulé 1999; Millennium Ecosystem Assessment 2005). However not all non-indigenous marine species (NIMS) become marine pests. Possibly the most widely known examples of non-indigenous marine species becoming pests are the black striped mussel (*Mytilopsis sallei*) in Darwin Harbour, Australia, the comb jellyfish (*Mnemiopsis leidyi*) invasion of the Azov and Black Seas (Minchin 1996), and the rapid spread of *Caulerpa taxifolia* in the Mediterranean (Ribera and Boudouresque 1995; Ruiz *et al.* 1997).

In a 'natural' state, for a non-indigenous species to become established in a new community (with little 'empty niche' space), let alone outcompete a native species, it would have to have conditions comparable to its home range or be so competitively dominant over the native species that environmental differences are inconsequential (Tyrrell and Byers, 2007). However there is another state that accounts for most incursions. A non-indigenous species may enter a disturbed environment that has been altered by anthropogenic disturbance. These disturbed habitats can create a 'mismatch between native species and the environmental conditions to which they have become adapted (Byers 2002).

Like other places in the world, non-indigenous species have been introduced into Western Australia, with 60 species having been introduced and currently surviving in the State (Huisman *et al.* 2008). Most of the introductions that have been reported have generally remained innocuous, or have been largely restricted to disturbed environments such as harbours. This parallels the situation in other Australian areas.

The National Introduced Marine Pests Coordination Group (NIMPCG) is currently developing a National System for the Prevention and Management of Marine Pest Incursions. The National System is designed to comprehensively address all marine pest risks. This system includes governance and infrastructure arrangements, measures for prevention (focused on ballast water and biofouling risks), emergency response, ongoing management and control, and supporting arrangements for monitoring, communications, research and development, and evaluation and review. Eighteen major ports nationwide are in the national monitoring system, including three Western Australian ports: Dampier, Port Hedland and Fremantle (NIMPCG 2006).

In October 2006, the Western Australian Department of Fisheries initiated a Natural Heritage Trust funded project on introduced marine pests in Western Australia. The main focus of this research was a trial of the National Marine Pest Monitoring Methodology in Albany. Another complementary component of this research was a survey of the Cockburn/Fremantle and Swan River region (hereafter referred to as Swan region – Figure 2) for the following four species of non-indigenous species (Figure 1):

- The Asian bag mussel *Musculista senhousia*,
- The European shore crab *Carcinus maenas,*
- The European fan worm *Sabella spallanzanii,* and
- The East Australian scallop *Scaeochlamys livida.*

Cockburn Sound and Fremantle Harbour, with 46 known non-indigenous species, have the greatest number of non-indigenous species in Western Australia (Huisman *et al.,* 2008). The four species surveyed here were chosen for two main reasons. The first three species are listed pest species with the Consultative Committee for Introduced Marine Pest Emergencies

(CCIMPE) and have documented distributions within the target region (Zeidler 1978; Slack-Smith and Brearley 1987; Clapin and Evans 1995). For these species the purpose was to document the extent of existing populations and to collect samples of *Musculista senhousia* for DNA analysis (a separate research project).

The remaining species, *Scaeochlamys livida,* is a non-indigenous species from the east coast of Australia. This species is a relatively new incursion (Morrison and Wells 2008) and is believed to have displaced the native scallop species. As such this study aimed to document the spatial extent of this species.

2.0 Materials and methods

2.1 Study sites

In September and October 2007 a series of visual surveys were conducted by two divers on SCUBA at 43 locations throughout the Swan Region (Figure 2, Table 1). These sites are based upon sites where the target species have been reported previously or would most likely occur.

Within the broader Swan Region there are two major vector nodes for introduction of non-indigenous species: Fremantle Harbour (including the anchorage areas of Gage Roads) and the southern and eastern parts of Cockburn Sound (Figure 3). The major potential source of introductions is through international shipping. The Fremantle inner harbour area is the main shipping port for this part of Western Australia. In 2006 there were 1722 ship visits to Fremantle Port. Of these, 937 were international and 785 were domestic. A total of 8,532,086 tonnes of ballast water was discharged, with 4,655,172 tonnes being from international sources and 3,876,914 being domestic (McDonald 2008).

Immediately adjacent to the harbour is the small, artificial Rous Head. There are a variety of marine industries in Rous Head, including a terminal for ferries and other service industries. Immediately to the south of Fremantle inner harbour are several small boat harbours, with the southernmost being the South Fremantle Yacht Club. Offshore, Gage Roads is the anchorage area for the Port of Fremantle. Upstream of Fremantle harbour area is the Swan Canning River system. There are scattered yacht and boat clubs throughout this area. However most tend to be concentrated in the lower Swan region.

Cockburn Sound is a large marine embayment in the southern part of the survey area. Within this broader region is Kwinana, which is the major heavy industry area of Western Australia, and includes all of the industrial area south of the actual port. The Royal Australian Navy also operates out of this region.

2.2 Diver visual surveys

Visual surveys by divers on SCUBA are one of the most widely used methods due to the low costs and high efficacy of the method, and are one of the accepted methodologies of the NIMPCG (2006) survey methodology. Divers entered the water together and descended to the seafloor where they would space themselves approximately 1-2 m apart, depending upon visibility, and available space. Divers would proceed along the seafloor searching for the four target non-indigenous species identified. The length of each survey varied according to the area being examined.

2.3 Abundances and collections

For *Scaeochlamys livida* estimates of mean abundance (number 0.5 m^2) were derived from three randomly placed square quadrats measuring 0.5 x 0.5 m. Four levels of relative abundance were utilised in the survey: absent, sparse, medium, and dense. These estimates are based on those of Clapin and Evans (1995), where sparse equates to < 1 individual per m^{-2}, medium 1-50 individuals per m^{-2}; and dense 50+ individuals per m^{-2}.

Length frequency data on *Scaeochlamys livida* was derived from a random sample of the population collected from numerous sites by each diver.

Samples of *Sabella spallanzanii* and *Scaeochlamys livida* were collected and identified in the laboratory to verify field-based identifications. All collected material was preserved in 70% ethanol.

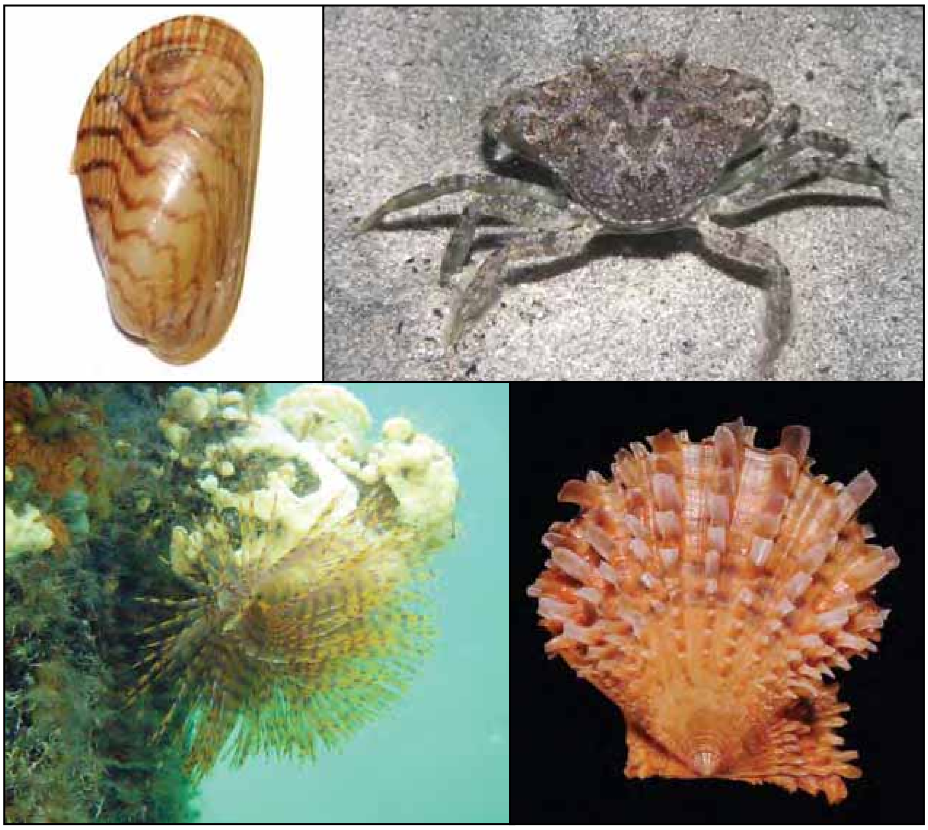

Figure 1. The four introduced marine species examined in this study: From top left to bottom right) Asian bag mussel *Musculista senhousia*, European shore crab *Carcinus maenas*, European fan worm *Sabella spallanzanii*, and East Australian scallop *Scaeochlamys livida.* (Photo credits: Helen Cribb; Karen Gowlett-Holmes; Justin McDonald and Clay Bryce).

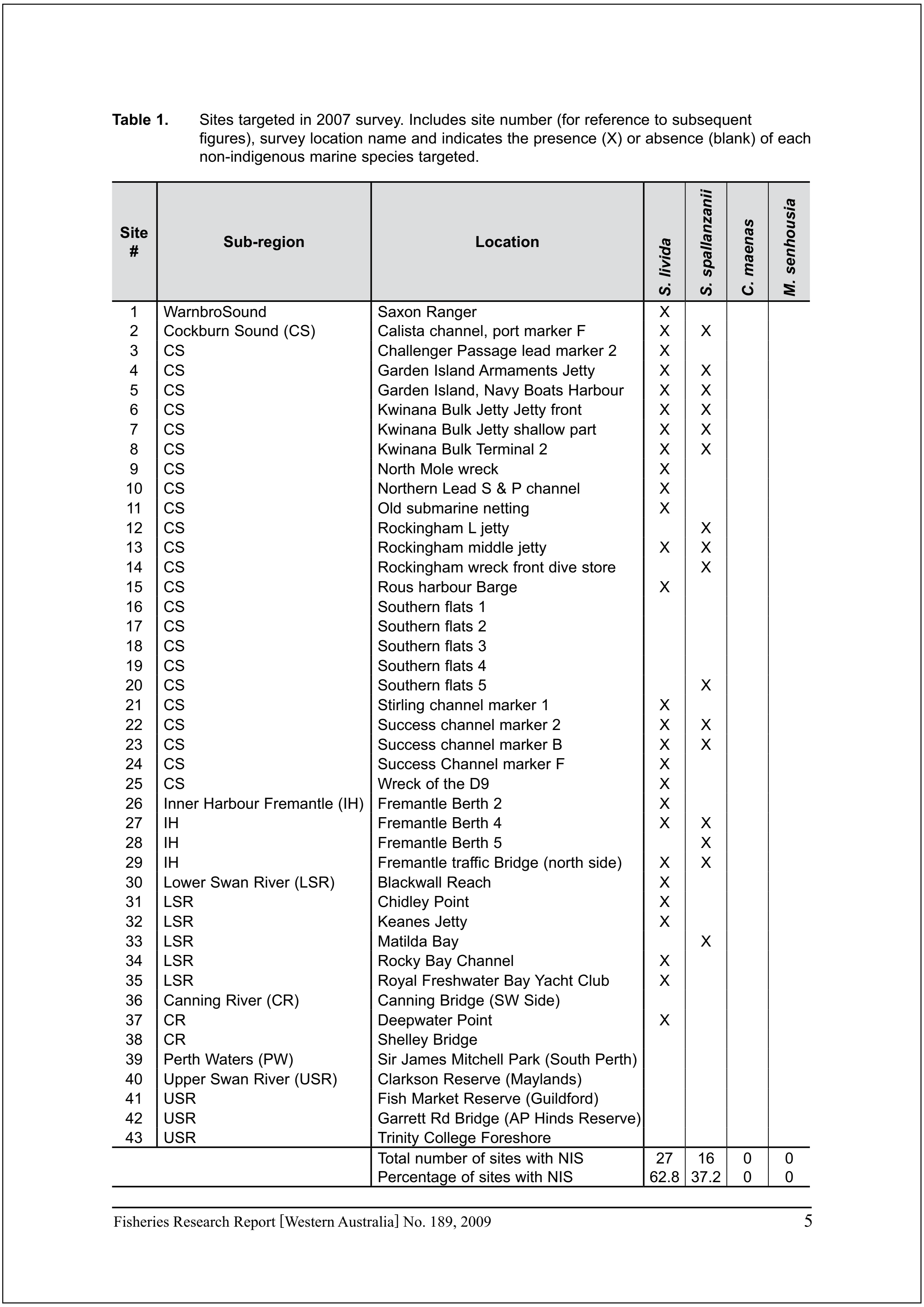

Table 1. Sites targeted in 2007 survey. Includes site number (for reference to subsequent figures), survey location name and indicates the presence (X) or absence (blank) of each non-indigenous marine species targeted.

Site #	Sub-region	Location	*S. livida*	*S. spallanzanii*	*C. maenas*	*M. senhousia*
1	WarnbroSound	Saxon Ranger	X			
2	Cockburn Sound (CS)	Calista channel, port marker F	X	X		
3	CS	Challenger Passage lead marker 2	X			
4	CS	Garden Island Armaments Jetty	X	X		
5	CS	Garden Island, Navy Boats Harbour	X	X		
6	CS	Kwinana Bulk Jetty Jetty front	X	X		
7	CS	Kwinana Bulk Jetty shallow part	X	X		
8	CS	Kwinana Bulk Terminal 2	X	X		
9	CS	North Mole wreck	X			
10	CS	Northern Lead S & P channel	X			
11	CS	Old submarine netting	X			
12	CS	Rockingham L jetty		X		
13	CS	Rockingham middle jetty	X	X		
14	CS	Rockingham wreck front dive store		X		
15	CS	Rous harbour Barge	X			
16	CS	Southern flats 1				
17	CS	Southern flats 2				
18	CS	Southern flats 3				
19	CS	Southern flats 4				
20	CS	Southern flats 5		X		
21	CS	Stirling channel marker 1	X			
22	CS	Success channel marker 2	X	X		
23	CS	Success channel marker B	X	X		
24	CS	Success Channel marker F	X			
25	CS	Wreck of the D9	X			
26	Inner Harbour Fremantle (IH)	Fremantle Berth 2	X			
27	IH	Fremantle Berth 4	X	X		
28	IH	Fremantle Berth 5		X		
29	IH	Fremantle traffic Bridge (north side)	X	X		
30	Lower Swan River (LSR)	Blackwall Reach	X			
31	LSR	Chidley Point	X			
32	LSR	Keanes Jetty	X			
33	LSR	Matilda Bay		X		
34	LSR	Rocky Bay Channel	X			
35	LSR	Royal Freshwater Bay Yacht Club	X			
36	Canning River (CR)	Canning Bridge (SW Side)				
37	CR	Deepwater Point	X			
38	CR	Shelley Bridge				
39	Perth Waters (PW)	Sir James Mitchell Park (South Perth)				
40	Upper Swan River (USR)	Clarkson Reserve (Maylands)				
41	USR	Fish Market Reserve (Guildford)				
42	USR	Garrett Rd Bridge (AP Hinds Reserve)				
43	USR	Trinity College Foreshore				
		Total number of sites with NIS	27	16	0	0
		Percentage of sites with NIS	62.8	37.2	0	0

3.0 Results

Despite previously published evidence to the contrary, there was no evidence of either *Carcinus maenas* or *Musculista senhousia* in the 43 sites examined in the Swan region.

Non-indigenous marine species were recorded in 74.4% (32) of the sites examined. The European fan worm *Sabella spallanzanii* was recorded at 37% (16) of the sites surveyed (Figure 4). Unfortunately no density estimates were made for this species, therefore data are presence/absence only.

The east Australian scallop *Scaeochlamys livida* was recorded at approximately 63% (23) of the sites surveyed (Figure 5). Scallops were recorded in all locations with the exception of the upper Swan region. Densities of *S. livida* were greatest in Cockburn Sound and the Inner Harbour area (Table 2). Mean size was 56.2 mm ± 13.7 mm SD (minimum size 12 mm; maximum size 92 mm)(Figure 6). While scallops from Warnbro Sound had a smaller mean size (48.2 mm ± 18.2 mm SD; minimum size 24 mm; maximum size 65 mm) than those at other locations sampled, the mean size of *S. livida* did not differ significantly across locations within the survey area ($p > 0.05$).

Sabella spallanzanii and *Scaeochlamys livida* co-occurred at 11 (25.6%) of the 43 sites surveyed. However when we remove sites where no introduced species were found and examine infested sites only (32 sites), then these species co-occurred in 34.4% of infested sites. These co-occurring sites are located in the inner harbour of Fremantle port and scattered along the coastal region of Cockburn Sound (Figure 7).

Table 2. Estimates of Saeochlamys livida density within each sub-region examined.

Sub-region (number of sites examined)	**Number of sites in each density category**			
	Absent	**Sparse (< 1 m^{-2})**	**Medium (1-50 m^{-2})**	**Dense (> 50 m^{-2})**
Warnbro Sound (1)			1	
Cockburn Sound (24)	7	7	7	3
Fremantle inner harbour (4)	1		1	2
Lower Swan River (6)	3		2	1
Canning River (3)	2	1		
Perth Waters (1)			1	
Upper Swan River (4)	4			
Totals	17	8	12	6

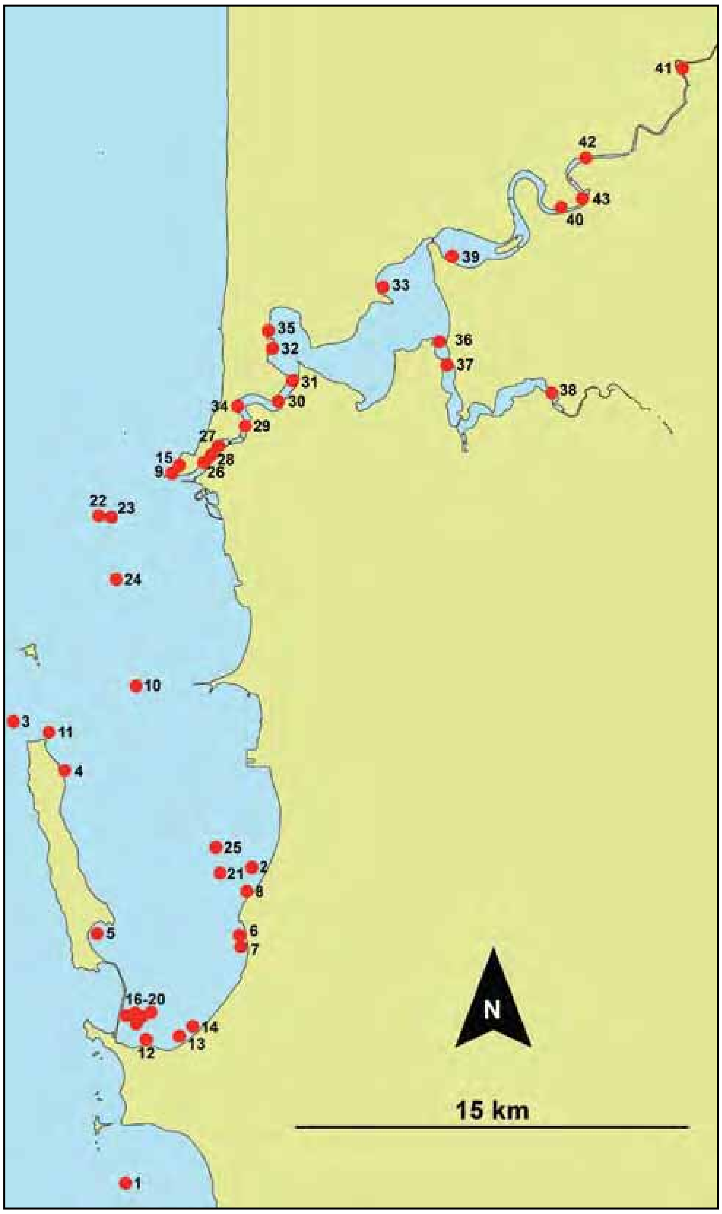

Figure 2. Sites surveyed within the Swan region (see Table 1 for site name details).

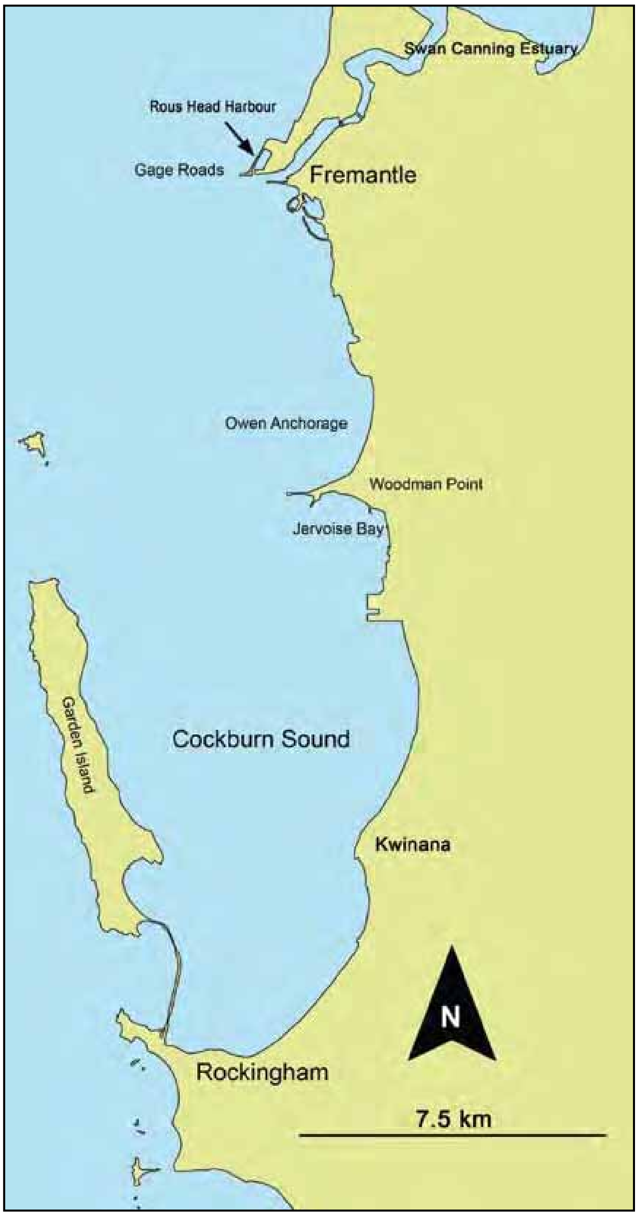

Figure 3. Map of entrance to Swan Region showing two major nodes of vessel activity Fremantle harbour and Cockburn Sound.

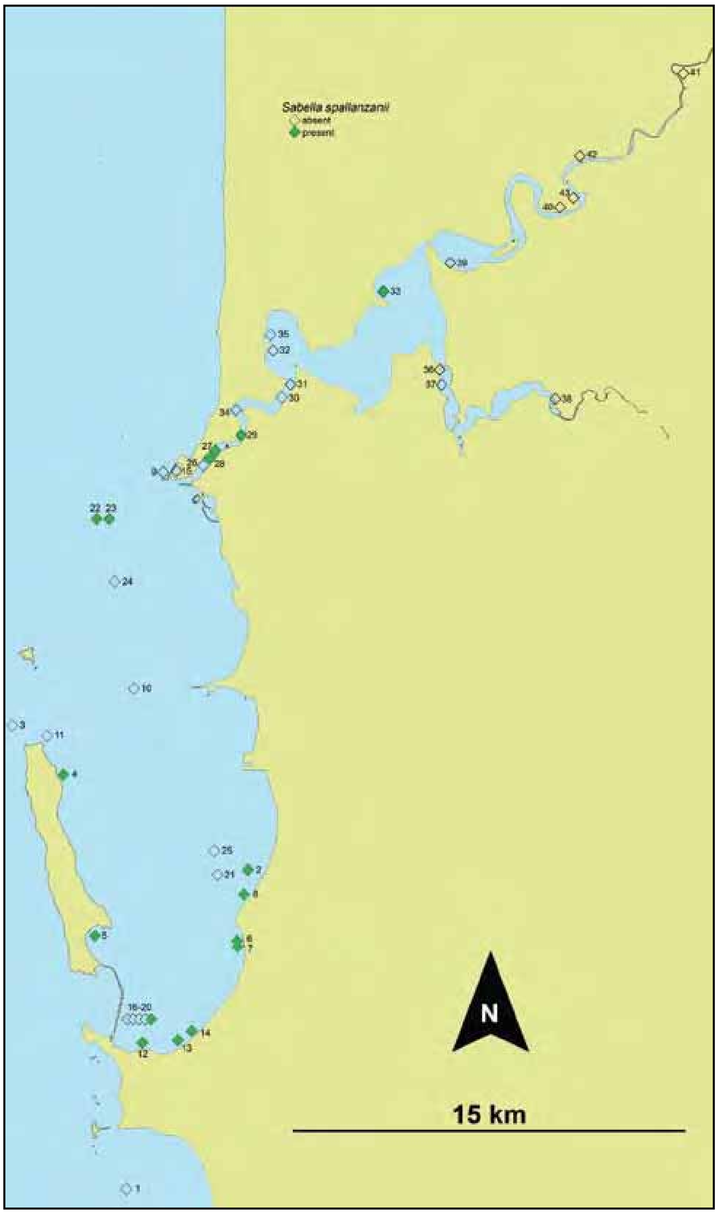

Figure 4. Distribution of *Sabella spallanzanii* within the Swan region.

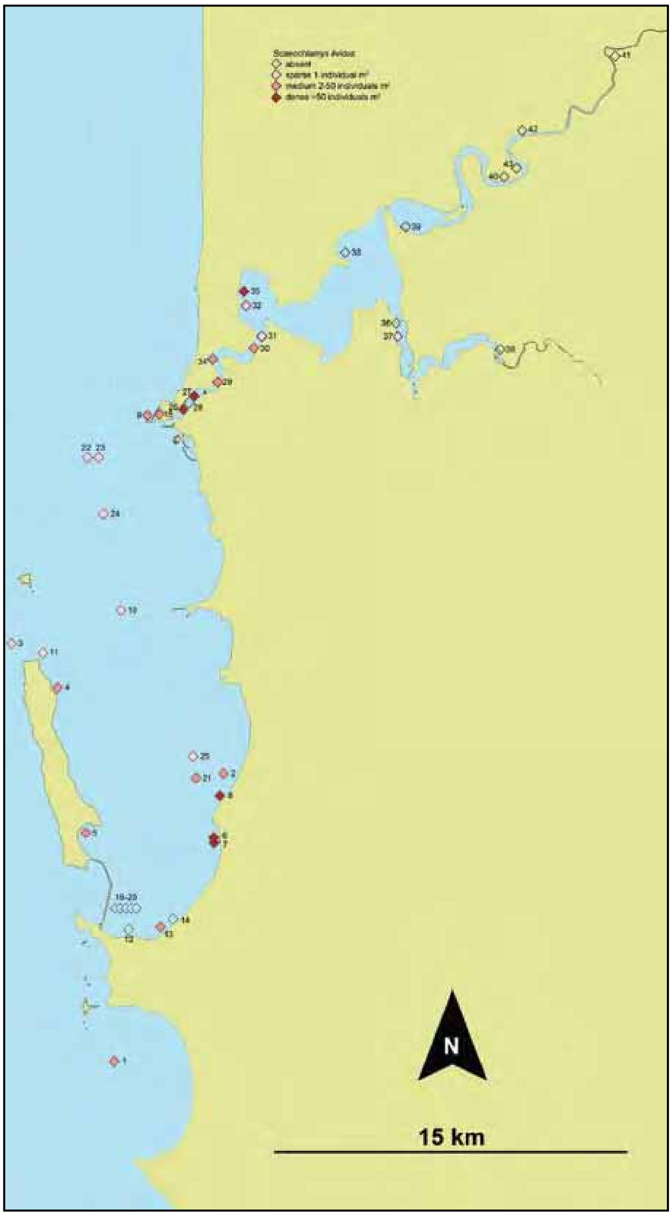

Figure 5. Distribution of *Scaeochlayms livida* within the Swan region.

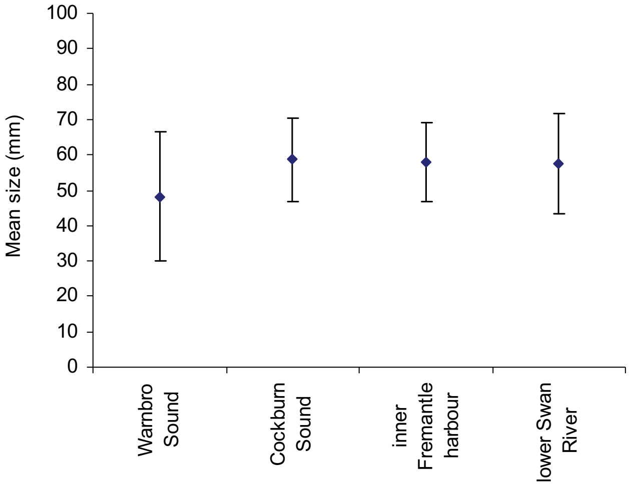

Figure 6. Mean size (mm ± SD) of *Scaeochlayms livida* across locations within the greater Swan region surveyed (sites where no scallops were recorded are not shown).

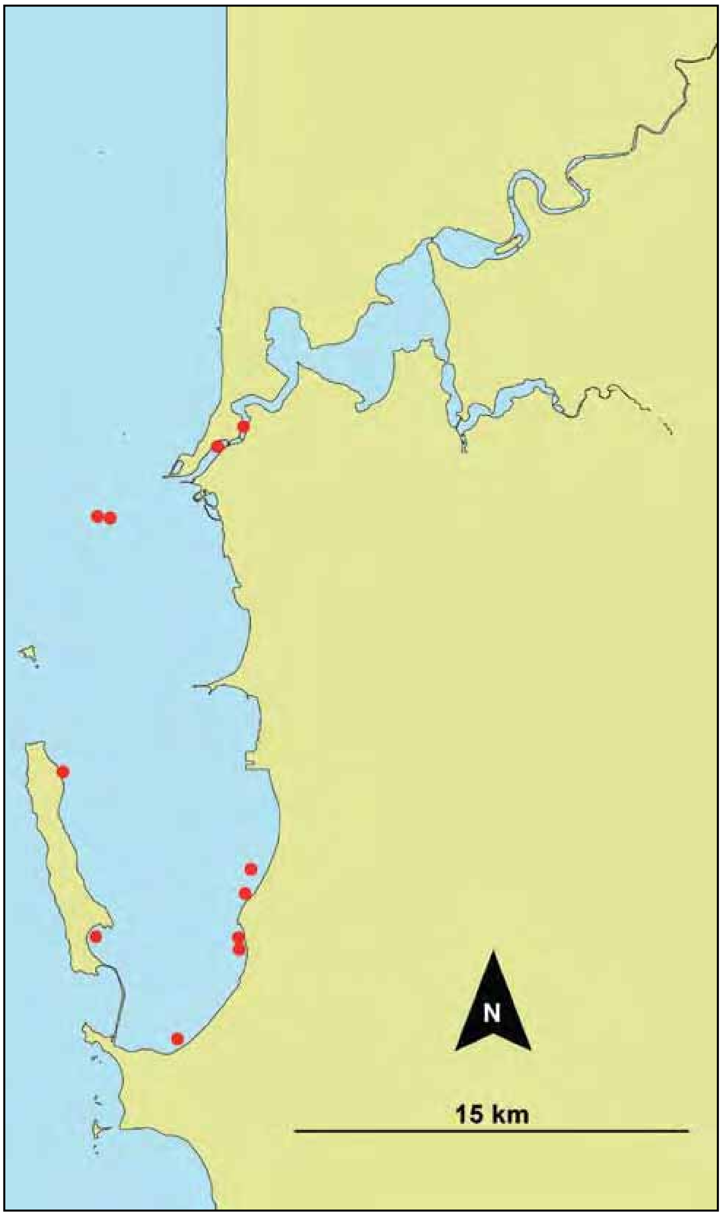

Figure 7. Sites showing co-occurrence of non-indigenous species.

4.0 Discussion

Three of the four species targeted in this study are on the Consultative Committee for Introduced Marine Pest Emergencies (CCIMPE) introduced marine pest target species list. Furthermore all three are regarded to be among the worst invasive marine species in the world (Hayes *et al*. 2005). As such it is important to know if they are established in the Swan region and if so what is their geographic distribution.

4.1 *Musculista senhousia* – Asian date mussel

The Asian date (or bag) mussel, *Musculista senhousia*, is native to the western Pacific coasts from Siberia and south to Singapore with the type locality in China (Slack-Smith and Brearley 1987). Once settled on soft substrata, the mussel will form a protective cocoon, and at high densities (>1500 m^2) the individual byssal cocoons coalesce to form a continuous mat or carpet on the sediment surface. The presence of these mats dramatically alters the natural benthic habitat, changing both the local physical environment and the resident macro invertebrate assemblage.

In Western Australia this mussel was first recognised in the Swan River in 1983, was subsequently found to be abundant in the middle and upper regions of that river, and also as far upstream as Canning Bridge in the Canning River (Slack-Smith and Brearley 1987). Densities of this species are recorded as high as 2500m^2 (Slack-Smith and Brearley 1987), well above the base density for mat forming. A smaller number of *M. senhousia* were also recorded in the upper reaches of the Swan River in 2005 by Wildsmith (2007).

In the 2007 survey, there was no evidence of *Musculista senhousia* living in any of the sites examined. Slack-Smith and Brearley (1987) note that *M. senhousia* populations in the Swan River exhibited high mortality. They postulate that this could be due to decreasing salinity, as with *Mytilus edulis planulatus*, or be post-reproductive, as in *Musculista glaberrima* (Wilson and Hodgkin 1967). This high mortality is further supported by Summers (1994) who documents significant declines associated with winter in populations monitored at Chidley Point (also the population used initially to identify this species). Summers (1994) states that populations declined by as much as 97% over autumn/winter.

We propose that an uncharacteristic summer rainfall event in 2000 (139 mm, compared to a mean of only 17.6 mm) (Bureau of Meteorology, 2008), coupled with the natural variability of the Swan populations may have been contributing factors to the apparent death of most *Musculista senhousia* populations in this system (McDonald and Wells in prep). A small number of *M. senhousia* were collected in 2005 in the upper reaches of the Swan (Wildsmith 2007), however there was no evidence of any *M. senhousia* at these sites in this study. The high-post reproductive mortality associated with this species seems the most likely cause of this upper Swan populations decline.

4.2 *Carcinus maenas* – European shore crab

The European shore crab *Carcinus maenas* is native to Europe but is a problem pest in several countries (Australia, Japan, South Africa and North America) (Cohen *et al.* 1995; Grosholz and Ruiz 1995). It is a tough, voracious, generalist predator of other crustaceans, bivalves and other benthic invertebrates, and thought to have a significant impact on invaded systems (e.g. Cohen *et al.* 1995; Thresher 1997 and papers therein; Grosholz *et al.* 2000). It was first recorded in

Australian waters in 1900 at Port Phillip Bay, Victoria and has a current range on the east coast of Australia that extends from eastern Tasmania in the south to Port Jackson in central New South Wales (Ahyong 2005).

The 2007 study did not find any evidence of this species at any of the 43 sites examined. The presence in this region of *Carcinus maenas* was based on a single mature male collected from Blackwall Reach in the Swan River in 1965 (Zeidler, 1978), this record was subsequently cited by Furlani (1996), Hass and Jones (1999), Pollard and Hutchings (1990) and Ahyong (2005). It is not known what became of any remaining animals.

4.3 *Sabella spallanzanii* – European fan worm

The European fan worm, *Sabella spallanzanii*, is a major introduction that occurred about the same time in eastern Australia. This species probably came on the hull of a ship (Carey and Watson 1992). It was found in Albany, Western Australia, as early as the mid 1960s and in Cockburn Sound in 1994 (Clapin and Evans 1995). It has since been found in other southwestern Australian harbours (Huisman *et al.* 2008) from Fremantle to Esperance.

Sabella spallanzanii is generally found in shallow subtidal areas between 1-30m depth, preferring harbours and embayments sheltered from direct wave action. It colonises both hard and soft substrata, often anchored to hard surfaces within the soft sediments. In Australia, the worm is usually found in harbours where it readily colonises man-made hard surfaces such as wharf piles and facings, channel markers, marina piles and pontoons, and submerged wrecks. It can also be found in extensive beds at densities greater than 300 individuals m^{-2} (Parry *et al*. 1996).

Sabella spallanzanii is not known to be predated by native fish due to high arsenic and/or vanadium content (Notti *et al.* 2007) and if attacked has a high tolerance to wounding (Clapin and Evans 1995; Furlani 1996), to the extent of being capable of regenerating from fragments (Hewitt *et al.* 2002). In Port Phillip Bay, Victoria, *S. spallanzanii* has been observed to overgrow seagrass beds (Hewitt *et al.* 2002) and is regarded as significant pest species and a threat to the local scallop fishery. Holloway and Keough (2002a) found that the presence of a canopy of *S. spallanzanii* feeding fronds resulted in substantial short-term differences in the establishment of an underlying sessile community but no apparent changes in established systems. Epifaunal growth and survival were affected although responses lacked consistency (Holloway and Keough 2002b).

In the 1990's this species had very high densities in the Swan region (Clapin and Evans 1995). Surveys conducted in early 2000's speculated that the populations of *S. spallanzanii* in Cockburn Sound had died out and it became accepted locally that this species was no longer present in the region (Anonymous). Results from this study prove conclusively that not only is *S. spallanzanii* present in many of the original sites, but also has spread to sites further up the Swan River. The impacts of *S. spallanzanii* in Western Australian marine systems are unknown and require further investigation, particularly given the geographic spread of this species over recent time.

4.4 *Scaeochlamys livida* – Eastern Australian scallop

The introduction and the apparent successful colonisation of the eastern Australian scallop *Saeochlamys livida* in Cockburn Sound is an example of how introductions occur, not only between countries, but also between different regions of the same country, *i.e.* from the east to west coasts of Australia (Morrison and Wells 2008). *Saeochlamys livida* was likely to have been first introduced into temperate waters in Western Australia between the late 1970's and early 1980's and the first confirmed specimen was collected in south-western Cockburn Sound in 1989 (Morrison and Wells 2008). In 2000, the CSIRO Centre for Research into Introduced Marine Pests (CRIMP 2000) surveyed Fremantle Harbour, including Cockburn Sound, for introduced pest species. Specimens of *Saeochlamys livida* were recorded from four different stations in Fremantle Harbour and the lower Swan River.

The native scallop *Mimachlamys asperrimus* previously occupied much of the range now occupied by populations of *Scaeochlamys livida.* It has been speculated as to whether the populations of *M. asperrimus* declined independently at about the same time as *S. livida* bloomed, or whether *S. livida* out competed *M. asperrimus*. The two species are taxonomically related, feed and reproduce in the same way, and live in similar habitats. The mechanism by which *S. livida* would out compete *M. asperrimus* is not known. The impacts of *S. livida* in Western Australian marine systems are uncertain and requires further investigation, this is particularly so given the apparent spread of this species, and the possible displacement of local species.

5.0 Conclusions

The results from the investigations through the Cockburn/Swan region were from both ends of the spectrum. There was no evidence of *Musculista senhousia* or *Carcinus maenas* at any of the sites examined. At the other extreme there was an increase in the geographic spread of *Sabella spallanzanii* and *Scaeochlamys livida*.

The distributions of *Sabella spallanzanii* and *Scaeochlamys livida* were not surprisingly all closely linked to the main commercial port of Fremantle and the Kwinana industrial area, both highly modified habitats. Furthermore the densities of the scallop *Scaeochlamys livida* were greatest in these regions. There is a significant body of knowledge that demonstrates that non-indigenous species (NIS) are more likely to occur in disturbed habitats. Anthropogenic disturbances can change community dynamics and facilitate the establishment of non-indigenous species through a variety of mechanisms. The most common is through increased resource availability, either by the introduction of new resources or by decreasing resource-use by resident species (Davis *et al*. 2000). Anthropogenic disturbance can play a very important role in the creation of available open space within an affected assemblage (Johnston and Keough 2002). Anthropogenic disturbance may also facilitate invasion by decreasing diversity in native recipient communities. Species richness may be negatively related to the invasibility of a system (Naeem *et al*. 2000; Kennedy *et al*. 2002). Furthermore specific types of anthropogenic disturbance, often associated with harbours have been demonstrated to increase the invasion potential of exposed systems by complimenting inherent characteristics of NIS. For example, it has been shown that certain species and/or populations of NIS have a greater tolerance to heavy metal pollution relative to closely related native species (Piola and Johnston 2006a, 2006b; 2008). Such NIS may experience a competitive advantage over native species at recipient locations subject to transient or persistent metal pollution. Metal pollution in particular has been shown to greatly decrease the diversity of sessile and benthic fauna (Medina *et al*. 2005).

Both *Sabella spallanzanii* and *Scaeochlamys livida* were concentrated in areas that may be regarded as anthropogenically 'disturbed' habitats. There were no *S. livida* and only one

S. spallanzanii associated with the more 'natural' southern flats area. The impacts of both species need to be investigated, as it seems illogical to assume these species are having no effect. Furthermore both of these species have the capacity to be translocated within the Swan River region quite easily and they have the capacity to be translocated to iconic areas such as Rottnest Island or further afield. As such a study into the potential of these species to be translocated and the new translocation 'hot-spots' is recommended.

It seems likely that in addition to human-caused modifications in the local environment, climate change, in particular, will interact with species arrivals in new areas to modify ecosystem functions and biological diversity. Changes in the environment (both of origin and recipient environments) will alter species availability for transport and the degree of susceptibility to invasions, such that they are expected to continue to occur at unprecedented rates in nearly all ecosystems on earth (e.g., Vitousek *et al*. 1997; Janzen 1998).

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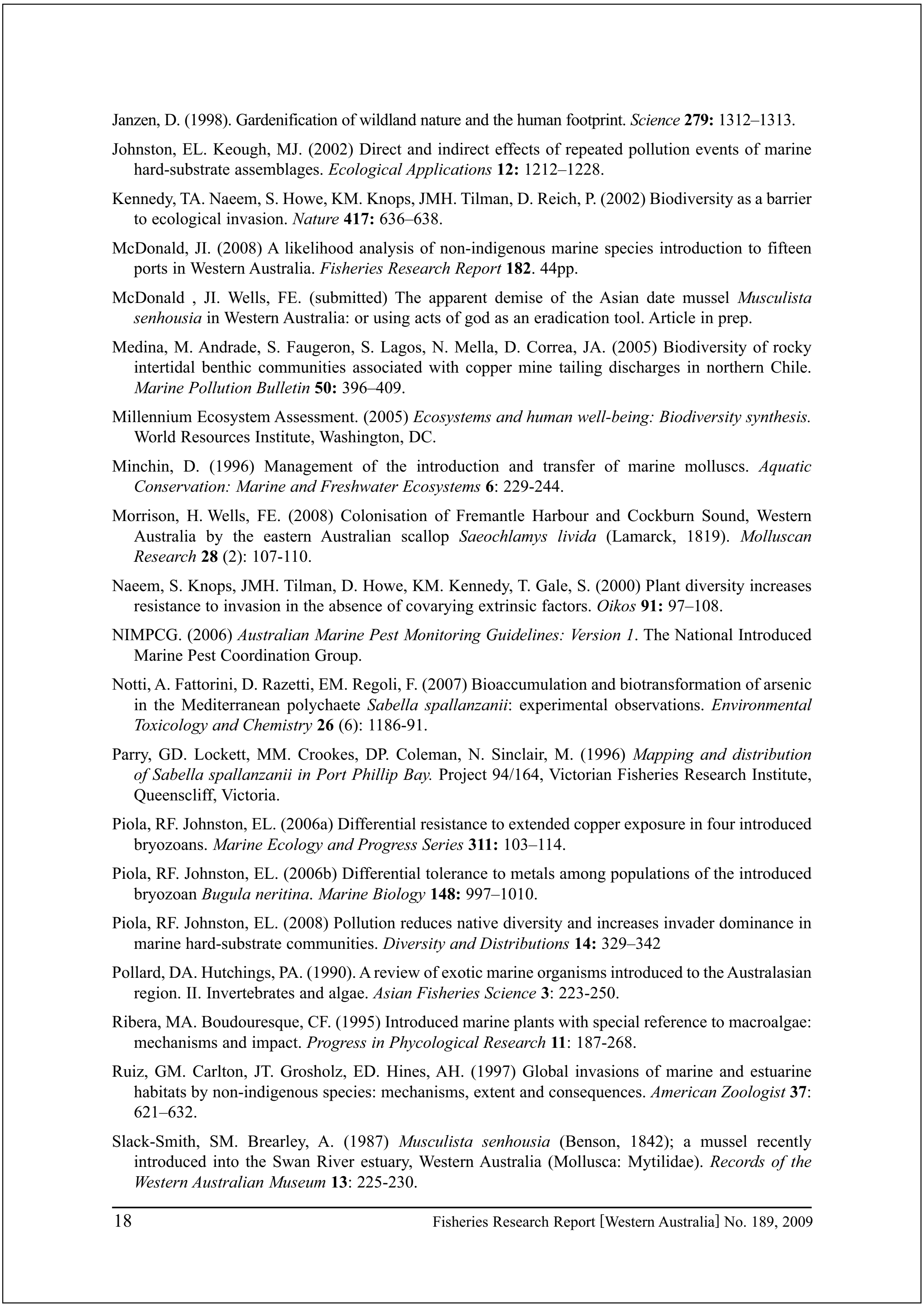

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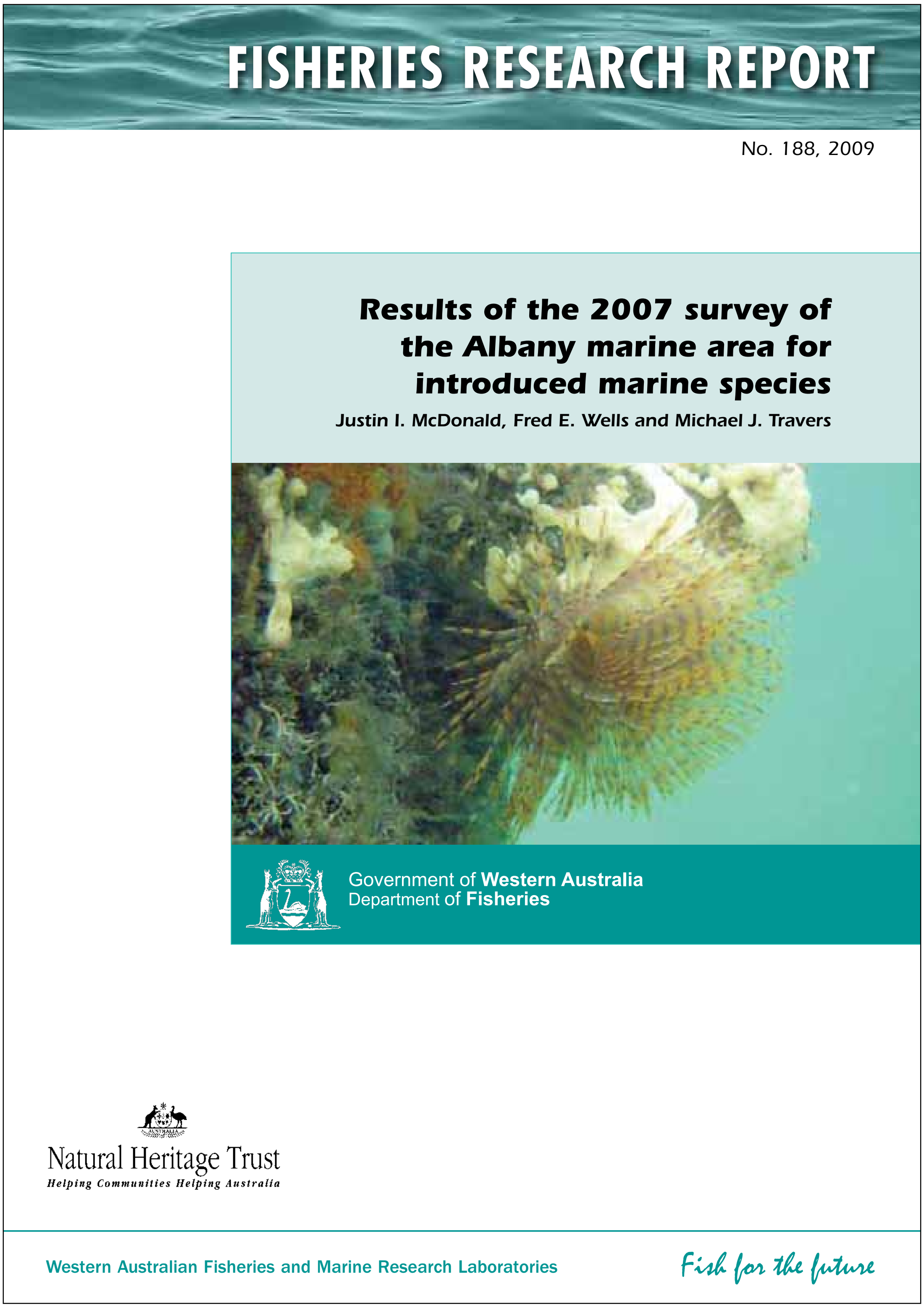

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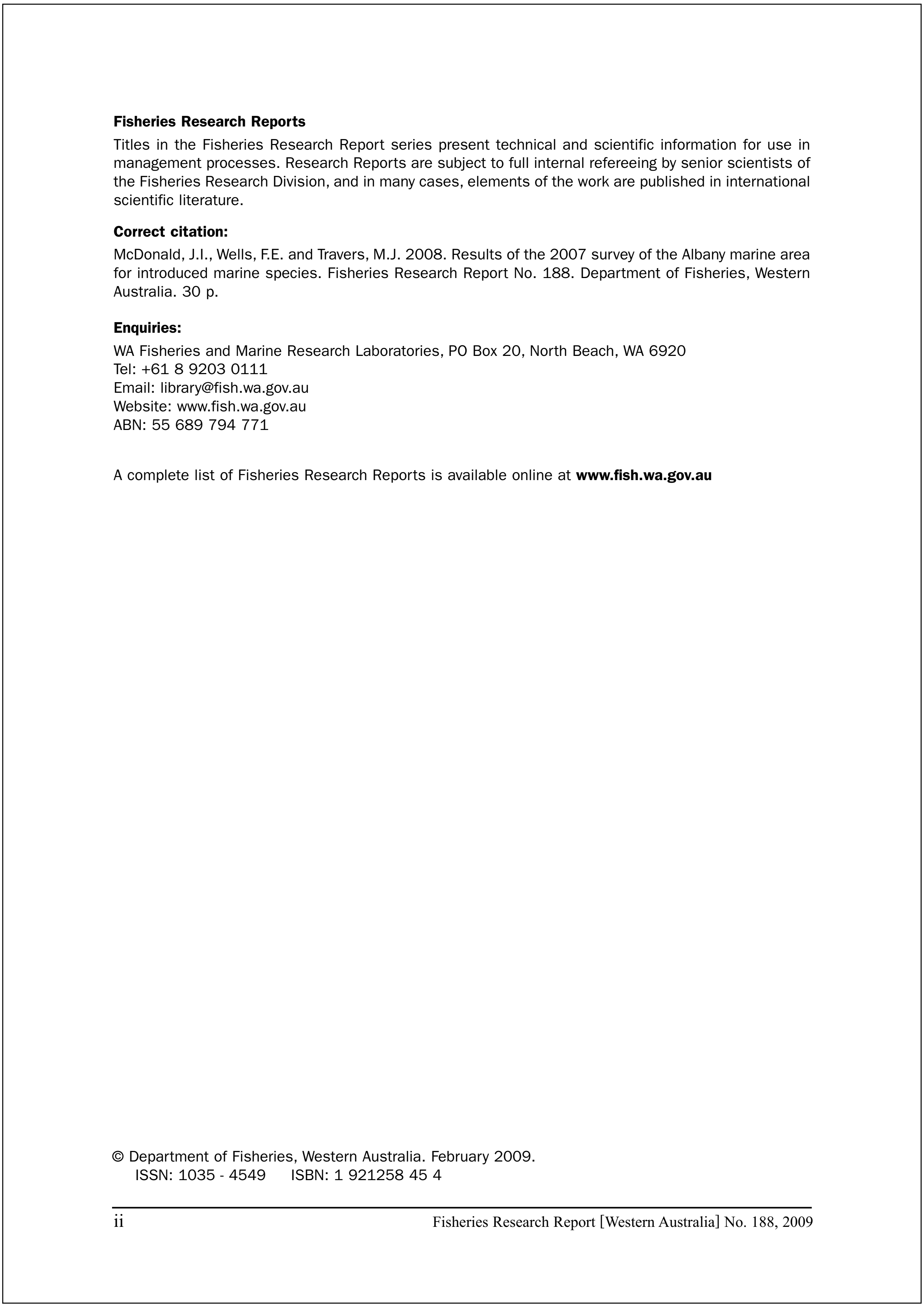

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Contents

Results of the 2007 survey of the Albany marine area for introduced marine species

J.I. McDonald, F.E. Wells and M.J. Travers

Executive summary

A survey of the Albany marine area (King George Sound, Princess Royal Harbour and Oyster Harbour) for introduced marine pest species was conducted in 2007. This survey was trialling the new system of monitoring for introduced marine pests developed by the National Introduced Marine Pests Coordination Group (NIMPCG). This study represents one of the first trials of this system (the first trial commenced in South Australia is still ongoing). In this survey fifty-two of the fifty-five potential pest species were targeted. Three species were excluded on the basis of salinity and/or temperature tolerances being exceeded. A wide variety of sampling methods were all used in two seasons (winter and spring): surface scrapes, grabs, visual census, small cores, large cores, traps, and plankton nets. A total of 875 flora and fauna samples were collected from 39 locations within the Albany marine area. Samples were sorted to major taxonomic groups and scanned for individuals that could possibly be one of the 52 target species; only possible target pest species were identified to species. In addition, 108 settlement plates were installed in the Albany marine area in October 2007 and collected in February 2008.

The only species recorded from Albany that were on the target list was the polychaete *Sabella spallanzanii* and the marine alga *Codium fragile* ssp. *tomentosoides* (now *C. fragile* ssp. *fragile*). *Sabella spallanzanii* was previously known from the area, but the single specimen of *C. fragile* ssp. *fragile* was a new record. Following the finding of *C. fragile* ssp. *fragile* in Princess Royal Harbour, an extensive survey specifically targeting this species was conducted in June 2008. No further specimens were found during the survey. The Port of Albany later collected thirteen additional individuals outside the initial survey area and their identity was confirmed as *C. fragile* ssp. *fragile*.

Six introduced species not on the NIMPCG target list were also recorded during the present study. Two (the marine algae *Grateloupia imbricata* and *Ulva fasciata*) are new records for the Albany marine area, bringing the total number of introduced species known from this region to 27. It emphasises the fact that additional surveys in any given area of Western Australia have a high probability of detecting more species

1.0 Introduction

Introduced marine species are organisms that have moved from their native environment to another area of the world's oceans. In their new region, introduced marine species can potentially threaten human health, economic values, or the environment, thereby becoming introduced marine pests. This is a global problem, second only to habitat change and loss in reducing global biodiversity (Millennium Ecosystem Assessment 2005). Many introduced marine species remain inconspicuous, but one in six to ten becomes a pest (Anonymous 2002). Most introductions are accidental due to vessels moving from country to country, with the pests being transported in ballast water, on hulls, or in internal seawater pipes. There have been no successful deliberate introductions for aquaculture, aquaria or recreational fishing to the WA marine environment (Huisman *et al.* 2008). Introduced marine species may also arrive naturally via marine debris and ocean currents (Wells and Kilburn 1986).

Over 250 introduced marine species are known in Australia (NIMPIS 2002); Port Phillip Bay, Victoria has the greatest known number of introductions, at 99 species (Hewitt *et al.* 2004). Sixty marine species have been introduced to Western Australia and are currently established here (Huisman *et al.* 2008). Most (37) are temperate species that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 occur in both the southern and northern halves of Western Australia. Because of the prevalence of temperate species, southern marine areas have more introduced marine species than northern areas: the Fremantle marine area (including Cockburn Sound and the lower Swan River) has 46 introduced species. Fremantle is the largest port in temperate WA by vessel movements. Albany (25 introduced species), Bunbury (24 introduced species) and Esperance (15 introduced species) are all smaller ports than Fremantle and consequently have fewer numbers of introduced marine species (Huisman *et al.* 2008).

Once a species becomes established in the marine environment, it is almost impossible to eradicate. Introduced marine pests in Australia and overseas have caused many millions of dollars of damage to local economies and can require the expenditure of many more millions of dollars annually in control and remediation efforts. There has only been one successful eradication of an introduced marine species in Australia, the black striped mussel that was found in Darwin Harbour in 1999 (Willan *et al.* 2000).

During the 1990s and earlier in this decade, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Centre for Research into Introduced Marine Pests (CRIMP) undertook extensive baseline surveys of most major Australian ports for introduced marine species. The goal was to establish a national database of the distribution of introduced species present as a first step in addressing the problem. The underlying objective was that to understand if a species is introduced, there must first be a thorough understanding of what species occur naturally in an area. Hayes and Sliwa (2003) and Hayes *et al.* (2005) analysed the CSIRO results and conducted an extensive search of the international literature on introduced marine species and their effects. Information was developed on 1582 species reported worldwide as having being introduced. A comprehensive risk assessment then developed a list of 55 species that have been shown to be invasive and to cause problems in Australia or overseas. The National Introduced Marine Pests Coordination Group (NIMPCG) used this information to develop a new national introduced marine pest monitoring strategy (NIMPCG 2006a; 2006b) to target these 55 species. The strategy has at its core a set of minimum requirements for marine pest monitoring and the collection of monitoring data from marine environments. The primary monitoring objectives of the strategy are:

- "To detect new incursions of established target species in various habitats in a given location, *i.e.* those species already established in Australia or New Zealand but have not been previously recorded at that location.

- To detect target species not previously recorded in Australia or New Zealand that are known to be pests elsewhere.

The secondary monitoring objective is:

- To detect species that appear to have clear impacts or invasive characteristics."

The second monitoring objective recognises that there may be species that invade an area but are not on the target list.

It should be noted that the NIMPCG methodology is based on presence or absence; it is not quantitative. If even a single individual of a target species is located, other mechanisms will then be used to determine the required response.

The present survey was undertaken to trial the NIMPCG manual in a Western Australian marine area. A separate report (Wells *et al*. 2008) has been submitted to NIMPCG detailing any problems associated with the NIMPCG methodology when put into practice. This report presents the survey results. The statistical methodology used in Albany was based on a 95% probability of detecting the presence of a species on the target list; to reduce costs and sampling efforts NIMPCG has since reduced the level to 80%.

The National Monitoring System includes 18 marine areas around Australia, the areas were chosen as representing 80% of the risk of introducing marine pests in to Australia and to ensure a broad geographic coverage (NIMPCG 2006a; 2006b). Three marine areas in Western Australia are on the national system: Dampier, Port Hedland and Fremantle. Albany was chosen for the WA trial for a number of reasons. Albany has a long history of European interaction, including the original wooden sailing vessels that first explored Australia. Albany is not part of the 18 marine areas proposed in the National Monitoring System, as such a survey in Albany will provide additional information on introduced species in Western Australia. Furthermore Albany was the location of the first settlement in Western Australia in 1827, two years before Perth. The Albany marine area has the widest habitat diversity on the south coast (Wells 1990), but the area is still small enough to be sampled readily. In this region there are a wide variety of potential sources of introduced marine species, including aquaculture, fishing, a yacht club, and the commercial trading port. The whaling industry operated out of Albany until the late 1970s, and the town jetty has been used by a wide variety of vessels. Deliberately wrecked vessels (*Cheynes III* and *HMAS Perth*) also present opportunities for introduced species.

There is already considerable information on introduced species in the Albany marine area. Wells and Bryce (1993) recorded the introduced nudibranch species *Polycera hedgepethi* in Princess Royal Harbour. CRIMP (1997) recorded eight introductions: the polychaete *Sabella spallanzanii,* the dinoflagellate *Gymnodium catenatum,* the oyster *Crassostrea gigas,* and the ascidians *Ascidiella aspersa, Ciona intestinalis, Botrylloides leachi, Styela clava* and *S. plicata.* In addition three cryptogenic species were detected: the ascidian and the bryozoans *Cryptosula pallasiana, Bugula neritina,* and *Bugula flabellata.* The blue mussel (*Mytilus edulis*), a major aquaculture species, is believed to be introduced (Huisman *et al.* 2008), and the European oyster (*Ostrea edulis*) was recently found at Albany (Morton *et al.* 2003). The Pacific oyster (*Crassostrea gigas*) was transported to Albany for aquaculture, but the shipment was in poor condition and failed to survive (Thomson 1959). Overall, 25 introduced marine species are known from the Albany marine area (Huisman *et al.* 2008).

2.0 Methods

The sampling methods used in this survey were those outlined in the Australian Marine Pest Monitoring Guidelines: Version 1 (NIMPCG 2006). The sampling strategy for the trial of the Albany marine area was submitted by Travers (2007) to NIMPCG and approved prior to the survey commencing.

The NIMPCG (2006a; 2006b) methodology provides an Excel spreadsheet to use in determining sample sizes. Published information on the temperature and salinity tolerances of 41 of the 55 target species (Table 1) is incorporated into the Excel spreadsheet (for 14 species there is no published information). Water temperatures in both Princess Royal and Oyster Harbour range from about 14º C in June to 21º C in February to April. Princess Royal Harbour generally remains at about full strength seawater (35‰) throughout the year, as there is no riverine input. Salinities in Oyster Harbour are similar during summer, but during winter there is considerable freshwater input from the King and Kalgan Rivers and salinity throughout the harbour can reach very low levels, e.g. 5‰ in 2005 (G. Bastyan, pers. comm.). Incorporation of these temperature and salinity data into the spreadsheet eliminated three species that could not survive in the Albany marine area: the bivalve mollusc *Limnoperna fortunei*, and the fishes *Tridentiger barbatus* and *T. bifasciatus*.

2.1 General sampling

Maps of the area were used to categorise marine habitats in each of the three harbours: Oyster Harbour, Princess Royal Harbour and King George Sound (Figure 1). The seafloor of King George Sound consists mainly of sand, seagrasses, rocky areas, and artificial hard structures, such as shipwrecks and navigational markers. Oyster Harbour has large areas of sand and seagrass, smaller areas of rocks, and numerous artificial hard structures within the boating marina and navigational markers. Princess Royal Harbour contains large areas of shallow sandflats, seagrass, several shipwrecks, rocks, jetties, mud, and artificial hard surfaces within the Princess Royal Sailing Club, navigational markers, and the Port of Albany. The area of each of the habitats in each harbour was calculated using the NIMPCG habitat classifications: hard substrate horizontal or vertical; soft substrate epifauna; soft substrate infauna; and plankton volume. The spreadsheet then determined for each species the number of samples required to obtain the 95% confidence level of detecting a species if it is present. As suggested in the monitoring manual, the adult stage of each species was targeted where possible.

Once this total number of samples was derived, sampling sites within each habitat type within each region were assigned using a systematic, rather than random method, as described in the manual. To define the location of sampling sites, for each habitat type within each region a grid of an appropriate scale was overlain on the habitat map. Where a grid point intersected with the habitat type to be sampled, the latitude and longitude of that position were recorded until the total number of samples for that habitat in that region was reached. Locations in which any marine pests were previously recorded were also incorporated into this design, e.g. channel markers on which *Sabella spallanzanii* was recorded.

Seasonality is an important consideration when designing species-specific sampling designs. The monitoring manual states that the monitoring should be targeted towards the time of year when target species are at their predicted maximum abundance or in a particular life stage that is relatively easy and cost-efficient to detect, or both. As the adult stage of many species is likely to be found throughout the year, it is the detection of the juvenile stage that is the most important consideration when planning sampling times. From an analysis of the conservative estimates of the planktonic period for certain target species, the monitoring was planned for May/June and October/ November.

Several problems during the actual sampling caused modifications to the field program. Grab samples proved ineffective during the June field trip and were abandoned. The sediment was either too hard or the large corer could only be used in areas where grabs were originally intended. In other areas the sediment contained a deep layer of dead macroalgae that prevented a grab sample being taken. Beam trawls were initially used in Princess Royal Harbour but the cod-end quickly filled with dead macroalgae, making it impossible and dangerous to bring the beam trawl back to the surface. As the algal layer over trawl bottom in Oyster Harbour was similar to that in Princess Royal Harbour, beam trawls were abandoned there also. Fish were sampled from crab traps and seine nets. As the two target species were gobies, these were sampled with hand nets when conducting an underwater visual census. The plankton nets were built specifically for the sampling programme. Delays in their construction prevented their use in June. However, they were used during the October/ November sampling.

Despite these problems, extensive sampling was undertaken. Tables 2-4 show the details of the sampling program and Figures 2-4 show the sample locations. After collection samples were preserved in 70% ethanol. They were initially sorted into broad taxonomic groups (e.g. ascidians, barnacles, sponges etc.) prior to more detailed taxonomic examination for species on the NIMPCG (2006a; 2006b) list. Only specimens that could be target species were fully identified.

2.2 Settlement plates

Settlement plates were installed at 11 locations (Figures 5 and 6). Locations were selected to monitor a broad spatial range and also areas where vectors such as shipping, commercial fishing operations and open water sailing vessels are present, *i.e.* port operations, commercial harbours and sailing clubs. Twenty-seven settlement plate systems were deployed, with a total of 108 individual plates. They were similar to those used in CRIMP surveys and also by the Northern Territory Department of Primary Industry, Fisheries and Mines as part of long term monitoring for introduced marine species in Darwin Harbour. The system consists of 20 mm sections of PVC pipe on which two 10 x 10 cm plates are fixed in a horizontal position and two are fixed in a vertical position (Figure 7); thus each array contains four plates. Arrays also have rope collectors which act as a different type of habitat for settlement. Settlement plates were deployed in the middle of August 2007 and were collected in early February 2008. Twelve of the 108 plate arrays were missing due to storm activity in the area; four each from sites along the Albany wharf, Albany town jetty and Emu Point.

2.3 Codium survey

A single algal specimen collected at the Town Jetty, Princess Royal Harbour, was identified as the target species *Codium fragile tomentosoides* (now considered to be *C. fragile fragile* [Trowbridge 1996]). Following discussions with the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE), a detailed survey was conducted in June 2008 to determine whether there were additional individuals in the area.

Divers visual inspections on SCUBA were conducted at the Town Jetty, the Main Wharf area, Camp Quaranup Jetty, the Quarantine Jetty, and Princess Royal Harbour Sailing Club (Table

6, Figure 8). Inspections included examination of artificial structures such as pylons, mooring buoys, debris, and adjacent substratum. Intertidal surveys immediately surrounding these key sites were also conducted where practical. Table 6 provides details of all sites examined, the method(s) used and any extra information regarding the sampling undertaken at each site. Subtidal inspections always involved at least three divers or snorkellers. Divers entered the water together and descended to the seafloor where they would space themselves approximately 1-2 m apart, depending upon visibility, and available space. Divers would proceed along the seafloor until pylons or other structures were encountered. They would then inspect the entire structure for the presence of *C. fragile fragile.* This method ensured that all structures and benthic substratum were inspected in a methodical and thorough manner.

Intertidal and beach surveys were also undertaken by three people. In such cases, individuals traversed an area examining rocks, structures, beach, and shallows for the presence of the target species. Wrack, debris and rock walls were examined in detail to determine if any detached individuals were present, which would provide an indicator that it is or was present in the vicinity.

3.0 Results

The purpose of this survey was to identify if there were any NIMPCG listed introduced species present in the Albany marine area. As such only those specimens displaying characteristics similar to listed species were identified to lowest taxonomic unit. Identification of this material did not progress to species level if the material was found to differ from the characteristics of the listed species. The majority of the collected material were classed as indigenous and not identified beyond morpho-species (*e.g.* solitary ascidian 1).

3.1 General survey

A total of 875 flora and fauna samples were collected from 39 locations within the Albany marine area. In summary, 93% of the samples were animal material and 7% plant material. Of all samples collected 96% were identified as native species.

Algal samples were dominated by members of the Rhodophyta (Table 7). Eight phyla of animals from 22 classes were represented in the Albany samples. Crustaceans, molluscs and annelids made up the vast majority of the samples collected (37%, 25% and 21% respectively) (Figure 10). Within the crustaceans the malacostraca (amphipods) dominated the samples (Table 7).

The dominant dinoflagellate cysts encountered were *Gymnodinium microreticulatum* and protoperidinioids, including *Diplopelta parva* and *Protoperidinium avellana*.

Eight introduced marine species were identified in this study:

• polychaete:	*Sabella spallanzanii*
• bryozoans:	*Bugula flabellata*
	Bugula neritina
• solitary ascidians:	*Ciona intestinalis*
	Styela plicata
• algae:	*Grateloupia imbricata*
	Ulva fasciata
	Codium fragile fragile

The Centre for Research into Introduced Marine Pests (CRIMP) also recorded the four animal species listed above in their 1996 survey of the Albany region (CRIMP 1997). Neither of the two algal species was recorded. Both algal species are listed by Huisman *et al.* (2008) in their review of non-indigenous species in Western Australia.

The red alga *Grateloupia imbricata* is native to Japan and the Mediterranean. Within Western Australia it has only previously been recorded from a rocky groyne in Cottesloe (Huisman *et al.* 2008). The green alga *Ulva fasciata* is regarded as widespread in tropical to temperate regions and has been recorded in the Swan River Estuary. It is, however, regarded as cryptogenic on the lower west coast of WA (NIMPIS 2002) and has not been recorded in Albany.

3.2 Settlement plates

Five introduced species were identified from the settlement plate arrays: the bryozoans *Bugula flabellata* and *Bugula neritina*; the ascidians *Ciona intestinalis* and *Styela plicata*; and the European fanworm *Sabella spallanzanii*. *Sabella spallanzanii* is the only NIMPCG listed pest species.

3.3 Codium survey

Codium fragile ssp. *fragile* has an undifferentiated juvenile vaucherioid (mat-forming) stage that can persist for months or even years. As this stage is extremely difficult, if not impossible, to detect in the field all information pertaining to the absence of *C. fragile* ssp. *fragile* relate to the adult erect thalli stage, but no thalli were found during the survey.

4.0 Discussion

At the commencement of this study there were three known introduced species listed on the NIMCPG (2006) target list present in Western Australia (Huisman *et al.* 2008):

- toxic dinoflagellate *Alexandrium minutum*;
- European fanworm *Sabella spallanzanii*; and
- Asian date mussel *Musculista senhousia*

This survey recorded two of the 52 listed pest species identified as having the potential to inhabit the Albany marine area. The first was the polychaete worm *Sabella spallanzanii. Sabella spallanzanii* was recorded in very high densities on piles, rocks and debris and on the substrate in 48% of sites surveyed and as a species represented 4% of all samples collected. It is highly probable that the European fanworm (*Sabella spallanzanii*) is translocated within Australia by domestic hull fouling. It is not possible to determine the origin of *Sabella spallanzanii* in the Port of Albany on the basis of existing information; genetic evaluation is required. *Sabella spallanzanii* was first introduced into Western Australia (Albany) in 1965. Since then this species has also been detected in Bunbury and Fremantle ports, as well as ports of the eastern seaboard (Clapin and Evans 1995; Huisman *et al.* 2008).

The second NIMPCG listed pest species recorded in this study is the invasive macro-algae *Codium fragile* ssp. *fragile.* This is the first record of this pest species in Western Australia. A single individual of the alga *Codium fragile* ssp. *fragile* was collected from the Albany Town Jetty. *Codium fragile* ssp. *fragile* is identified by Hayes *et al.* (2005) as one of the ten most damaging potential domestic target species based on overall impact potential (economic and environmental). A hazard ranking of potential domestic target species, based on invasion potential from infected to uninfected bioregions, identifies *C. fragile* ssp. *fragile* as a 'medium priority species' - these species have a reasonably high impact/or invasion potential. This species is listed on the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) Trigger List as a "Species Established in Australia, but not Widespread". The presence of *C. fragile* ssp. *fragile* initiated a CCIMPE response and a survey for the species was conducted in June 2008. No individuals were found in the June investigation. However, in July 2008 thirteen specimens were collected outside the initial June survey area by the Albany Port Authority and their identity confirmed by Dr John Huisman.

An interesting finding of the June 2008 survey was that many of the algal species collected during the initial June 2007 trial in Albany were not present. Since a mature, reproductively active specimen of this species was collected in June 2007 (southern hemisphere winter) it was expected that if *Codium fragile* ssp. *fragile* were in Princess Royal Harbour it would be present at this time of year. The absence of *Codium fragile* ssp. *fragile* and other algal species, collected during the previous monitoring suggests that there may be significant temporal variability in algal community structure in this region. Trowbridge (1996) reported that *Codium fragile* ssp. *fragile* dies back during winter months in the northern hemisphere. Information from New Zealand, support this and indicates that the thalli of *Codium fragile* ssp. *fragile* dieback in autumn, with the visible thalli growing in spring and summer. It is therefore proposed that the same sites targeted in this June 2008 field survey, be re-surveyed in the spring/summer period of 2008/2009.

CRIMP (1997) recorded two species on the NIMPCG (2006a; 2006b) list that were not collected in this current study: the dinoflagellate *Gymnodinium catenatum* and the oyster *Crassostrea gigas.*

The original identification to CRIMP was: "*Gymnodinium catenatum* – like cysts" (Prof Gustaaf Hallegraeff, 2007, pers. comm. to Dr John Huisman, including emphasis). This taxon was subsequently described as a new, non-toxic species *Gymnodinium microreticulatum* (Bolch *et al*., 1999). *Gymnodinium catenatum* has never been seen in WA waters (Hallegraeff, 2007, pers. comm. to Dr John Huisman).

Thomson (1952; 1959) reported that the Pacific oyster, *Crassostrea gigas* was introduced into Oyster Harbour, Albany and Tasmania after World War II for aquaculture. As the broodstock was shipped by sea and was in poor condition when it arrived in Australia, the species did not survive in either area. In 1949 a second shipment was sent by air to Tasmania and survived. Furlani's (1996) distribution maps (by biogeographical regions) showed *C. gigas* as occurring in Western Australia from the South Australian border to North West Cape. However these distributions are based on a single record from Albany and a single dead shell recorded from Cockburn Sound (west coast). The survey of Albany by CRIMP (1997) listed *C. gigas*. The NIMPIS (2002) website used these records. However, *C. gigas* was not recorded by a WA Museum survey of molluscs of the Albany area (Roberts and Wells 1980), nor was it collected by any of the mollusc experts at the 1988 Albany international marine biological workshop (Wells *et al.* 1990; 1991). Extant, properly labelled material from CRIMP surveys in WA has been accessed into the collections of the WA Museum, but there was no material of *C. gigas* from Albany. Following representations by one of the authors (F.W.), *C. gigas* was removed from the NIMPIS database. The species does not occur in WA (Huisman *et al.* 2008).

In addition, six introduced species not on the NIMPCG (2006a; 2006b) list were recorded during the present study: the bryozoans *Bugula flabellata* and *B. neritina*; the solitary ascidians *Ciona intestinalis* and *Styela plicata*; and the marine algae *Grateloupia imbricata* and *Ulva fasciata.* The four species of bryozoans have all been previously recorded from Albany (CRIMP 1997; Huisman *et al.* 2008). *Grateloupia imbricata* (Cottesloe) and *Ulva fasciata* (Swan River) have previously been recorded in WA only from the Perth metropolitan area (Huisman *et al.* 2008). The addition of these two species brings the total number of introduced species known from the Albany marine area to 27. It emphasises the fact that additional surveys in any given area of Western Australia have a high probability of detecting more introduced marine species.

5.0 Acknowledgements

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7.0 Tables and figures

7.1 Tables

Table 1. Target species of introduced and potentially introduced marine species on the national monitoring program (NIMCPG 2006).

Group	Species	Group	Species
Ballast Water			
Dinoflagellates	*Alexandrium catenella*	Diatoms	*Chaetoceros convolutus*
	Alexandrium minutum		*Chaetoceros concavicornis*
	Alexandrium monilatum		*Pseudo-nitzschia seriata*
	Alexandrium tamarense	Ctenophorans	*Beroe ovata*
	Dinophysis norvegica		*Mnemiopsis leidyi*
	Gymnodinium catenatum	Copepods	*Acartia tonsa*
	Pfiesteria piscicida		*Pseudodiaptomus marinus*
			Tortanus dextrilobatus
Hull Fouling			
Algae	*Bonnemaisonia hamifera*	Cnidarians	*Blackfordia virginica*
	Caulerpa racemosa	Polychaetes	*Sabella spallanzanii*
	Caulerpa taxifolia		*Hydroides dianthus*
	Codium fragile spp.		*Marenzelleria* spp.
	Grateloupia turuturu	Barnacles	*Balanus eburneus*
	Sargassum muticum		*Balanus improvisus*
	Undaria pinnatifida	Crabs	*Callinectes sapidus*
	Womersleyella setacea		*Carcinus maenus*
Bivalves	*Corbula amurensis*		*Charybdis japonica*
	Ensis directus		*Eriocheir* spp.
	Limnoperna fortunei		*Hemigrapsus sanguineus*
	Mya arenaria		*Hemigrapsus takanoi*
	Varicorbula gibba		*Rhithropanopeus harrisii*
	Musculista senhousia	Ascidians	*Didemnum* spp.
	Mytilopsis sallei	Seastar	*Asterias amurensis*
	Perna perna	Fish	*Neogobius melanostomus*
	Perna viridis		*Siganus luridus*
	Crassostrea gigas		*Siganus rivulatus*
Gastropods	*Crepidula fornicata*		*Tridentiger barbatus*
	Rapana venosa		*Tridentiger bifasciatus*

Table 2. Key to regions sampled, the map reference number and site name.

Region	Map reference #	Site
King George Sound	1	Anchorage B
	2	Channel Marker 4
	3	Channel Marker 5
	4	Channel Marker 6
	5	Cheynes 3
	6	Frenchmans Bay
	7	HMAS Perth
	8	Middleton Beach
	9	Mossie Marker
	10	Vancouver Beach (beach walk)
	11	West of Mossie Marker
Oyster harbour	1	Emu Point Marina jetty 1
	2	Emu Point Marina jetty 2
	3	Emu Point Marina jetty 3
	4	Emu Point Marina jetty 5
	5	Kalgan River Bridge
	6	King River Bridge
	7	Marker 4
	8	Mid harbour
	9	Starboard marker 5
	10	Starboard marker N/W Green Island
Princess Royal harbour	1	Camp Quaranup Rocks
	2	Cheynes II wreck
	3	Kingfisher wreck
	4	Marker 16
	5	Navigation marker ISO 8S4
	6	Princess Royal Harbour Yacht Club - pylon 1
	7	Princess Royal Harbour Yacht Club – pylon 2
	8	Princess Royal Harbour Yacht Club – pylon 3
	9	Princess Royal Harbour Yacht Club – pylon 4
	10	Princess Royal Harbour Yacht Club – pylon 5
	11	Camp Quaranup Jetty
	12	Sarah Burnett Wreck
	13	South east Pile
	14	South east of Princess Royal Harbour Yacht Club
	15	South spit
	16	Town Jetty 1
	17	Town Jetty 2
	18	Town Jetty 3
	19	Tug boat harbour
	20	West of Princess Royal Harbour Yacht Club
	21	Wharf 1 – pylon 1
	22	Wharf 1 – pylon 2
	23	Wharf 1 – pylon 3
	24	Wharf 3 – pylon 1
	25	Wharf 3 – pylon 2
	26	Wharf 3 – pylon 3
	27	Wharf 6 – pylon 1
	28	Wharf 6 – pylon 2
	29	Wharf 6 – pylon 3

Table 3. Sampling methods used in monitoring the Albany marine area for species on the NIMPCG (2006a; 2006b) list.

Habitat	Functional Group	Sampling Method
Hard-surfaces	Motile	Trap, Scrape, Visual
Hard-surfaces	Sessile fouling	Scrape, Visual, Settlement plates
Sub-tidal Soft surfaces	Motile epifauna	Visual, Trap, Grab, Seine, Beam Trawl
Sub-tidal Soft surfaces	Sessile epifauna	Visual, Core, Grab, Settlement plates
Water Column	Holoplanktonic	Plankton net (20, 100 & 300 µm)
Water Column	Meroplanktonic	Plankton net (20, 100 & 300 µm)

Table 4. The sampling methods and numbers of samples collected at each of the three regions in the Albany marine area.

Method	Princess Royal Harbour				Oyster Harbour			King George Sound		
	APA Wharf	Princess Royal Sailing club	Vancouver Peninsula	Channel Markers	Emu Point Marina	Kalgan/King Bridge	Channel Markers	Anchorage	Cheynes III	Total
Scrape	27	6	6	9	9	6	10	–	4	77
Settlement plate	12	6	–	–	6	–	–	–	–	24
Grab	6	3	3	–	3	4	–	6	–	25
Visual census	6	3	5	3	3	4	5	4	2	35
Small core	6	3	–	–	6	4	–	6	–	25
Large core	6	3	–	–	6	4	–	6	–	25
Trap	9	–	3	–	6	6	–	–	–	24
Plankton net (20 µm)	3	2	2	–	3	4	–	6	3	23
Plankton net (100 µm)	3	2	2	–	3	4	–	6	3	23
Plankton net (300 µm)	3	2	2	–	3	4	–	6	3	23
Total	81	34	27	12	54	50	15	40	15	**328**

Table 5. Locations in Albany where settlement plates were installed. Details of water depth and numbers of plates at each location are shown.

Albany			
Location number	**Location**	**Depth (m)**	**# Plates**
1	Town Jetty North	1	4
	Town Jetty North	4	4
2	Town Jetty Middle	1	4
	Town Jetty Middle	4	4
3	Town Jetty South	1	4
	Town Jetty South	4	4
4	Wharf 1 west	1	4
	Wharf 1 west	4	4
	Wharf 1 west	10	4
5	Wharf 1 east	1	4
	Wharf 1 east	4	4
	Wharf 1 east	10	4
6	Wharf 3 west	1	4
	Wharf 3 west	4	4
	Wharf 3 west	10	4
7	Wharf 3 east	1	4
	Wharf 3 east	4	4
	Wharf 3 east	10	4
8	Wharf 6 west	1	4
	Wharf 6 west	4	4
	Wharf 6 west	10	4
9	Wharf 6 east	1	4
	Wharf 6 east	4	4
	Wharf 6 east	10	4
10	Princess Royal Harbour Yacht Club NW corner	1	4
	Princess Royal Harbour Yacht Club NW corner	1	4
11	Emu Point Marina north	2	4
	Emu Point Marina south (a)	2	4
	Emu Point Marina south (b)	2	4
Total for Albany	**11**		**108**

Table 6. Site numbers of sample locations for *Codium fragile fragile*, as shown in Figure 8.

Site	Location	Method(s) used	Additional information
1	Main wharf – berth 6 (max depth 14.6 m)	Sub-tidal survey Multiple depths	3 divers spaced 1 m apart. Approx length 180 m, three depths.
2	Main wharf – berth 1 (max depth 10 m)	Sub-tidal survey Multiple depths	3 divers spaced 1 m apart. Approx length 100 m, three depths.
3	Town Jetty (max depth 6 m)	Sub-tidal survey Multiple depths	3 divers spaced 1 m apart. Approx length 180 m, three depths.
4	Middleton Beach	Inter-tidal survey	3 people, haphazard surveys of beach, wrack and shallow waters. Approx distance covered 1,500 m.
5	Camp Quaranup Jetty (max depth 2.6 m)	Sub-tidal survey Multiple depths	3 divers spaced 1m apart. Approx length 20 m, two depths. Surveyed 2 m either side, and end of Jetty.
6	Quarantine Jetty (max depth 2.2 m)	Sub-tidal survey Multiple depths	3 divers spaced 1 m apart. Approx length 50 m, two depths. Surveyed 2 m either side, and end of Jetty.
7	Princess Royal Sailing Club. Main Jetty facing into harbour (max depth 5 m)	Sub-tidal survey Multiple depths	3 divers spaced 1 m apart. Approx length 100 m, three depths. Surveyed 1 m either side of Jetty.
8	Oyster Harbour opening and Emu Point Marina	Inter-tidal survey	3 people, haphazard surveys of rock walls, marina structures, beach, wrack and shallow waters. Approx distance covered 1,500 m.
9	Enclosed area west of Town Jetty (less than 3 m deep)	Sub-tidal survey	4 people, back and forth snorkel surveys of shallow waters (< 3 m). Surveys 1.5 m apart, each person completed at least three 300 m long surveys. Examined substratum, rock walls.
10	Shallow areas of Town Jetty (less than 3 m deep)	Sub-tidal survey	4 people, back and forth snorkel surveys of shallow waters (< 3 m). Surveys 1.5 m apart, each person completed at least two 150 m long surveys. Examined substratum, rock walls, pylons and boat berths.
11	Shallow water area east of Town Jetty (less than 3 m deep)	Sub-tidal survey	4 people, back and forth snorkel surveys of shallow waters (< 3 m). Four people at 1.5 m apart, each person completed at least two 150 m long surveys. Examined substratum, rock walls and pylons.
12	Melville Point	Inter-tidal survey	3 people, haphazard surveys of rock walls, any structures, beach, wrack and shallow waters. Approx distance covered 100 m.
13	Frenchman Bay Road	Inter-tidal survey	3 people, haphazard surveys of rock walls, beach, wrack and shallow waters. Approx distance covered 100 m.

Site	Location	Method(s) used	Additional information
14	Rushy Point	Inter-tidal survey	3 people, haphazard surveys of beach, wrack and shallow waters. Approx distance covered 100 m.
15	Quaranup Road	Inter-tidal survey	3 people, haphazard surveys of beach, wrack and shallow waters. Approx distance covered 150 m.
16	Goode Beach	Inter-tidal survey	3 people, haphazard surveys of beach, wrack and shallow waters. Approx distance covered 200 m.
17	Whalers Beach	Inter-tidal survey	3 people, haphazard surveys of beach, wrack and shallow waters. Approx distance covered 100 m.
18	Whaling Station	Inter-tidal survey	3 people, haphazard surveys of beach, wrack and shallow waters. Approx distance covered 100 m.
19	Salmon Pools	Inter-tidal survey	3 people, haphazard surveys of beach, wrack and shallow waters. Approx distance covered 50 m.

Table 7. The phylum, class and common name (group), and the relative proportion of each group collected from the Albany marine area.

Phylum/division	Class	Common name	% of total species number
Chlorophyta		Green algae	17.2
Rhodophyta		Red algae	44.8
Phaeophyceae		Brown algae	38.0
			100.0
Dinoflagellates			None found
Diatoms			Not assessed
Copepoda			None found
Annelida	Polychaeta	Worm	19.2
Chordata	Ascidiacea	Ascidian	4.1
Chordata	Osteichthyes	Fish	0.2
Cnidaria	Anthozoa	Coral	0.6
Cnidaria	Gorgonacea	Sea pen	0.1
Cnidaria	Anthozoa	Anemone	1.9
Crustacea	Bivalvia	Bivalve	2.3
Crustacea	Brachiopoda	Prawn / Shrimp	0.1
Crustacea	Brachiopoda	Shrimp	0.6
Crustacea	Malacostraca	Crab	7.2
Crustacea	Malacostraca	Amphipod	13.9
Crustacea	Maxillopoda	Barnacle	9.4
Crustacea	Polyplacophora	Chiton	1.5
Echinodermata	Asteroidea	Sea star	0.8
Echinodermata	Echinoidea	Urchin	1.9
Echinodermata	Holothuroidea	Cucumber	2.3
Echinodermata	Ophiuroidea	Basket star	0.1
Mollusca	Bivalvia	Oyster	4.7
Mollusca	Bivalvia	Mussel	12.9
Mollusca	Gastropoda	Nudibranch	0.9
Mollusca	Gastropoda	Gastropod	5.3
Porifera	Demospongia	Sponge	2.7
			100.0

7.2 Figures

Figure 1. Map of the Albany marine area showing Princess Royal Harbour, Oyster Harbour and King George Sound.

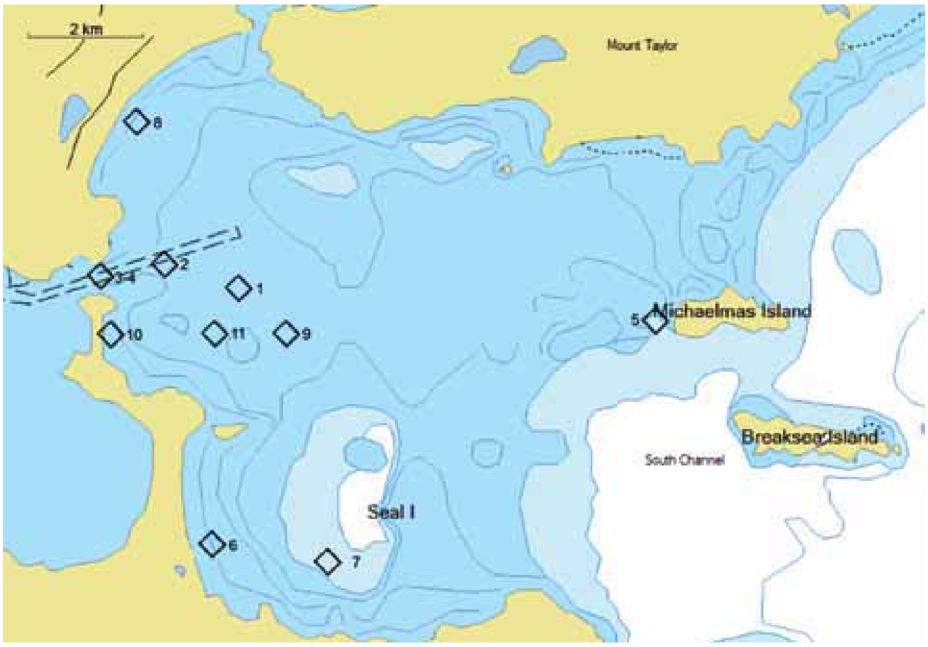

Figure 2. King George Sound sampling sites within the broader Albany marine area. Refer to Table 2 for site names.

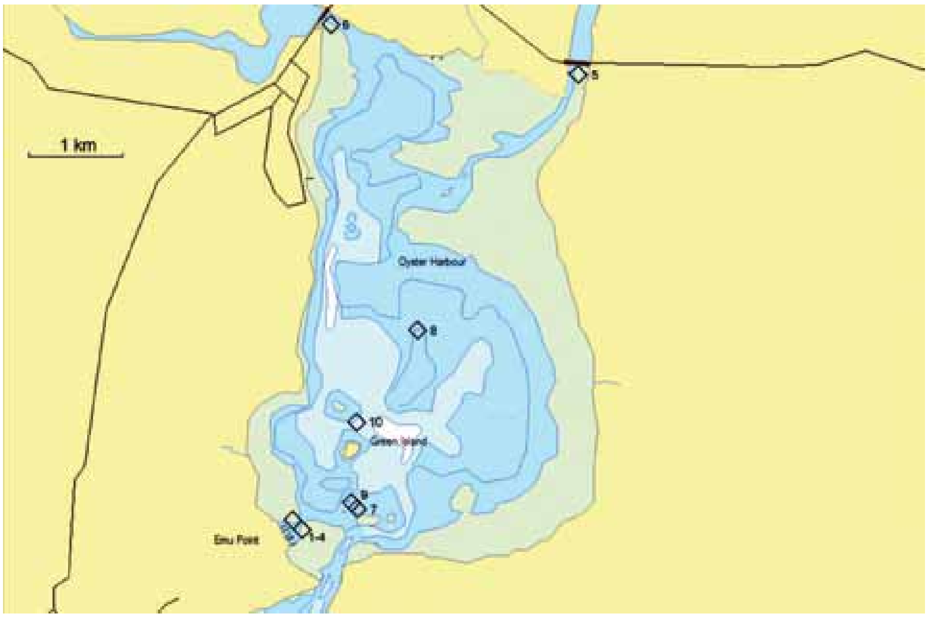

Figure 3. Oyster harbour sampling sites within the broader Albany marine area. Refer to table 2 for site names.

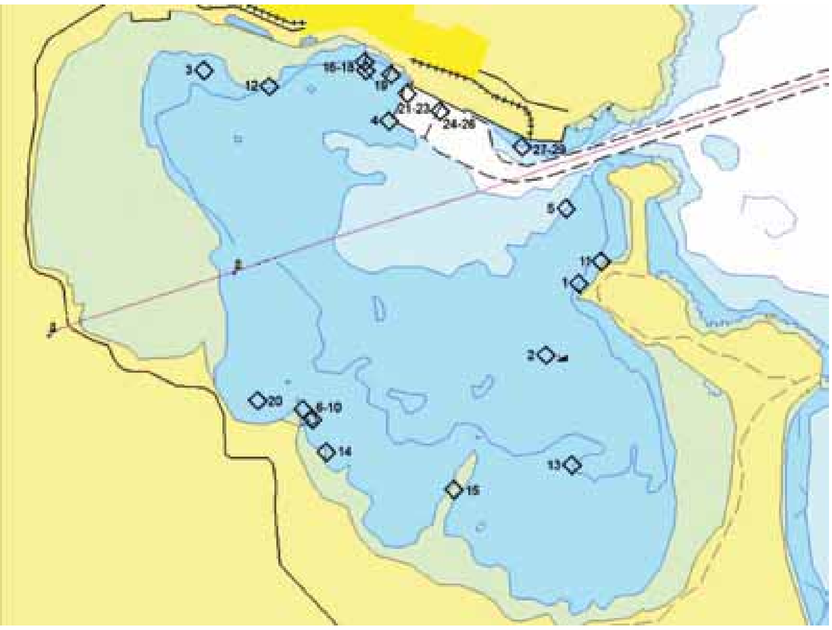

Figure 4. Princess Royal Harbour sampling sites within the broader Albany marine area. Refer to Table 2 for site names.

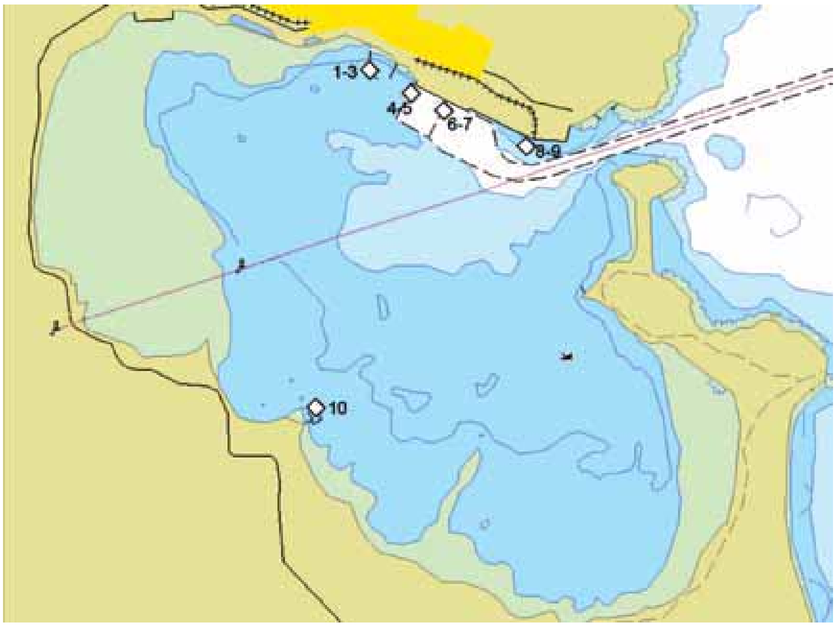

Figure 5. Locations (1-10) of settlement plates within Princess Royal Harbour, Albany. See Table 5 for location key.

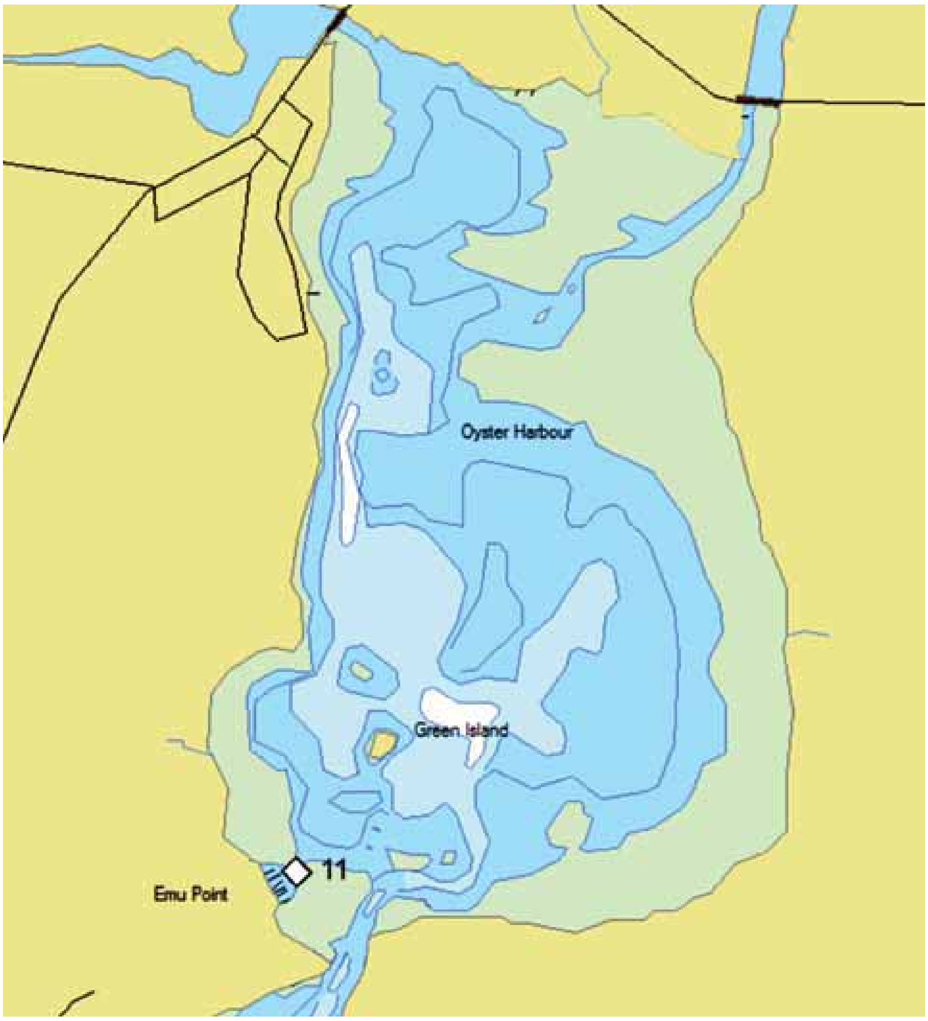

Figure 6. Location (11) of settlement plates within Oyster Harbour, Albany. See Table 1 for location key.

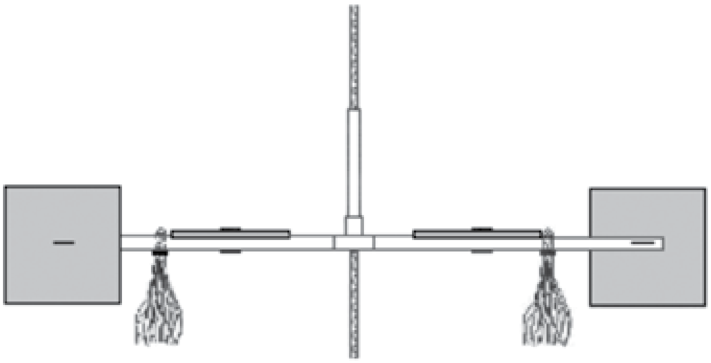

Figure 7. Illustration of the settlement plate system showing one vertical and one horizontal plate attached to each of the two arms of the system.

Figure 8. Sites surveyed to detect the invasive alga *Codium fragile fragile*. See Table 7 for site names and survey details.

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Evaluation of the National Introduced Marine Pest Monitoring Manual Trialled in Albany, Western Australia

Fred E. Wells, Michael Travers, Justin I. McDonald

Introduction

The Australian and New Zealand governments have recognised the importance of ongoing monitoring for introduced marine pests. Working collaboratively they developed the national introduced marine pest monitoring strategy (NIMCPG 2006a; 2006b). This strategy has at its core a set of minimum requirements for marine pest monitoring and the collection of monitoring data from marine environments. As part of the overall strategy a 'how to guide' was developed to allow researchers and government and regional council representatives, stakeholders, etc with a user friendly format that produces scientifically defensible data that can be used to make informed and scientifically sound management decisions.

The objectives of the National Monitoring strategy are:

Primary Monitoring Objectives

- To detect new incursions of established target species in various habitats in a given location, *i.e.* those species already established in Australia or New Zealand but have not been previously recorded at that location.
- To detect target species not previously recorded in Australia or New Zealand that are known to be pests elsewhere.

Secondary Monitoring Objectives

- To detect species that appear to have clear impacts or invasive characteristics.

The NIMCPG (2006a; 2006b) documents are necessarily long and complex. They represent a new strategy for handling monitoring for marine pests now that the major port surveys have been completed. As the documents highlight, they are evolving and will be adapted as new information and methods for detecting incursions are developed.

The present report is an evaluation of the NIMCPG (2006a; 2006b) methodology to evaluate its usefulness.

Methods

The trial of the NIMCPG methodology was undertaken as an investigation of the NIMCPG target species in the Albany marine area, southwestern Western Australia, in 2007. A separate report is being prepared on the findings of the project. The present document is restricted to an evaluation of the NIMCPG methodology used.

The NIMCPG (2006a; 2006b) documents are to be used in the national survey program for 18 ports in Australia of introducing marine pests, but they were also written for use in other ports and marine areas by a wide variety of stakeholders with an equally wide range of backgrounds and capabilities. Our strategy was to independently follow the NIMCPG (2006a; 2006b) documents as they were written. A similar trial is being undertaken in South Australia, but the Albany survey remained separate from that on the basis that if the manual worked for both assessments, the writing and intent are likely to be clear. If it did not work for either assessment, then it may be unclear. If it worked for one and not the other, then further clarification in the manual might be appropriate.

Overall Assessment

Overall, the manual provides a clear method of sampling for introduced marine pest species throughout Australia. Any such document written as a desktop study will have issues that must be resolved when the actual fieldwork and laboratory analysis are undertaken. The documents provide an agreed national minimum standard so resulting data can be incorporated into a national database. There are a number of places where the manuals state that procedures can be modified as necessary in the actual project. This is a valuable recognition, but it does raise the problem of how much flexibility is taken in individual projects.

Comments

Taxonomic Problems

Lack of experienced marine taxonomists

There are very few marine taxonomists in Australia, most of whom are in their late 50s and 60s. Many have already retired. As these scientists retire they are in general not replaced. A recent study by Leis *et al.* (2007) showed that in the last 20 years the number of fish taxonomists in the country has declined from 11 to three, all of whom are over 55. Similar figures can be provided for key invertebrate groups such as molluscs. For many phyla, there are only one or two taxonomists in Australia, including groups such as ascidians that have invasive pest species. Other phyla have been completely unstudied.

The lack of taxonomic expertise in Australia is well known to many of the NIMCPG members, and the solutions lie well outside the brief of NIMCPG. However, the issue is crucial to properly undertaking marine pest species, and thus impacts directly on the functionality of the NIMCPG (2006a; 2006b) strategy.

Identification

There are substantial taxonomic problems with some of the species on the target list. For example, the mussel *Musculista senhousia* is shown by NIMPIS (2002) as being native to southeast Asia and cryptogenic in Indonesia. The data presented on temperature tolerances, etc are very wide, but it is likely that there are in fact two species being confused.

Target species

The monitoring manual provides a listing of 55 target species. This listing is easily construed as 'the list' to use, to the exclusion of other species. Whilst page 19 of the manual states that this is a '*possible list…not intended as comprehensive of all possible species that could be monitored...rather those most likely to be introduced…"* the actual list as Attachment 1 does not have this same information and as such may have been interpreted by the users as 'the list'. The fact that this list is not comprehensive and is to be used as a basis only needs to be stated more clearly in the manual. Perhaps this fact could be reinforced in correspondence when those conducting the monitoring submit their planning documents.

Any such list will attract criticism of why a particular species is on the list and why another is not. The background to the development of the list should be briefly explained. Our understanding is that the list was the result of an extensive analysis of the published literature (Hayes *et al.* 2005). This provides a sound basis for determining which species to include. However, the paper appears to be based on computer literature searches and does not include species that have long been known to be invasive. For example, the gastropod oyster drill *Urosalpinx cinerea* was introduced into England in the late 19th century on the American oyster *Crassostrea virginica,* and is regarded as a pest species. Many of the species have no known distributions near Australia and are unlikely to become established here.

Selection of species to measure

The Albany survey used Version 3 of the Excel spreadsheet. This resulted in eliminating only three of the 55 species from consideration, hardly of much use in restricting the survey. We have recently received Version 11, but the macros were not working, so the sample plans being designed for Fremantle, Dampier and Port Hedland could not be completed. It turned out that the version was written on a newer version of Excel than is available at the Department of Fisheries. This problem has been eliminated, but others may not know the Excel version they require. We understand the release of a manual is imminent, which will eliminate this type of problem.

However, it does illustrate that there is limited information available outside NIMCPG. If outside workers are to use the NIMCPG (2006a; 2006b) strategy, the necessary information must be readily and easily available.

Consistency of staff

A crucial problem for each jurisdiction will be the development of well trained staff to undertake the surveys. Clearly, visual searches will only be as effective as the person undertaking them. Material collected from quadrats will require sorting so suspect material can be sent to experts for confirmation of their identities. The system will break down if the sorter is not familiar with the groups being sorted. Also there is a requirement continuity for monitoring species of concern.

Identifications

The list of experts for identifications of various groups is out of date. Many have since retired, and there may be some young new people not on the list.

Species tolerances

Whilst providing data on species tolerances may be useful to 'fine-tune' sampling the range of species, tolerances provided on the Excel spreadsheet are extremely broad. This means that sampling in a cool temperate habitat such as Albany, Western Australia one still needs to monitor for tropical species based on provided tolerance limits of –3 to +30 degrees. This is clearly unlikely to occur from a biological standpoint. Whilst species may have large tolerances, it seems biologically impossible that a species can tolerate, what is essentially a frozen environment and a warm tropical environment.

Methodologies

Collection & preservation

Monitoring should include as mandatory that *in-situ* colour photographs and/or video are taken of habitats surveyed and in particular potential target species. These then provide a record of colour and form that may be used to assist in subsequent identifications.

Visual records of habitat are particularly important when trying to establish the strategy's secondary objectives "*To detect species that appear to have clear impacts or invasive characteristics*". The collection of photographic (video and/or still image) data can provide a useful tool in determining habitat changes, *i.e.* if one species is in low numbers at time A, and recorded in imagery, then increase in numbers, and potential effects could then be compared with imagery from time B. Photographs also help to allow for new staff to verify that what the previous researcher called species A as a potential pest is the same the new person is calling species A.

Table 21 in the National monitoring strategy has a listing of taxa and the 'preferred' narcotizing, fixation and preservation methods for the major groups of marine taxa. The manual states, for example, that tunicates are best fixed with 4% formalin then preserved in 70% ethanol. Compound, colonial, or other gelatinous ascidians should be photographed alive as form and colour patterns are very important diagnostic features. Large solitary ascidians should be relaxed before fixing; menthol or magnesium chloride in seawater overnight is usually effective. Large solitary ascidians may also need to have preservatives injected into them to insure adequate fixation; fix in formalin; store in 70% alcohol.

On page 51 the strategy states *"If genetic analysis is required, sub-sample the original sample to keep part for DNA analysis*". The use of formalin as a fixative effectively precludes any subsequent genetic analyses. Surely it would be 'wiser' to treat all samples as potential DNA sources, rather than rely upon those conducting the monitoring at the time to sub-sample based on if they consider DNA analysis may be needed. It is strongly suggested that methods should state to the user that all samples should be collected and preserved for DNA analysis.

DNA probes

DNA probes are one method for determining presence of target species. When we started there were only three probes available. There are apparently more now, but we do not know what species they are for or where to obtain them.

Issues with sampling gear

In this study some of the methods prescribed for use in the manual could not be used. For example grab samples proved ineffective and were abandoned from the sampling procedures as sediment at sites was either too hard at those locations or the large corer was able to be used in those location where grabs were originally intended to be taken. The corer was easier to manage than the grab.

In other areas the sediment contained a deep layer of dead algae, which prevented a grab sample being taken. Likewise beam trawls were initially to be used but quickly filled with dead algae making it impossible and very dangerous to bring the beam trawl back to the surface.

Sample size

Minimum sample size was calculated using the formula given in the monitoring manual. This formula is a product of the threshold density of each species and the efficiency and area/volume sampled by each sampling method. Many of these calculations resulted in extremely low number of samples, which would obviously not sample species in a particular habitat effectively, whilst others resulted in exceptionally high number of samples (Table 1), e.g. *ca* 3500 core samples, which would be a logistically and economically unrealistic number of samples to obtain and analyse.

Sampling frequency

The strategy states that sampling should occur when *"target species are at their predicted maximum abundance or in a particular life stage that is relatively easy and cost-efficient to detect"* yet information on when maximum abundances or particular life phases occur are presented for only a small number of target species. Considerable time and effort could be saved by having such information for all pest species provided to the personnel developing the monitoring design.

The requirement of sample at numerous times to capture different life phases of target species, whilst thorough from a monitoring perspective poses problems from a logistics and financial perspective. This is particularly problematic when sampling 'remote' sites such as Albany (remote relative to distance from Perth), and will be even more problematic when sampling occurs for sites such as Dampier and Port Hedland which will require monitoring teams to fly in (with equipment, ethanol etc…), sample, and then transport material back to laboratories in Perth.

Confidence limits

The Albany field program was undertaken at a time when the confidence level was 95%. It has since been reduced to a more realistic 80%. However, the level of confidence is misleading. It is much easier for an experienced taxonomist to find a target species by looking in the appropriate habitats than it is to sample specifically in limited quadrats.

For example, the native *Brachidontes erosus* is the second most common mussel in Albany after the commercial *Mytilus edulis.* It occupies a shallow water soft sediment habitat similar to that in which the target *Musculista senhousia* is found. On intertidal and subtidal sandflats *B. erosus* live in small clumps of up to a dozen individuals with the upper shells emergent. Algae attach to the shells, forming a clump which can be seen for a distance of many metres. However, the personnel undertaking the Albany sampling were not familiar with this species and its habitat and found only a single individiual.

Availability of information

There is considerable confusion and misinformation among consultants as to how to undertake such monitoring programs. The program is new, but if it is to be effective all of the information about it, where to obtain information and assistance, must be readily available.

Final comment

Page 125 has a website address www.marinepests.gov.au where you can supposedly find changes and further instructions for users. Despite numerous attempts this site was not there, and the viewer was redirected to www.daf.gov.au/fisheries/invasive where I received an error message *"page cannot be found – 404 error."*

Acknowledgements

We gratefully acknowledge the considerable support given to the implementation of the monitoring program in Albany by the Albany Port Authority and numerous other stakeholders. The field program was organised in conjunction with Geoff Bastyan of Albany. Technical assistance during the design and implementation of this program was provided by Emily Gates of the WA Department of Fisheries.

Table 1. Minimum number of samples required for each of the 52 target species based upon National strategy guidelines.

Group	Species	Primary method	# Samples	Secondary method	# Samples
Dinoflagellate	Alexandrium catenalla	Vertical tow	0.04	Small core	3466.29
Dinoflagellate	*Alexandrium minutum*	Vertical tow	0.04	Small core	3466.29
Dinoflagellate	*Alexandrium monilatum*	Vertical tow	0.04	Small core	3466.29
Dinoflagellate	*Alexandrium tamarense*	Vertical tow	0.04	Small core	3466.29
Dinoflagellate	*Dinophysis norvegica*	Vertical tow	0.04	Small core	3466.29
Dinoflagellate	*Gymnodinium catenatum*	Vertical tow	0.04	Small core	3466.29
Dinoflagellate	*Pfiesteria piscicida*	Vertical tow	0.04	Small core	3466.29
Alga	*Bonnemaisonia hamifera*	Visual	0.005	Vertical tow	0.38
Alga	*Caulerpa racemosa*	Visual	0.005	Scrape	6.66
Alga	*Caulerpa taxifolia*	Visual	0.004	Scrape	5.55
Alga	*Codium fragile spp.*	Visual	0.005	Scrape	33.29
Alga	*Grateloupia turuturu*	Visual	0.005	Scrape	33.29
Alga	*Sargassum muticum*	Visual	0.025	Scrape	33.29
Alga	*Undaria pinnatifida*	Scrape	6.66	Visual	0.01
Alga	*Womersleyella setacea*	Visual	0.05	Scrape	33.29
Diatom	*Chaetoceros convolutus*	Vertical tow	0.04	Horizontal tow	0.01
Diatom	*Chaetoceros concavicornis*	Vertical tow	0.04	Horizontal tow	0.01
Diatom	*Pseudo-nitzschia seriata*	Vertical tow	0.04	Horizontal tow	0.01
Bivalve	*Corbula amurensis*	Grab	0.27	Large core	0.46
Bivalve	*Crassostrea gigas*	Scrape	22.19	Visual	0.03
Bivalve	*Ensis directus*	Grab	0.27	Large core	0.46
Bivalve	*Musculista senhousia*	Grab	0.04	Large core	0.06
Bivalve	*Mya arenaria*	Grab	47.93	Large core	82.46
Bivalve	*Mytilopsis sallei*	Scrape	0.01	Visual	0.00001
Bivalve	*Perna perna*	Scrape	33.29	Visual	0.05
Bivalve	*Perna viridis*	Scrape	33.29	Visual	0.05
Bivalve	*Varicorbula gibba*	Grab	0.28	Large core	0.49
Gastropod	*Crepidula fornicata*	Scrape	22.19	Visual	0.02
Gastropod	*Rapana venosa*	Scrape	33.29	Visual	0.02
Jellyfish	*Beroe ovata*	Vertical tow	0.24	Horizontal tow	0.05
Jellyfish	*Blackfordia virginica*	Vertical tow	0.21	Horizontal tow	0.04
Jellyfish	*Mnemiopsis leidyi*	Vertical tow	0.24	Horizontal tow	0.05
Polychaete	*Hydroides dianthus*	Scrape	0.08	Visual	0.0001
Polychaete	*Marenzelleria spp.*	Grab	47.93	Large core	82.46
Polychaete	*Sabella spallanzanii*	Visual	0.002	Scrape	17.99

Copepod	*Acartia tonsa*	Vertical tow	0.04	Horizontal tow	0.01
Copepod	*Pseudodiaptomus marinus*	Vertical tow	0.04	Horizontal tow	0.01
Copepod	*Tortanus dextrilobatus*	Vertical tow	0.04	Horizontal tow	0.01
Barnacle	*Balanus eburneus*	Scrape	1.51	Visual	0.001
Barnacle	*Balanus improvisus*	Scrape	1.51	Visual	0.001
Crab	*Callinectes sapidus*	Trap	0.0011	Vertical tow	1.91
Crab	*Carcinus maenus*	Trap	0.0011	Vertical tow	1.91
Crab	*Charybdis japonica*	Trap	0.0011	Vertical tow	1.91
Crab	*Eriocheir* spp.	Trap	0.0011	Vertical tow	1.91
Crab	*Hemigrapsus sanguineus*	Trap	0.0011	Vertical tow	1.91
Crab	*Hemigrapsus takanoi*	Trap	0.0011	Vertical tow	1.91
Crab	*Rhithropanopeus harrisii*	Trap	0.0011	Vertical tow	1.91
Tunicate	*Didemnum* spp.	Scrape	33.29	Visual	0.02
Seastar	*Asterias amurensis*	Visual	1.25	Horizontal tow	0.19
Fish	*Neogobius melanostomus*	Beam trawl	0.07	Horizontal tow	1.91
Fish	*Siganus luridus*	Beam trawl	0.10	Horizontal tow	1.91
Fish	*Siganus rivulatus*	Beam trawl	0.05	Horizontal tow	1.91

Consideration of the Need for a Dampier Baseline Survey

Out-of-Session submission to the National Introduced Marine Pests Coordinating Group (NIMPCG)

Fred E Wells

Background

During the 1990s and early 2000s, the CSIRO Centre for Research into Introduced Marine Pests (CRIMP) developed a method for conducting baseline surveys of Australian ports for introduced marine species (also referred to as non-indigenous marine species). The goal was to establish a national database of introduced marine species across Australia as a first step in addressing the problem. The hypothesis was that to understand if a species is introduced, there must first be a thorough understanding of what species occur naturally in an area. Baseline surveys were conducted by CRIMP, or other agencies using CRIMP methodology, of all of the major Australian ports, with the exception of the Port of Dampier.

Now that the baseline surveys have been completed, there is a much better understanding of non-indigenous marine species in Australia. The NIMPCG focus has changed to undertaking surveys to determine the presence/absence of 55 target species. These are non-indigenous species that are known to be invasive in Australia, are invasive elsewhere, or are considered to be potentially invasive. The national program of future surveys will target these species, with consideration during the surveys that other species could be introduced.

Extensive risk analyses and other studies were conducted which resulted in 18 major ports, including Dampier, being included on the national survey program. Targeted monitoring will concentrate on these ports in the future.

The present paper proposes that the Western Australian Museum/Woodside partnership and other activities in Dampier have developed a far greater knowledge of the marine biodiversity of that region than any of the port surveys in other areas. Accordingly, it is considered that there is no justification for requiring that a baseline survey of Dampier is undertaken using the CRIMP methodology.

The Western Australian Museum/Woodside Energy Ltd Partnership 1998-2002

In the late 1990s, the Western Australian Museum and Woodside Energy Ltd formed a multi-year partnership to examine the marine biodiversity of the Dampier region. The study area was the Dampier Archipelago, Burrup Peninsula and nearby continental coastline, the area shown in the insert on the attached Figure. Woodside contributed over $1 million to support this work. There was a similar in-kind contribution from the WA Museum and other agencies. The Western Australian Museum/Woodside partnership was established (Jones, 2004):

- To document the marine biodiversity of the Dampier Archipelago and produce a detailed inventory of species-level biodiversity;
- To develop a representative *Woodside Collection* at the Western Australian Museum to permanently record the fauna collected;
- To liaise with stakeholders in the Dampier Archipelago regarding the conservation of the marine biodiversity of the area;

- To present information generated to the scientific community and make data available to environmental managers and policy makers in Western Australia; and
- To communicate information generated to the public, both in Western Australia and world wide, through a variety of media.

The following major surveys were undertaken, in addition there were numerous smaller expeditions to the area of two or three people each:

- Two intensive diving expeditions to the Dampier Archipelago in 1998 and 1999;
- A major dredging and trawling trip on the Department of Fisheries research vessel *Flinders* in 1999; and
- A marine biological workshop at Dampier that involved 40 scientists from Western Australia, the eastern States and overseas in 2000. The workshop was divided approximately equally between sublittoral and intertidal studies.

Jones (2004) states:

"*The innovative, multi-partner approach taken by the Western Australian Museum/Woodside Energy Ltd partnership has resulted in over 70 scientists from 15 countries co-operating with nine scientists from the Western Australian Museum and staff from Woodside's Environmental teams. Four Australian and four international museums, 23 Australian universities, research institutions and schools, 27 international universities and research institutions and 19 local and Australian organisations, including Western Australian government departments, the local Shire, marine research institute and other resource companies in the Dampier area, have participated in the project to date.*"

Known Biodiversity of Western Australian Port Areas

Published information is available for Dampier on molluscs, echinoderms, scleractinian corals, sponges, crustaceans, fish, marine plants, and several minor groups. Together, papers published by the Western Australian Museum list over 3,014 species (Table 1) (Wells et al., 2003; Jones, 2004). The Museum has a list of 4,500 species recorded from Dampier, by far the largest list for any area of Western Australia, and possibly even Australia-wide.

Table 2 compares the known marine biodiversity in the Dampier area with the results of CRIMP surveys in other ports in Western Australia. In all respects, data from Dampier are far more comprehensive than for the other areas. The diversity of identified species at Dampier ranges from 12.7 times that of Bunbury to 28.7 times that of Albany. The proportion of species identified at Dampier (about 67%) is substantially higher than the combined percentage from the other areas (40%).

The most diverse groups (molluscs, crustaceans, fish, echinoderms, marine plants and corals) have all been better surveyed in Dampier than the other areas. Less diverse groups have been studied to varying intensities in the five different areas. Although they have not been formally published, hydroids, bryozoans and ascidians were all collected in Dampier and are held in the Western Australian Museum. No hydroids were reported by CRIMP in Fremantle and only six species (four identified) in Bunbury. Only three bryozoans were identified by CRIMP and the total number collected is not stated. Some of the bryozoans from the Dampier Workshop have been reported by Dr Josh Mackie, but these papers are not yet available. Only two ascidians were reported by CRIMP from Albany and six species from Bunbury.

Other Information Sources for Dampier

As one of the largest ports (in some years the largest port) in Australia by tonnage, various aspects of the Dampier marine environment are routinely monitored by environmental consultants, primarily URS Australia, Sinclair Knight Merz and MScience. There is a close working relationship between the consulting companies, the Department of Fisheries, and the Western Australian Museum. Scientists from the companies frequently dive at Dampier, both inside the harbour and at control sites outside, and specimens are routinely sent to the Museum. To date, none of the species included in the CCIMPE Revised Trigger List (November 2006) or in NIMPCG's National Monitoring Target Species List (August 2006) have been recorded in the material submitted for identification. The current resources boom in the Pilbara is centred at Dampier and Port Hedland. With the numerous development projects in progress in Dampier, the amount of environmental work has increased considerably.

One vessel recently entered the port of Dampier and was found to have the Asian Green Mussel (*Perna viridis*) on its hull. The vessel was requested to leave the port for cleaning in Singapore. A monitoring program, including deployment of settlement plates and surveys of wharf structures where the vessel berthed, has been underway to determine if the species has been introduced, but no Asian Green Mussel have been found.

Costs of a Baseline Survey of Dampier

The Department of Fisheries has been undertaking the background work for planning a targeted survey of the Port of Dampier. Based on the preliminary figures available, it is estimated that a stand-alone baseline survey of Dampier would cost at least $400,000.

Summary

Because of the work undertaken by the four year Western Australian Museum/Woodside Energy Ltd partnership, knowledge of the marine biodiversity of the Dampier area is better than any other area in Western Australia. The continuing work of environmental consultants in this area provides added comfort that there have been no introductions of pest species since the partnership results were published.

Recommendation

It is recommended that NIMPCG determine that the extensive information from the Western Australian Museum/Woodside partnership is an outstanding baseline of marine biodiversity information and that it should be considered to have met the requirement for a baseline survey of Dampier.

Table 1. Marine species recorded from the Dampier Archipelago and Burrup Peninsula in the Western Australian Museum surveys (Wells et al., 2003; Jones, 2004).

	Dampier			
Taxon	**Author**	**Where published**	**No. species**	**Introduced**
Animals				
Molluscs*	Brearley et al. Seapy et al Slack-Smith and Bryce Taylor and Glover	Wells et al., 2003	6 shipworms 19 heteropods 695 (422)	1
Crustaceans	Jones Hewitt	Jones, 2004	49 barnacles 68 amphipods 381 crustaceans	6
Fish	Hutchins	Wells et al., 2003	736	
Polychaetes	Hutchings and Avery	Jones, 2004	19 (terebellids)	
Echinoderms	Marsh and Morrison	Wells et al., 2003	286	
Sponges	Fromont	Wells et al., 2003; Jones, 2004	275	
Hydroids				
Bryozoans				
Ascidians				
Scleractinian corals	Griffiths	Wells et al., 2003	229	
Soft corals	Salotti et al	Jones, 2004	12 genera	
Oligochaetes	Erseus and Wang; Rota et al.	Wells et al., 2003	26	
Marine mites	Bartsch; Smit	Wells et al, 2003	15	
Plants				
Marine algae	Huisman	Wells et al., 2003	201	
Seagrasses	Huisman	Wells et al., 2003	9	
Total			**>3014**	**7**

*Molluscs of Dampier were examined by several authors. The papers by Slack-Smith and Bryce (museum surveys) and Taylor and Glover (dredging) overlap in their taxonomic composition and need to be compared. The paper by Brearley is on teredinids and Seapy et al. is on planktonic heteropods; neither group is included by Slack-Smith and Bryce or Taylor and Glover.

Table 2. Comparison of known marine biodiversity in the Dampier area with the results of CRIMP surveys in other ports in Western Australia.

Phylum	**Port**				
	Dampier	**Fremantle (identified/ total)**	**Albany (identified /total)**	**Bunbury (identified /total)**	**Port Hedland (identified /total)**
Animals					
Molluscs*	720	102/141	29/136	51/53	19/81
Crustaceans	498	21/186	3/3	9/12	37/160
Fish	736		22/37	12/12	23/23
Polychaetes	19	0/130	1/1	2/2	64/161
Echinoderms	286	28/35	4/5	3/4	0/not stated
Sponges	275				Not stated
Hydroids			15/26	4/6	10/28
Bryozoans		23/31	22/30	12/15	3/not stated
Ascidians		7/43	2/2	6/6	18/39
Scleractinian corals	229				
Soft corals	12 genera				0/7
Oligochaetes	26				
Other cnidarians		12/27	3/6	2/3	
Marine mites	15				
Other groups		0/30			
Plants					
Dinoflagellates			8/13	25/41	
Marine algae	201	45/97			
Seagrasses	9				
Total	**3014/4500**	**238/720**	**109/259**	**126/154**	**174/499**

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Prevention of introduction of species brought into Geraldton Harbour, Western Australia, by the dredge *Leonardo da Vinci*

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Abstract

In October 2002 the dredge *Leonardo da Vinci* arrived in Geraldton, Western Australia, for a major port enhancement program. It sailed from Jamaica, West Indies, through warm seas during the entire voyage. An arrival inspection in Geraldton demonstrated the stern and sea chests were fouled with a variety of non-indigenous marine species that could potentially be introduced to Geraldton, including pest species. The vessel was cleaned in water in Geraldton, with several steps taken to minimize the possibility of species being introduced. Surveys of key species of molluscs and crustaceans were undertaken in October 2003 and 2007. To date, none of these potential pest species have been found, except for *Amphibalanus reticulatus* which had already been recorded north and south of Geraldton.

Running head: *Leonardo da Vinci* in Geraldton

Keywords: Introduced marine species, mollusc, crustacean, NIMS

Introduction

The introduction of marine species into new environments is one of the leading marine environmental issues on a worldwide scale (Padilla *et al.* 1996). Most introduced, non-indigenous species cause no apparent harm in their new environments. For example, Huisman *et al.* (2008) recorded 60 introduced marine species in Western Australia, but only three are on the national list of target species (NIMPCG 2006). A minority of the introduced species become pests that cause disease in native species and even humans, interfere with fisheries and aquaculture, foul industrial equipment, disrupt local ecosystems and/or even change the habitat in which they are living (Hallegraeff *et al.*1988; Grosholz and Ruiz 1995; Siguan 2003; Schwindt *et al.* 2004; Bando 2006; Wallentinus and Nyberg 2007). There are three major mechanisms for introducing marine species: ballast water discharge; biofouling of vessel hulls, immersible equipment, or niche areas (e.g. anchor lockers, sea chests, internal seawater systems, etc), deliberate introductions, such as for aquaculture, and accidental escape from aquaculture facilities (Carlton 1985; Fofonoff *et al.* 2003; Minchin 2007).

Nationwide data on non-indigenous marine species known from Australian waters are available in Hewitt *et al.* (2002). Hewitt and Campbell (2007) review Australian mechanisms for prevention of marine bioinvasions. Port Phillip Bay, where the Port of Melbourne is located, has the highest known number of non-indigenous species in an Australian marine area: 99 species are regarded as introduced, and 61 are cryptogenic (Hewitt *et al.* 2004). In contrast, only 60 introduced species and 26 cryptogenic species are known from the entire state of Western Australia, with some 14,000 km of coastline (Huisman *et al.* 2008). The greatest concentration (46 species) is in the Fremantle area, the port with the largest number of vessel movements and a diverse marine environment. Seven introduced species, none of which are pest species, are known from Geraldton (Campbell 2003; Huisman *et al.* 2008).

In early October 2002 the cutter suction dredge *Leonardo da Vinci* arrived in Geraldton, Western Australia to undertake a major dredging program in the harbour. The vessel sailed directly to Geraldton from Jamaica via the warm waters of the tropical Atlantic Ocean, Mediterranean Sea, Suez Canal, Red Sea, and the Indian Ocean with only brief refueling stops in Egypt and the Maldives. On arrival inspection in Geraldton it was discovered that the forward sections of the hull had been cleaned prior to the vessel departing Jamaica, but the stern and sea chests (containing about 60 m^3 of seawater) were heavily fouled with a variety of organisms, including several molluscs (Table 1): *Thais haemastoma* (Linnaeus 1767); *T. rustica* (Lamarck 1822); *Crepidula plana* Say 1822; and *Brachidontes exustus* (Linnaeus 1758). A juvenile oyster that was too small to be identified was also found. The following barnacles were identified: *Lepas anserifera* Linnaeus 1767; *Chthamalus* sp.; *Striatobalanus amaryllis* (Darwin 1854) (some were ovigerous); *Amphibalanus reticulatus* (Utinomi 1967) (some were ovigerous); *Balanus trigonus* Darwin 1854; and *Megabalanus coccopoma* (Darwin 1854). Of these, all the identified species except *M. coccopoma* were previously known from Western Australia (Jones 1990; 1992; 2004). *Megabalanus coccopoma* occurs in the tropical East Pacific Ocean, the Atlantic Ocean, Gulf of Mexico and southeastern United States). The species has also been collected from vessels in New Zealand (A. Hosie, pers. comm.) and there is one recent record from a vessel at Brisbane, Queensland (D. Jones, unpublished data). Four decapod crustacean species were found in the samples provided. As they do not occur in Western Australia, WAM had no comparative material of the species. Provisional identifications are: *Pachygrapsus* sp.; *Percnon* sp.; xanthid sp., and grapsid sp. (juvenile). Because of the lack of appropriate taxonomic expertise in Western Australia and the urgent requirement for a decision on how to proceed, tubeworms, an encrusting sponge, ascidians, hydroids, and a filamentous green alga were not identified to species level. Material collected from *Leonardo* is held in WAM.

A hastily convened committee representing a range of government departments determined there was a serious risk of introducing marine pests into the port of Geraldton. Once in Geraldton, it was considered that it would be difficult to stop the spread of these species into other Western Australian and Australian ports where suitable environments exist. Particular concern was expressed about the two species of *Thais.* If distributed in WA, these oyster drills could potentially disrupt the pearl oyster fishery, at the time the largest aquaculture industry in Australia with an annual value of over $A 100 million.

The dredge was too large for any of the drydocks in Western Australia; the nearest drydock of sufficient size was in Singapore, some 1500 nautical miles away. Even if the drydock were available, it would take a minimum of three weeks to clean the vessel in Singapore. Because of the urgency of starting a major dredging program during the limited period of favourable weather, taking the dredge to Singapore for cleaning in drydock was not a viable option. The decision was made to immediately clean the vessel in water in Geraldton. A number of procedures were undertaken immediately to minimize the threat of introductions. Above water fouled portions of the hull were scraped; animals and plants removed were collected and disposed of at a terrestrial dumpsite. Slats of the sea chests open to the ocean were sealed and biodegradable detergent was added to the sea chests to provide a total concentration of 5% (3 tonnes were used). The treated water was circulated to ensure uniform exposure to all areas. Detergent remained in the compartments until an inspection by the Department of Fisheries 48 hours later determined that mortality of related test species (the gastropods *Thais orbita* (Gmelin 1791) and *Turbo intercostalis* Menke 1843) placed in the sea chests had occurred; by this stage water in the sea chests was fetid. Liquid waste trucks were then used to remove as much treated water as possible prior to the slow release of remaining water and detergent into the port area. The stern of the vessel was scraped in-water by divers to remove fouling organisms. Material scraped fell into collecting bags. Prior to scraping a tarpaulin was placed along the berth face to prevent material accidentally attaching to existing wharf structures in inaccessible locations. After the stern was scraped, smaller basin dredges were used to extract material all material on the bottom in the vicinity of *Leonardo da Vinci* and to pump it into the centre of a nearby land reclamation area.

Berth 5, where the *Leonardo da Vinci* had been berthed was surveyed on 22 October 2003, just over a year after the arrival of the dredge. The survey concentrated on the species of barnacles and molluscs listed above. All were shallow water species that extended no more than a few metres below the waterline. The 2003 survey concentrated on the pilings on the seaward side of berth 5. At each piling, divers descended to the bottom at 6 m then searched the piling from bottom to the surface for non-indigenous species; the muddy bottom was also checked. Representatives of live barnacles near the surface were scraped off each piling and identified in the laboratory. No mollusc species from the *Leonardo da Vinci* were found. The barnacle species collected were typical of the Western Australia west coast barnacle fauna and contained three species, all of which had been previously collected from the Port of Geraldton (Huisman *et al.* 2008): *Amphibalanus amphitrite* (Darwin 1854)*, Balanus trigonus* and *Megabalanus tintinnabulum* (Linnaeus 1758). The only thaid gastropod found was the Western Australian species *Cronia avellana* (Reeve 1846).

A resurvey of Geraldton Harbour was undertaken on 24 October 2007, five years after the *Leonardo da Vinci* first arrived. Vessels were present at berths 2, 3, 4 and 6, precluding them from examination. Four sites were examined by divers using similar techniques to the 2003 survey (Figure 1): berth 5, on the southwest of the harbor, where *Leonardo da Vinci* had berthed in 2002; berth 1 and adjoining rock walls, and an adjacent slipway on the south east; and rock groynes on the northeast and northern side of the port. The four sites gave a good coverage of the port. The rock groynes extended to a depth of about 4 m before a muddy bottom was encountered. As all of the species on *Leonardo da Vinci* were either attached to the vessel or in association with the hard substrate of the vessel, the muddy bottom of Geraldton harbour was not examined except to ensure that it was in fact all mud.

None of the molluscs found on *Leonardo da Vinci* were found in 2007. Oysters were abundant on the rock groynes, but all were identified as the southern Australian *Ostrea angasi* (Sowerby 1871). The only mussel found was the tropical *Stavelia horrida* Récluz 1852, which occurs naturally in the region. The native thaids *Cronia avellana* and *Thais orbita* were found, but neither of the Caribbean species (*Thais haemastoma* and *T. rustica*). Barnacles collected were: *Tetraclita squamosa* (Bruguière 1789)*, Amphibalanus amphitrite, A. reticulatus* and *Austromegabalanus nigrescens.* Two species, *T. squamosa* and *A. nigrescens,* are typical of the Western Australia west coast barnacle fauna. *Amphibalanus amphitrite,* a cosmopolitan, cryptogenic species*,* has been previously collected from the Port of Geraldton (Huisman *et al.* 2008). Live specimens of *A. reticulatus* were identified from the *Leonardo da Vinci*. *Amphibalanus reticulatus* has been collected previously from a number of localities in Western Australia, both north and south of Geraldton, but not from Geraldton itself (Jones 2004; Huisman *et al.* 2008). Specimens collected in the present resurvey, near berth 1, indicate that this species has become established in the Port of Geraldton. *Amphibalanus reticulatus* is known to have originated in Japan and its widespread distribution has most probably been via ship fouling (Utinomi 1967). No introduced species of crabs were found. Several specimens of native crabs, *Portunus pelagicus* (Linnaeus 1766), *Atergatis integerrimus* (Lamarck 1801), *Leptodius exaratus* (H. Milne Edwards 1834) and *Thalamita sima* H. Milne Edwards 1834, were collected.

To date the procedures employed to prevent the introduction of Caribbean species into Geraldton appear to have worked. There is always a possibility that there may be one or more species that have established breeding populations that have not yet increased to a level where they have been found. Also, there is a possibility that groups not identified when *Leonardo da Vinci* arrived, may have been introduced. Therefore, it is recommended that a resurvey be undertaken in another five years.

The Geraldton experience has been beneficial in raising the profile of introduced marine pests in Western Australia. Ship operators are very much aware of the problems caused by the arrival of *Leonardo da Vinci* and the potential financial losses which will occur if a fouled vessel enters a Western Australian port and is denied entry to the port. The WA Environmental Protection Authority closely assesses all major development projects in the state, including marine and coastal projects. On EPA advice, the WA Minister for the Environment now routinely includes legally binding Ministerial Conditions that vessels entering WA waters for these projects are cleaned of attached species prior to arrival or are inspected for marine pests within 48 hours of arrival. *Leonardo da Vinci* returned to Port Hedland, Western Australia, late in 2006 under such Ministerial Conditions. Before coming to WA on this occasion it was slipped and cleaned in drydock in Singapore and inspected by an environmental consultant for the proponent and by an officer of the Department of Fisheries. The dredge was in general well cleaned. After some areas were further cleaned the vessel was cleared for entry to Western Australia, which occurred without incident. More recently (July 2008), *Leonardo da Vinci* was inspected by both environmental consultants for the proponent and officers of the Department of Fisheries in Abu

Dhabi before sailing to Western Australia.

The evidence is that the original incident of *Leonardo da Vinci* bringing pest species into Western Australia was handled effectively, and the species do not appear to have been introduced. Following this experience, detailed procedures are in place to minimize the chances of a similar incident.

This incident is not unique, and should serve to heighten awareness both that sea chests are important potential sources of introduced species and the risks posed by mobile infrastructure. Coutts *et al.* (2003) considered that sea chests are often overlooked as a potential source of introduced species. Coutts *et al.* (2007) followed up by surveying 42 vessels in New Zealand. A total of 150 species were recorded from the sea chests, approximately 15% of which were non-indigenous. In contrast to the restricted areas occupied by sea chests on most vessels, the 60 m^3 area occupied by those on *Leonardo da Vinci* were very accessible. Mobile infrastructure has been implicated in other studies, including a floating drydock that introduced two species of sponges and one mollusc into Hawaii (Eldredge and Smith 2001). Similarly, Foster and Willan (1979) reported barnacles being introduced into New Zealand by a floating oil platform. Mobile infrastructure such as dredges, oil rigs, drydocks, etc are particularly high risk for a number of reasons, including the fact that they may undertake a broad range of activities and may move considerable distances from one port to another. Often the vessels remain in port for extended periods, allowing the development of fouling communities on the hulls. The work often occurs in shallow waters where marine pests are concentrated, with equipment left in the water for 24 hours or more in close contact with the sea floor (Kinloch *et al.* 2003).

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Table 1. Species recovered from the dredge *Leonardo da Vinci* and subsequent surveys of Geraldton port.

Species	**Previously recorded in WA**	***Leonardo da Vinci***	**2003 survey**	**2007 survey**
Molluscs				
Brachidontes exustus		X		
Cronia avellana	X		X	X
Crepidula plana		X		
Ostrea angasi	X			X
Stavelia horrida	X			X
Thais haemastoma		X		
Thais orbita	X			X
Thais rustica		X		
Crustaceans				
Barnacles				
Amphibalanus amphitrite	X		X	X
Amphibalanus reticulatus	X	X		X
Austromegabalanus nigrescens	X			X
Balanus trigonus	X	X	X	
Chthamalus sp.		X		
Lepas anserifera	X	X		
Megabalanus coccopoma		X		
Megabalanus tintinnabulum	X		X	
Striatobalanus amaryllis	X	X		
Tetraclita squamosa	X			X
Crabs				
Atergatis integerrimus	X			X
Leptodius exaratus	X			X
Pachygrapsus sp.		X		
Percnon sp.		X		
Portunus pelagicus	X			X
Thalamita sima				X

Rapid Assessment of Willie Creek, Western Australia, for Selected Introduced Marine Pest Species

Fred E Wells

Abstract

For some years, many of the illegal Indonesian fishing vessels apprehended off the north coast of Western Australia have been detained at Willie Creek, 38 km north of Broome until their cases have been heard in court. A survey was undertaken of the creek in February 2008 to determine whether two invasive mussel species (*Mytiliopsis sallei* and *Perna viridis*) have inadvertently been introduced into the creek by the impounded vessels. Neither species was found. Three species of barnacles were collected during the survey, including the cryptogenic *Amphibalanus cirratus* and the introduced *Megabalanus occator,* both of which have previously been recorded in WA. Vessels held at Willie Creek have been Type 1 or Type 2, which are considered to be low risk for the introduction of marine pests. There is no apparent requirement for a detailed survey of Willie Creek.

Introduction

As a result of an agreement between Australia and Indonesia signed in 1974, Indonesian fishermen are permitted to fish in a traditional manner in an offshore area termed the MOU Box (for Memorandum of Understanding). The box is well offshore, and includes Scott Reef and Seringapatam Reef. When apprehended, a frequent practice has been to tow the illegal vessels to Willie Creek, 38 km north of Broome, Western Australia. The impounded vessels have been kept at Willie Creek, either moored in the channel, or beached on shore, often for some weeks, until the court case is heard. Vessels determined to have been fishing illegally are confiscated, and destroyed, sometimes by burning on the shore. Destruction may be some months after the vessel first arrived. The fishing vessels are wooden perahus. In recent years a number of perahus have been inspected at sea by the WA Department of Fisheries. Some have been infested with the highly invasive marine pest species *Mytiliopsis sallei,* the Caribbean black striped mussel, or the Asian green mussel, *Perna viridis.* These vessels were sunk at sea and were not taken to Willie Creek.

The black striped mussel invaded three small marinas in Darwin in 1999 and rapidly formed dense populations. Fortunately, the mussels remained in the marinas and did not colonise the open harbour areas. All three marinas have locks that form saltwater lakes at low tide. Because the marinas were discrete artificial habitats, the Northern Territory Government decided that high concentrations of chemicals could be added to eliminate the mussels from the marinas. The eradication was successful, and there are no known populations of *M. sallei* in the open areas of Darwin Harbour (Willan *et al.* 2000). A detailed monitoring program for introduced marine pest species is now in place (Marshall *et al.* 2003). In a similar fashion, high densities of *P. viridis* were found in August 2001 on the hull of a vessel that had recently arrived at Cairns, Queensland, from overseas. The species has subsequently bred in Trinity Inlet (Stafford *et al.* 2007).

Detention of perahus in Willie Creek for weeks carries a risk of introducing marine pest species, particularly *M. sallei* and/or *P. viridis.* Russell *et al.* (2003) noted that neither the ports of Broome or Wyndham have been surveyed for introduced marine pests. They specifically recommended that any marine pest survey of Broome, include Willy [sic] Creek. The present survey was conducted to determine whether populations of the two mussel species occur in Willie Creek, and if a more detailed survey is required. At the same time, a number of species of barnacles have been introduced into WA from overseas (Huisman *et al.* 2008), so barnacles were also examined.

Methods

The shoreline adjacent to the Willie Creek Pearl Farm was searched for introduced mussels and barnacles on 9 February 2008 on a spring low tide. The pearl farm is located on the north side of the creek inland of the customs holding area (Plate 1). Any species spreading into the creek from the customs area would pass through the channel at the pearl farm. The upper part of the shoreline at the pearl farm is dominated by mangroves, predominately *Avicennia marina* and *Rhizophora stylosa,* with a rock platform in the high upper intertidal (Plates 2-4). The lower intertidal is a combination of soft mud and rocky shore. There is also a series of metal steps leading into the lower intertidal and in the mud are a number of discarded 200 litre steel drums that were used some years ago to house pearl oysters. All of these intertidal habitats were searched for mussels and barnacles. These habitats are representative of most of the intertidal area of the creek. They are also only a few hundred metres from the vessel holding area.

The lower intertidal of the vessel holding area of the southern side of the creek is an open sand bar (Plate 5) with no hard structures to which mussels and barnacles could attach; because of entry restrictions this area was not investigated. However, the lack of suitable habitat makes the holding area low risk for maintaining mussel populations.

In addition, three subtidal sites in the creek channel were examined. Each site contained surface buoys spaced about 1.5 m apart from which ropes were hanging. One set of rope and buoys had been in the water for one to two years; the second for about 10 years; and the third had panels, each with six live pearl oysters, which had been in the water for about two years. At each site three to four buoys and the intervening ropes were examined. In addition one panel of pearl oysters at the third site was examined.

Results and Discussion

No mussels of either species (*Mytiliopsis sallei* or *Perna viridis*) were found. Three species of barnacles were found at Willie Creek: *Amphibalanus littoralis*, *Amphibalanus cirratus* and *Megabalanus occator*. *Amphibalanus littoralis* is native to the region. *Amphibalanus cirratus* is cryptogenic and can be a fouling species. *Megabalanus occator* has been introduced into Australian waters, but is not included as a species of concern on the Consultative Committee for Introduced Marine Pest Emergencies (CCIMPE) Trigger List (2006). Its presence in Western Australia was recently confirmed by re-examing material previously identified as *Megabalanus tintinnabulum* (Jones, 2008; attached).

Russell *et al*. (2004) and Neil *et al.* (2005) described in detail the illegal Indonesian fishing vessels that have been apprehended in Australian waters. Three types are recognised, based largely on the sails used on the vessels. All three types are of wooden construction. Type 1 vessels have lateen sails while Type 2 vessels have fore- and aft- rigs similar to those used in modern yachts. Both Type 1 and 2 vessels, which are up to 15 m long, are hauled up on shore between fishing trips to reduce rotting and prolong the lifespan of the hulls. This significantly reduces the amount of biofouling and the risk of introductions of marine species to Australia. Both Type 1 and Type 2 vessels operate from small fishing communities or pass through villages that are not likely to colonised by marine pests as they have relatively undisturbed marine habitats. Type 3 vessels, which include the iceboats, are larger (up to 22 m) and have diesel motors; they usually lack sails, and are left in the water. They tend to operate from Indonesian commercial ports, many of which have invasive marine pests. Types 1 and 2 have not been considered to be high risk for the introduction of marine pests into Australia. On the other hand, Type 3 boats pose a high risk and ice boats have been found to have both species of mussels attached. Ports such as Surabaya have both *Mytilopsis sallei* and the barnacle *Austromegabalanus krakatauensis* (Russell *et al.*, 2004; Neil *et al.* (2005).

Willie Creek is small and shallow. The Indonesian boats that have been detained at the creek have been small boats of Types 1 and 2; no Type 3 vessels have been brought in to Willie Creek (Craig Astbury, Dept. of Fisheries, pers. comm. 2008). Some of the vessels have been hauled up onto the beach (Plate 4). It appears that the small size of the creek, which has prevented the use of Willie Creek for Type 3 boats (most of these have been taken to Darwin), has protected the creek from invasion by mussels and barnacles. With increasing awareness over the years of the marine pest issue, all boats are now inspected before they are taken close to shore (Neil *et al*. 2005), and high standards are now in place for minimising the risk of introduction of marine pest species. The present report indicates that there is no apparent requirement for a detailed survey of Willie Creek.

Acknowledgements

In cooperation with several other agencies, the Department of Fisheries started a project *Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia* in October 2006. The present report is part of the project, which is funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State government. This component was funded through the W.A. Strategic Reserve Fund (project no. 053085).

I am pleased to acknowledge the considerable help of Diana S. Jones of the Western Australian Museum, who collected and identified the barnacles. Melissa Coates of the Department of Fisheries, Broome, participated in the survey and Andrew Graffen and Don Bacon of Willie Creek Pearls provided access to the site. Craig Astbury of the Department of Fisheries provided information on the handling of Indonesian fishing boats at Willie Creek. Dr Stephanie Turner, Dr Justin McDonald and Craig Astbury all commented on a draft of this report. Dr Justin McDonald provided plate 1 and Craig Astbury provided plate 5.

Plate 1. Map of Willie Creek showing locations of the customs holding area for impounded vessels and the sample sites (source of original image Google Earth, 2008).

Plate 2. North side of Willie Creek from Willie Creek Pearl Farm. The upper parts of the metal steps are in the foreground. On the right is a mixed habitat of mangroves, rocky shore and mud. Pearl lines can be seen on the left side, and the sand dunes at the mouth of the creek are in the distance. The customs area is behind mangroves at the top of the photograph.

Plate 3. Muddy lower intertidal shoreline and mangroves in the upper intertidal at the Willie Creek Pearl Farm.

Plate 4. Rocky intertidal shoreline at the Willie Creek Pearl Farm.

Plate 5. Impounded Indonesian perahus at Willie Creek at low tide. The perahus will be floating at high tide. (Photo: Craig Astbury).

Barnacle Samples from Willie Creek Survey

Species identified by Diana S. Jones
Western Australian Museum
February 2008

SYNOPSIS

Three barnacles are present in the samples (Tables 1, 2), as follows:

This cirripede fauna contains two elements, as follows:

1. **Common northern Australian intertidal and shallow water species**
   Amphibalanus littoralis (Ren and Liu, 1978)
2. **Fouling species previously collected from northwestern Australia**
   Amphibalanus cirratus (Darwin, 1854)
3. **Introduced species previously collected from northwestern Australia**
   Megabalanus occator (Darwin, 1854)

Specimens of all species are housed in the WA Museum crustacean collection. Although *Megabalanus occator* is considered to be an introduction to Australian waters it is not included as a pest species in the National Introduced Marine Pests Information System (NIMPIS, 2002).

Report

A total of three species occur in the samples (Tables 1, 2). Specimens of all species are housed in the WA Museum crustacean collection. *Amphibalanus littoralis* (Ren and Liu, 1978) is a littoral species occurring predominantly on mangroves trees. *Amphibalanus cirratus* (Darwin, 1854) is considered to be a cryptogenic species that also has fouling propensities. One species, *Megabalanus occator* (Darwin, 1854), is considered to be introduced to Australian waters but is not included as a pest species in NIMPIS.

CLASS MAXILLOPODA Dahl, 1956
SUBCLASS CIRRIPEDIA Burmeister, 1834
SUPERORDER THORACICA Darwin, 1854
ORDER **SESSILIA** Lamarck, 1818
Suborder **Balanomorpha** Pilsbry, 1916

Family **Balanidae** Leach, 1817
Subfamily **Amphibalaninae** Pitombo, 2004
Genus ***Amphibalanus*** Pitombo, 2004

Amphibalanus cirratus (Darwin, 1854)

Distribution: Indo-west Pacific – India, Indonesia, Australia, Philippines N to Korea; fouling species; littoral-sublittoral

Remarks: First recorded from Australia by Darwin (1854) and now recognized in northern Australian waters as a common species with fouling propensities. It is possible that its Australian distribution has been enhanced by shipping. This cirripede also fouls molluscs (e.g.

mussels) and may be transported inadvertently during commercial aquaculture operations.

Amphibalanus littoralis (Ren and Liu, 1978)

Distribution: China; Australia – northwestern WA.

Remarks: *Amphibalanus littoralis* was originally described from China (Ren and Liu, 1978), but has since been recorded from Exmouth Gulf, the Dampier Archipelago and Dampier Creek, Broome, northwestern Australia (Jones, unpublished data). The species attaches to hard substrata and commonly occurs on mangrove trees (e.g. *Avicennia marina* (Forsk.) Vierh.).

Subfamily **Megabalaninae** Newman, 1979

Genus ***Megabalanus*** Hoek, 1913

Megabalanus occator (Darwin, 1854)

Distribution: Coasts of East China Sea, Taiwan, Mindanao (Philippines), Bonin and Fiji Islands; Australia; fouling species.

Remarks: The type locality of *Megabalanus occator* is "South Seas" and its distribution is recorded as East China Sea, Taiwan, Philippines, Bonin and Fiji Islands by Henry and McLaughlin (1986) and east coast of China by Ren and Liu (1978), as *Megabalanus xishaensis* Ren and Liu, 1978. *Megabalanus occator* is easily confounded with *M. tintinnabulum* (Linnaeus, 1758) and has been only recently identified as occurring in Western Australian waters, from material previously determined as *Megabalanus tintinnabulum*. In Western Australia, the species is now positively recorded from Shark Bay, Barrow Island, the Dampier Archipelago and Broome (Jones and Burton, in prep.) and eastern Australian ports (Jones, unpublished data), suggesting that it has been introduced into Australian waters by shipping.

Table 1. Barnacles collected from Willie Creek Pearl Farm, N of Broome, WA (17°76'S, 122º21'E).

Station/Site	Date	Order/ Family	Genus and species	Number of specimens
From tin drums in small creek just W of Willie Creek Pearl Farm	9/2/2008	Balanidae	*Amphibalanus cirratus*	6 specimens (5 used for ontogenetic series), plus numerous disassociated plates
From tin drums in small creek just W of Willie Creek Pearl Farm	9/2/2008	Balanidae	*Amphibalanus littoralis*	2 specimens (1 test, 1 live adult), plus numerous disassociated plates
From tin drums in small creek just W of Willie Creek Pearl Farm	9/2/2008	Balanidae	*Megabalanus occator*	2 specimens (1 test, 1 live adult)
From ropes and oysters of Willie Creek Pearl Farm	9/2/2008	Balanidae	*Amphibalanus cirratus*	14 specimens
From ropes and oysters of Willie Creek Pearl Farm	9/2/2008		*Megabalanus occator*	1 specimen (1 live adult)

Table 2. Comparative material collected from Dampier Creek, Broome, WA.

Station/Site	Date	Order/Family	Genus and species	Number of specimens
Dampier Creek	9/2/2008	Balanidae	*Amphibalanus littoralis*	20 specimens (1 test, 19 live adults)

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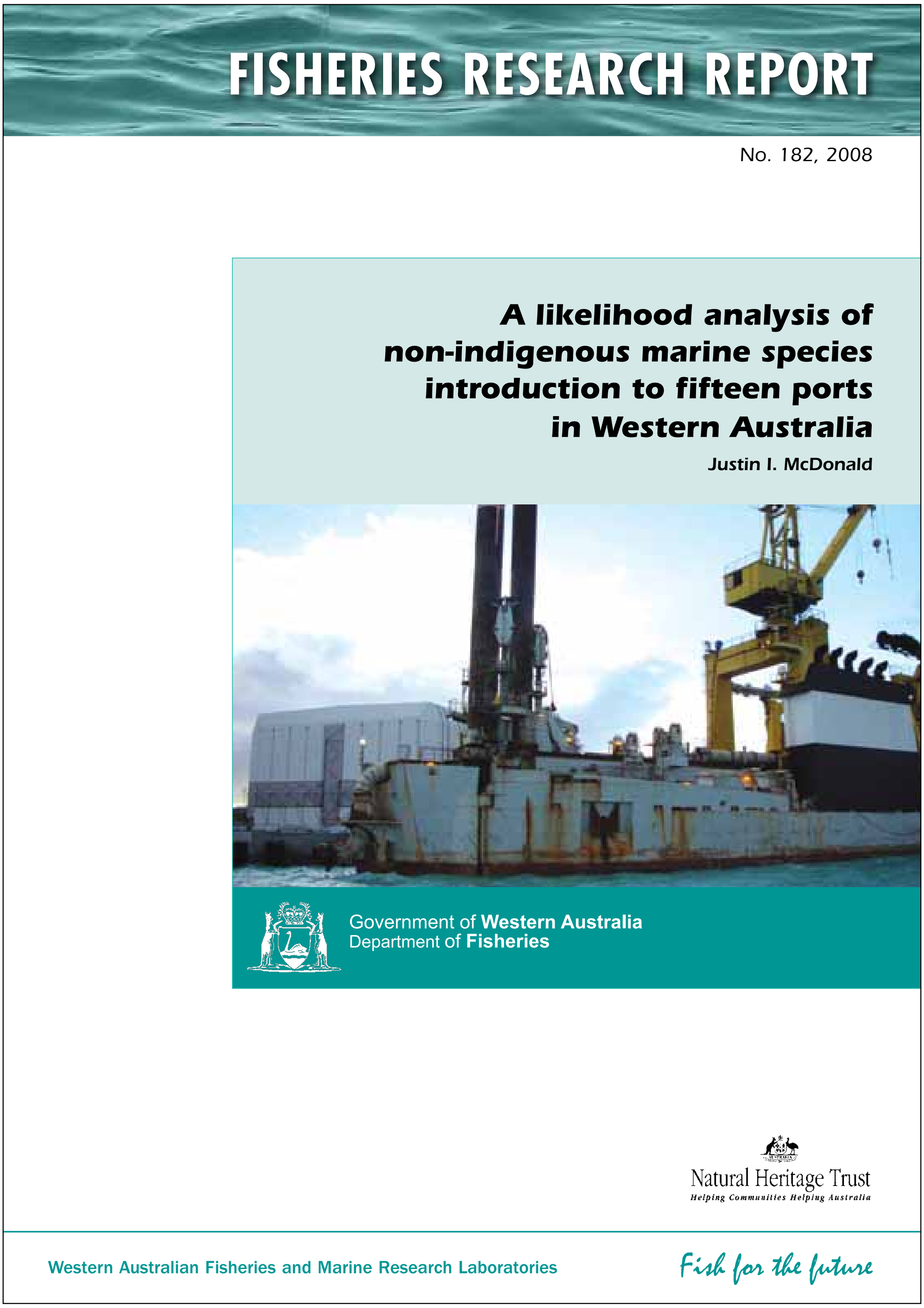
A likelihood analysis of non-indigenous marine species introduction to fifteen ports in Western Australia



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No. 182, 2008

A likelihood analysis of non-indigenous marine species introduction to fifteen ports in Western Australia

Justin I. McDonald

Government of **Western Australia**
Department of **Fisheries**

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Contents

A likelihood analysis of non-indigenous marine species introduction to fifteen ports in Western Australia

Abstract

As an island continent, Australia is heavily dependent upon maritime transport with over 95% of its imports and exports transported by ship (Australian State of the Environment Committee, 2001). With about one third of Australia's coastline, Western Australia ranks fourth of the six states and territory in the number of known non-indigenous marine species.

In this study fifteen ports in Western Australia were assessed on the potential for non-indigenous marine species to become introduced through ballast water and biofouling. The overall vessel-mediated incursion risk to Western Australian ports was calculated by summing the relative incursion threat posed by visits to each port (using 2006 port data). The relative threat value of these visits was determined by a set of uniformly applied criteria. These comprised:

- The number of vessels visiting the port;
- Their port of origin (domestic or international);
- The volume and source of ballast water discharged in each port;
- The dead weight tonnage (DWT – as a proxy for hull fouling potential); and
- The type of vessels visiting each port.

Using the criteria outlined above, the three ports at most risk of non-indigenous marine species introductions are:

- Dampier;
- Fremantle; and
- Port Hedland.

The rankings of each port in this study are consistent with results from the National Introduced Marine Pest Coordination Group (NIMPCG, 2006) study, which ranked all ports across Australia (based on data for 1998-2004).

1.0 Introduction

Non-indigenous marine species can cause serious environmental and economic impacts. Once established, they can prey on and/or displace indigenous species. Directly and indirectly, invasive species can damage or adversely effect (Wallentinus & Nyberg, 2007):

- Commercial fisheries and aquaculture;
- The tourism industry;
- Human health through transmission of diseases such as cholera via copepods;
- The commercial efficiency of ports; and
- Infrastructure such as port facilities, navigation aids, water pipe systems and even hydroelectric and desalination plants.
- Biodiversity and ecosystem functioning

Moreover, once established introduced species are typically difficult or expensive to eradicate. As an indication of the potential costs, in the Baltic Sea an invasion of comb jelly (*Mnemiopsis leidyi)* so affected the marine food chain of the region that it led to the collapse of most fishing industries there valued at an estimated $US 500 million a year (Low, 2003).

1.1 Non-indigenous marine species in Western Australia

A total of 60 non-indigenous marine species (NIMS) are regarded as having been introduced, or present in the coastal waters of Western Australia (Huisman *et al.* 2008). Most of the non-indigenous marine species in Western Australia are temperate species (37 species) that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 non-indigenous marine species occur in both the southern and northern halves of Western Australia. The greatest concentration of NIMS is in the southwest corner of Western Australia: Fremantle (including Cockburn Sound and the lower Swan River) has 46 non-indigenous marine species. In the southwest of the state Fremantle is the largest port based on the number of vessel movements. Albany (25 NIMS present), Bunbury (24 NIMS present) and Esperance (15 NIMS present) are all smaller ports with fewer numbers of non-indigenous marine species (Huisman *et al.* 2008).

As yet there are no published data regarding adverse impacts of non-indigenous marine species in Western Australia (Hass and Jones, 1999), but several have been shown to have significant impacts in other areas, by competition for food and/or space. Adverse impacts may not occur until decades after the initial introduction and establishment (Courtney, 1990) and it would, therefore, be extremely shortsighted to assume that Western Australia's relatively unaffected marine environment is immune to infestation by pest species.

With about a third of Australia's coastline, Western Australia ranks fourth of the six states in the number of non-indigenous marine species. It should be noted however, that there have been recent incursions of the black-striped mussel *Mytilopsis sallei* on illegal Indonesian fishing boats in Broome and Port Hedland and the Asian green mussel *Perna viridis* into Dampier. Whatever the current situation, there is still a great need for continued vigilance and implementation of pro-active mitigation.

1.2 Invasion potential

While Australia has taken steps to reduce pest introductions, for example through border controls, incursions continue to occur. The introduction of non-indigenous species into the marine environment is a major threat to native biodiversity and ecosystem health (Hass and Jones, 1999).

The two main vectors for marine introductions recognised are - via ballast water discharge or via hull fouling (Carlton, 1996). Ballast water is used in ships for stability while travelling. In 2001 around 150 million tonnes of ballast water were discharged in Australian coastal waters annually from international vessels, and a further 34 million tonnes from domestic vessels (Australian State of the Environment Committee, 2001). The amount of ballast discharged has increased considerably since that time. It has been estimated that 10,000 different species are being moved between various regions around the world in ballast water tanks each day (Low, 2003).

The management of ballast water is currently being addressed throughout the world by different governments at different levels. At an international level Australia has been very proactive in promoting the development of uniform international ballast water controls through its involvement as Chair of the Marine Environment Protection Committee (MEPC) of the International Maritime Organisation (IMO). Within Australia, Australian Quarantine and Inspection Service (AQIS) has been designated as the lead agency for the management of ballast water risks. In 1990, AQIS introduced voluntary ballast water guidelines in response to early concerns that ballast water from overseas ports may contain exotic species that have an adverse impact on the marine environment. The guidelines were refined and became mandatory in July 2001. These guidelines aim to reduce the risk of introducing non-indigenous marine species into Australia, primarily through processes of ballast water exchange at sea, ballasting in deep water and non-discharge in Australian ports.

The introduction of ballast water controls has changed the relative importance of ballast versus hull fouling as the primary vector introducing non-indigenous marine species. Hull fouling on vessels and translocation of species between Australian ports has now become recognised as more important means of pest introductions (Hayes, 2002). Hull fouling is a broad term that covers marine species fouling on vessels' hulls and associated niches, anchor chains, and in internal water systems through to attachment to drilling platforms.

Introductions of non-indigenous marine species have been detected in all states of Australia. The most intensively studied port region in Australia is Port Phillip Bay in Victoria. The port is one of the few areas where it is possible to evaluate the historical patterns of invasion by non-indigenous marine species (Hewitt *et al.* 1999). The study identified between 99 and 178 non-indigenous marine species in the bay, and estimated that the actual number of non-indigenous marine species is between 300 and 400. The study further estimated that two to three new non-indigenous marine species are establishing in Port Phillip Bay each year.

1.3 The aims of this document

All information used in this document is based on records of vessels visiting the ports within Western Australian for the period 1st January to the 31st December 2006, gathered from individual port Authorities and the West Australian Department for Planning and Infrastructure.

Data were provided by the Port Authority of each of the 15 Western Australian ports for the calendar year 2006. The data for each port included:

- Vessel name;
- Dead Weight Tonnage (DWT);
- Arrival date;
- Departure date;
- Port hours (hours in port);
- Origin (where vessel is from);
- Last port;
- Next port;
- Trade (purpose of vessel use);
- Vessel type (e.g. Barge); and
- Ballast water (BW) volume discharge estimate (using last port data to determine domestic or international source).

Note: while all the above data categories were represented in the data set examined many locations did not have all this data for every vessel. DWT and ballast water discharged were the two main categories often missing data for vessels.

The Department of Fisheries, Western Australia is the lead agency for aquatic biosecurity with the aim of reducing the risk of non-indigenous species introductions into the state. The results of the analysis presented in this report, are relative risk estimates. They do not represent an absolute measure of risk but rather relative risks of one port to another. The specific objectives of this report are:

1. Identify the number, type and origin of vessels visiting 15 West Australian high-risk locations (Figure 1);
2. Assess the amount and source of ballast water discharged into each location;
3. Assess potential of hull fouling as a vector;
4. Assess likelihood of each location becoming ‘infected’ and rank locations based upon points 1-3;
5. Compare the results of this study with the findings of the National Introduced Marine Pest Coordination Group (NIMPCG) 2006.

2.0 Methods

Ranking of locations on the likelihood for NIMS introduction was based on the port with the highest likelihood of receiving a pest. At the simplest level, the frequency of introduction can be assumed to be proportional to the number of vector movements between infected and non-infected regions. For ballast water and hull fouling, a simple relationship exists between the frequency of introduction and the volume of ballast water discharged into recipient locations and the fouled surface area of vessels that enter the location.

2.1 Ranking criteria

The overall vessel-mediated incursion risk was calculated by summing the relative incursion threat posed by visits to each port. The relative threat value of these visits was determined by a set of uniformly applied criteria. These comprised:

- Number of visits by vessels:
  - Total number of vessel visits;
  - Number of visits from a domestic location;
  - Number of visits from an international location;
- Volume of estimated ballast water discharged:
  - Total volume of ballast water;
  - Volume of ballast water from a domestic source;
  - Volume of ballast water from an international source;
- Dead weight tonnage (DWT – as a proxy of hull fouling potential) of vessels:
  - Mean DWT of vessels;
  - Maximum DWT of vessels;
- Vessel risk categorisation.

2.2 Dead weight tonnage

Dead weight tonnage of a vessel has been shown to provide a useable proxy for hull fouling potential (Ruiz et al., 2000). For the purposes of this analysis it was assumed that hull fouling propagule supply is a simple linear, monotonically increasing, function of the number of large commercial vessel visits (Hayes *et al.,* 2005). Therefore, when using DWT as a proxy for hull fouling potential, the larger the vessels visiting a port, the greater the fouling potential.

2.3 Vessel risk categorisation

While DWT provides a useful proxy for hull fouling potential, it could be misleading to assume that the greater the surface area of a hull, the greater the number or density of fouling organisms. In reality, fouling organisms are often most numerous in small nooks and crannies in and around a vessel. The number and complexity of these fouling communities varies according to vessel type, with working vessels such as dredges having a greater risk potential due to ‘nooks and crannies’ than an LNG tanker with extensive flat surfaces. As such, using a ranking of vessel fouling potential based upon vessel design (based on established risk determination methods used by URS Australia – Polglaze (2007, pers. comm.)) was used to complement the DWT measure as a proxy for hull-fouling potential. The risk ranking is assigned to a vessel based on a series of vessel features that include:

- Long distances between project sites;
- Time spent in port or coastal waters;
- Promiscuity of overall movement patterns;
- Number and range of niches;
- Transit or mobilising speed;
- Working speed at project site;
- Fouling coating (FC) presence;
- FC wear and tear rate; and
- Hull cleaning constraints*.
- this feature reflects difficulties in cleaning due to vessel size/hull area, amount of hard-to-reach surfaces and availability of suitable slipping locations and opportunities in Australia.

For each of the above criteria a score was assigned. The scoring system does not weight any particular factor, rather it assigns a 1 to 3 value based on the following:

1= low frequency/risk

2= medium or moderate frequency/risk

3= high frequency/risk.

A mean score for all factors is computed and ranked against the following risk rating:

< 2 = a low fouling propensity;

2.0 – 2.5 = a moderate fouling propensity; or

> 2.5 = a high fouling propensity

2.4 Ranking the high-risk locations using all likelihood criteria

The assessment of likelihood of NIMS introduction for each port was made on a relative, not absolute, basis. The 15 ports were ranked from highest (1) to lowest (15) likelihood for each of the criteria and the ranking scores for all nine criteria (listed on page 7) were summed and then a mean value determined.

For example, a port that was ranked 1st in terms of vessel visits, 11th for vessels from a domestic source, 2nd for vessels from an international source, 4th for the total amount of ballast water discharged, 3rd for the amount of domestic ballast water discharged, 5th for the amount of international sourced ballast water discharged, 1st for the mean DWT, 2nd for the maximum DWT, and 4th for vessel risk obtained a total likelihood score of 3.66 (1+11+2+4+3+5+1+2+4)/9). Once a likelihood value for each port (between 9 and 135) was determined they were ranked according to these likelihood values.

Note: all likelihood factor criteria were assigned an equal weighting.

3.0 Results

3.1 Vessels entering Western Australian ports

In total there were 8,874 visits recorded to the Western Australian 15 ports from 44 different types of vessel (Appendix 1). Given the large number of vessel types reported, they were classified into one of eight categories, which reflected the vessels primary use:

- Charter vessels;
- Cruise ships;
- Fishing vessels;
- Government vessels –government patrol boats, customs vessels and Western Australian police vessels;
- Military vessels;
- Other non-working –sailing vessels, ferries, ice breaker, research, super yacht and a private patrol vessel;
- Commercial trading vessels - carriers of general bulk, ore, oil, grain, LNG, woodchips; and
- Working vessels – tugs, barges, dredges, pipe laying vessels.

Data on vessel category was not provided for some vessel visits (0.5 % of total number). These were classified as 'unspecified', a ninth category (Table 1).

Of the 8,874 visits, 4,017 (45.3%) had an international last port of call, 4,857 (54.7%) had a domestic last port. Commercial trading and working vessels comprised over 87.9% of all vessel visits (7,790 visits) (Table 1). Commercial trading vessels are also generally the largest vessels visiting WA ports and as such are those ranked as more likely to be ballast or hull fouling vectors (see following Ballast and DWT sections for more information). Cruise ships and 'unspecified' vessels had the lowest number (49 each) of visits totaling only 1% of all visits.

Based upon the total number of visits, Dampier ranked highest with 3,278, then Fremantle (1,722), then Broome (1,015) (Figure 2). Dampier also ranked first in the total number of international and domestic vessels (Figure 3). Fremantle was second for number of international vessels. Third place was Port Hedland with the largest number of international vessels and Geraldton with a greater number of domestic vessels (Figure 3).

3.2 Ballast water discharge

Forty-four different vessel types were recorded entering WA ports. Of these vessel types only 17 actually discharged any ballast water (Table 2). In total approximately 123.4 million tonnes of ballast water were discharged in WA from 4,081 vessels.

Of this amount 5.4% had domestic origins (6.6 million tonnes from 478 vessels), 94.6% had international origins (116 million tonnes from 3,332 vessels) and 0.01% was classed as other where no last port of call data were provided (14,782 tonnes from 1 vessel).

Ore carrying vessels discharged the most ballast water of all vessel types, 95.2 million tonnes of which 95 million tonnes (99.8%) was from an international source. General bulk and LNG carriers were the next size classes, discharging 81.8% (12.4 million tonnes) and 100% (3.7 million tones) internationally sourced ballast water respectively.

3.3 Vessel categories

The vessel category (based on Table 1) discharging the greatest proportion of ballast water from a domestic source was working vessels (86% or 3,150 tonnes domestic; 14% or 500 tonnes international) (Figure 4). The other two vessel categories discharging ballast water were military and trading vessels (Figure 4). Military vessels discharged no domestic ballast water; all 450 tonnes was from an international source; whilst ballast water discharged from trading vessels was almost all from international sources (5% or 6.6 million tonnes domestic; 95% or 116 million tonnes international) (Figure 4).

Most working vessels carry a little ballast water for trim purposes, with the exception of large heavy lift ships and construction barges that usually have a large ballasting and trim capacity. Unlike the trading ships and charter or cruise vessels which transit WA waters and/or spend 1-3 days in a port, working vessels such as dredges, tugs and research ships may spend long periods at anchor or moored between jobs, undertake slow moving work in one location for long periods, and use seafloor equipment. As such these vessels have a greater propensity to 'take-on' non-indigenous species, the majority of which are reported from coastal and port locations.

Dampier had the highest recorded total ballast water discharge of 42.2 million tones (34.4% of WA total), then Port Hedland with 40.9 million tones (33.1% of WA total), then Cape Lambert with 19.1 million tonnes (15.5% of WA total) (Figure 5). Fremantle had the greatest number of vessels discharging ballast water (1,015 or 61.5% of vessels visiting this port), however as a percentage of vessels discharging ballast water then Cape Lambert (325 vessels), Cape Cuvier (55 vessels) and Useless Loop (47 vessels) all had 100% of vessels discharging ballast water, Port Hedland was next highest at 88.5% of vessels visiting the port (823 vessels)(Figure 6).

Ranking of ballast water volume discharged into each port based on the source of the ballast water (international or domestic) is as follows:

International source of ballast water:

- Dampier ranks first (42.2 million tonnes or 97.5% of all the ballast water discharged in this port was from international source);
- Port Hedland (40.9 million tonnes or 99.3% of all ballast water discharged in this port was from an international source);
- Cape Lambert (19.1 million tonnes or 99.5% of all ballast water was from an international source).

Domestic source of ballast water:

- Fremantle ranked first with 3.8 million tonnes or 45.4% of all the ballast water discharged in this port was from a domestic source;
- Bunbury (830,296 tonnes or 18.4% of all ballast water discharged in this port was from a domestic source);
- Geraldton (528,782 tonnes or 21.4% of all ballast water discharged in this port was from a domestic source).

3.4 Vessel Dead Weight Tonnage (DWT)

3.4.1 DWT per vessel category

Trading vessels had the highest mean, median and maximum DWT values of any vessel category (Table 3) therefore when using DWT as a proxy for hull fouling potential these vessels represent the greatest fouling risk, charter vessels the lowest risk (mean DWT 83 tonnes)(Table 3).

3.4.2 DWT for each high-risk location

On a port-by-port basis, a vessel visiting the Port of Dampier had the highest maximum DWT of 364,767 tonnes. This was an ore carrier. Cape Lambert had a maximum DWT of 310,698 tonnes, then Fremantle with 306,000 tonnes (maximum DWT) (Figure 7). The lowest DWT value for a vessel was 10 tonnes for the Harrietta, a barge visiting Varanus Island.

Figure 8 provides an indicator of the mean vessel DWT for each port. Cape Lambert had the highest mean DWT of 173,454 tonnes. The main vessel types contributing to this value were ore carriers, general bulk carriers and a single crude oil carrier. Port Hedland was next highest with a mean of 132,667 tonnes, then Bunbury with 48,920 tonnes. The lowest mean DWT was at Broome with only 2,390 tonnes.

3.5 Vessel risk categorisation

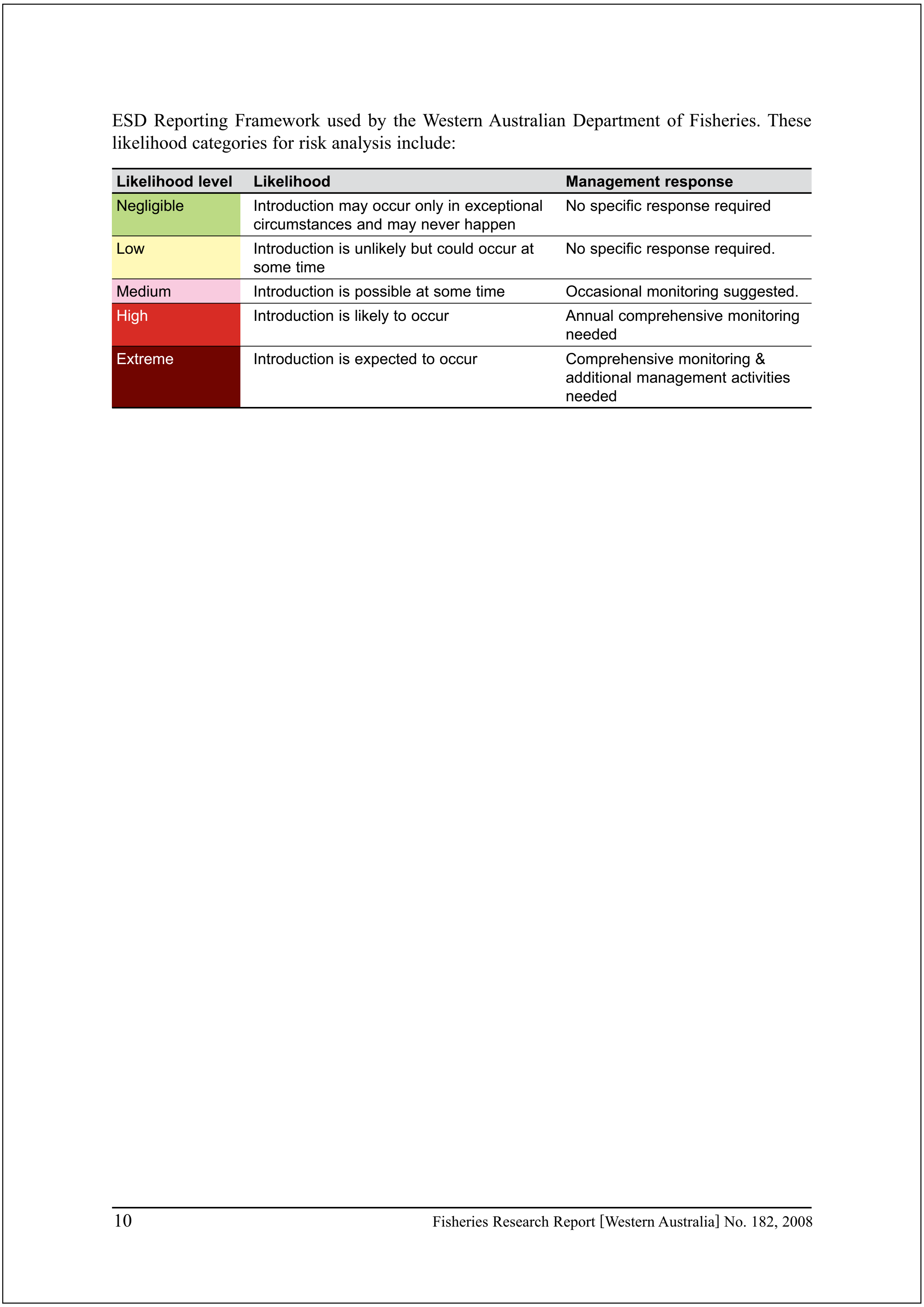
Using a ranking of vessel fouling potential (outlined previously on page 8) the risk factor assigned to the major vessel categories visiting Western Australian ports is shown in Table 4. Table 5 illustrates the total number of vessels visiting each port and the number of vessels in each risk category.

The extent of fouling upon a vessel is also highly dependant on the vessel's activity patterns, the time since it was last cleaned and anti-fouled, and the type of anti-foulant used. This type of information, however, was not readily available for those vessels operating in Western Australian waters.

3.6 Relative likelihood of NIMS introduction for each Port

The key findings from this report show that the top three Western Australian ports identified at most risk of non-indigenous marine species introduction (Dampier, Fremantle and Port Hedland) on the National Monitoring System (NIMPCG, 2006) have not changed in the last 4 years. Table 6 shows the complete ranking of all ports examined in this study alongside the rankings from the Australian wide study (NIMPCG, 2006) (The raw data used to determine the individual port rankings are shown in Appendix 2). The greatest likelihood of non-indigenous marine species introductions is to Dampier (Figure 9). This likelihood drops to Fremantle then Port Hedland, at which point a plateau is reached for Bunbury, Cape Lambert and Geraldton, indicating little difference in the relative likelihood amongst these ports. The likelihood is reduced once more and again plateaus out for the remaining nine ports.

These results were then separated into five likelihood categories ranging from negligible to extreme (Tables 7-21). These likelihood categories are modified from Fletcher (2005) and identify the relative likelihood of non-indigenous marine species introduction to each location. The ranking categories used to assign likelihood in one of five levels are consistent with the



ESD Reporting Framework used by the Western Australian Department of Fisheries. These likelihood categories for risk analysis include:

Likelihood level	Likelihood	Management response
Negligible	Introduction may occur only in exceptional circumstances and may never happen	No specific response required
Low	Introduction is unlikely but could occur at some time	No specific response required.
Medium	Introduction is possible at some time	Occasional monitoring suggested.
High	Introduction is likely to occur	Annual comprehensive monitoring needed
Extreme	Introduction is expected to occur	Comprehensive monitoring & additional management activities needed

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4.0 Discussion

As the largest State in Australia, Western Australia (WA) has a long and relatively pristine coastline that stretches over 12,500 km. The coast ranges over 20 degrees of latitude from 14°S in the most northerly parts of the Kimberley to 35°S on the south coast. While the impact of introduced species in WA is as yet unknown, the likelihood of a pest outbreak is high, as the State includes many high traffic ports with a variety of habitats, ranging from tropical to temperate. Even a cursory review of the marine species known to be pests elsewhere reveal that, for most, suitable conditions for their survival, growth and possible reproduction can be found somewhere in the State. Thus the likelihood of a pest incursion is high and on-going vigilance is important if WA is to remain relatively pest free.

Ballast water and fouling of vessels are believed to provide the primary pathways for non-indigenous marine species enabling the initial introduction, while domestic vessels provide a range of secondary pathways that can promote the spread of established marine pests. The use of ballast water by commercial vessels has created a highly efficient transfer mechanism (vector) for entire plankton communities. Ships take on ballast water from coastal areas, capturing diverse planktonic assemblages that inhabit these areas, which are then discharged en masse at subsequent ports of call (Carlton and Geller 1993; Carlton 1996; Ruiz *et al*. 2000a,b). For overseas ships arriving in Australia and the USA alone, ballast water discharges in each country are calculated in million metric tons annually (Kerr 1994; Carlton *et al*. 1995), creating a massive transfer of biota across the globe.

Domestic ballast water movement is currently not managed for non-indigenous marine species translocation nationwide, except Victoria. Therefore, there is a risk of translocating NIMS from areas where they are present to new areas. For example, Asian green mussels and Caribbean tubeworms are present in the Port of Cairns and are identified as taxa of concern for tropical Australia (NIMCPG, 2006). There is therefore a risk that any domestic ballast water collected from the Port of Cairns and discharged in suitable areas in WA, could introduce either of these taxa.

Australian management agencies have introduced a protocol to address fouling on small international vessels (< 25 m). This protocol requires international vessels (or domestic vessels that have an international last port of call) to demonstrate hull-cleaning practice, or be slipped shortly after arrival in an approved facility (i.e. where wastes are contained). This protocol is currently voluntary, however it could still significantly reduce fouling as a vector. These measures will aid in reducing the potential for non-indigenous marine species into and between Australian ports.

4.1 Recommendations

This likelihood assessment is a broad scale examination of 15 ports within Western Australia. An equal, linear and additive relationship between factors and likelihood of NIMS introduction was assumed, but this may not hold true. Further research is required to fully understand the full suite of factors that contribute to likelihood, the relationships between these factors and the actual likelihood posed by each factor. There is a particular need for these high-likelihood areas to be examined for non-indigenous species. An area currently designated as low likelihood may actually be at extreme likelihood of NIMS introduction if a neighbouring port from which it receives a lot of traffic is harbouring non-indigenous marine species.

The top three ports at risk of non-indigenous species introductions identified in this report (Dampier, Fremantle, and Port Hedland) are all scheduled for detailed non-indigenous marine species monitoring under the National System. In relation to future shipping activities in the remaining ports examined and the potential for non-indigenous marine species introductions the following recommendations are made:

1. A general need for education and awareness raising across all sectors utilising these areas;
2. Ensure that comprehensive records of all vessels visiting the port are maintained so that data on vessel movements, ballast water discharged, etc. can be examined;
3. Areas identified as high to extreme likelihood of NIMS introduction need to establish a non-indigenous species monitoring regime starting with detailed baseline surveys using the National System from which to detect new invasions through to comprehensive vector/species environmental compatibility analyses.

5.0 Acknowledgements

The Department of Fisheries initiated a project *"Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia"* in October 2006. The present report is part of the project. It is funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State government. This component was funded through the W.A. Strategic Reserve Fund (Project No. 053085).

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7.0 Tables and Figures

7.1 Tables

Table 1. The number of visits per vessel category and the number of vessel visits as a percentage of total visits in 2006. Data are ranked in descending order.

Vessel category	# visits per vessel category	% total visits
Commercial trading vessels	5,046	56.9
Working vessels	2,744	31
Government vessels	110	1
Other non-working vessels	13	0.1
Charter vessels	325	3.7
Cruise ships	49	0.5
Unspecified	49	0.5
Fishing vessels	474	5.4
Military vessels	64	0.7
Total	8,874	100

Table 2. Vessel type, the volume of ballast water discharged by ballast water source (domestic or international last port of call) and total volume of ballast water discharged per vessel type in 2006.

Vessel type	Ballast water source (based on last port of call)			Total ballast water discharged
	Domestic	International	Other	
Bulk/ chemical carrier	76,930			76,930
Chemical tanker	91,279	114,895		206,174
Container ship	1,660,485	1,225,779		288,264
Crude oil tanker	387,578	1,807,986		2,195,564
Gas carrier	38,976	463,552		502,528
General bulk carrier	2,741,812	12,410,506	14,782	15,167,100
General cargo ship	198,182	74,200		272,382
Grain carrier	253,765	1,068,633		1,322,398
Heavy lift ship	3,000			3,000
Livestock carrier	66,910	155,610		222,521
LNG carrier		3,718,151		3,718,151
Ore carrier	154,974	95,063,750		95,218,723
Pipe-lay Ship		500		500
Products tanker	941,818	293,937		1,235,756
Tug and barge combo	150			150
Woodchip Carrier		407,553		407,553
Military ship		450		450
Grand Total (tonnes)	6,615,859	116,805,503	14,782	123,436,143

Table 3. Vessel category mean (+se), median, minimum and maximum DWT for each vessel category in 2006. Note: does not include vessel visits where no DWT data was provided (n = 7431).

	Number	Mean	SE	Median	Min	Max
Charter vessel	16	83	40	28	20	668
Cruise ship	54	3,573	590	2,975	120	24,528
Fishing vessel	23	690	108	611	75	1,746
Government vessel	14	453	282	270	30	4,100
Military vessel	48	4,923	1,235	3,050	116	40,870
Other non-work	8	1,426	1,005	259	80	8,346
Trading vessel	4,841	84,408	958	53,540	27	364,767
Work vessel	2,427	1585	133	1,014	10	149,494

Table 4. Risk rating of major vessel categories visiting WA ports in 2006.

Vessel category	Risk rating
Fishing	1.7
Government	1.5
Military	2.0
Private	1.4
Research	1.5
Trading	1.3
Trading cruise	1.3
Working	2.0

Table 5. The total number of vessels visiting each port and the number of vessels in each risk grouping (based on criteria listed on page 8) in 2006. Note: Does not include visits where insufficient or no data were provided (does not include data for 860 vessel visits to Broome as insufficient data was provided for these visits).

Port	Total # visits	Vessel risk factor	
		low	moderate
Albany	115	108	7
Barrow Island	186	10	176
Broome	155	12	143
Bunbury	344	343	3
Cape Cuvier	55	55	0
Cape Lambert	325	325	0
Dampier	3,278	1,205	2,068
Esperance	175	174	0
Exmouth	6	6	0
Fremantle	1,722	1,650	67
Geraldton	369	235	134
Port Hedland	930	915	15
Useless Loop	47	47	0
Varanus Island	193	9	184
Wyndham	114	112	2
Totals	8,005	5,206	2,799

Table 6. Final ranking of each port using 2006 data based on rankings obtained in Table 5 (see Appendix 2 for raw data for each variable measured). NIMPCG national ranking is based on data from 1998-2004.). NIMPCG values are rankings adjusted for WA ports only. The values in brackets indicate the ranking of each port on an Australia wide basis.

Port	Likelihood ranking* this report	NIMPCG national ranking (1998-2004 data)**	Likelihood Category
Dampier	1	2 (6)	Extreme
Fremantle	2	1 (2)	High
Port Hedland	3	3 (9)	High
Bunbury	4	4 (24)	Moderate
Cape Lambert	5	n/a	Moderate
Geraldton	6	5 (27)	Moderate
Esperance	7	7 (37)	Low
Albany	8	6 (34)	Low
Varanus Island	9	11 (59)	Low
Barrow Island	10	12 (76)	Low
Broome	11	9 (43)	Low
Useless Loop	12	14 (81)	Low
Cape Cuvier	13	10 (46)	Low
Wyndham	14	8 (41)	Low
Exmouth	15	13 (79)	Negligible

* The likelihood ranking is based on the mean score from Appendix 2 and assigns a value from 1 to 15 (based on the number of ports examined).

** National ranking is based on the data from the Australian Marine Pest Monitoring Guidelines: Version 1 Monitoring Network (2006).

n/a in NIMPCG ranking means that this port was not evaluated.

Table 7. Likelihood of NIMS introduction to the port of Albany for each of the criteria examined**.**

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits		🟨			
	# domestic visits		🟨			
	# international visits		🟨			
	Total ballast discharged (t)		🟨			
	Ballast domestic source			🟥		
	Ballast international source			🟥		
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)		🟨			
	Highest vessel risk category			🟥		
	Overall likelihood of NIMS introduction to port		🟨			

Table 8. Likelihood of NIMS introduction to Barrow Island for each of the criteria examined.

		Relative likelihood				
		Negligible	low	moderate	high	extreme
Criteria	Total # vessel visits		🟨			
	# domestic visits			🟪		
	# international visits	🟩	🟨			
	Total ballast discharged (t)		🟨			
	Ballast domestic source		🟨			
	Ballast international source	🟩				
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)			🟪		
	Highest vessel risk category			🟪		
	Overall likelihood of NIMS introduction to port		🟨			

Table 9. Likelihood of NIMS introduction to Broome for each of the criteria examined.

		Relative likelihood				
		Negligible	low	moderate	high	extreme
Criteria	Total # vessel visits				🟥	
	# domestic visits				🟥	
	# international visits		🟨			
	Total ballast discharged (t)	🟩				
	Ballast domestic source	🟩				
	Ballast international source		🟨			
	Dead weight tonnage (mean)	🟩				
	Dead weight tonnage (max)			🟪		
	Highest vessel risk category			🟪		
	Overall likelihood of NIMS introduction to port		🟨			

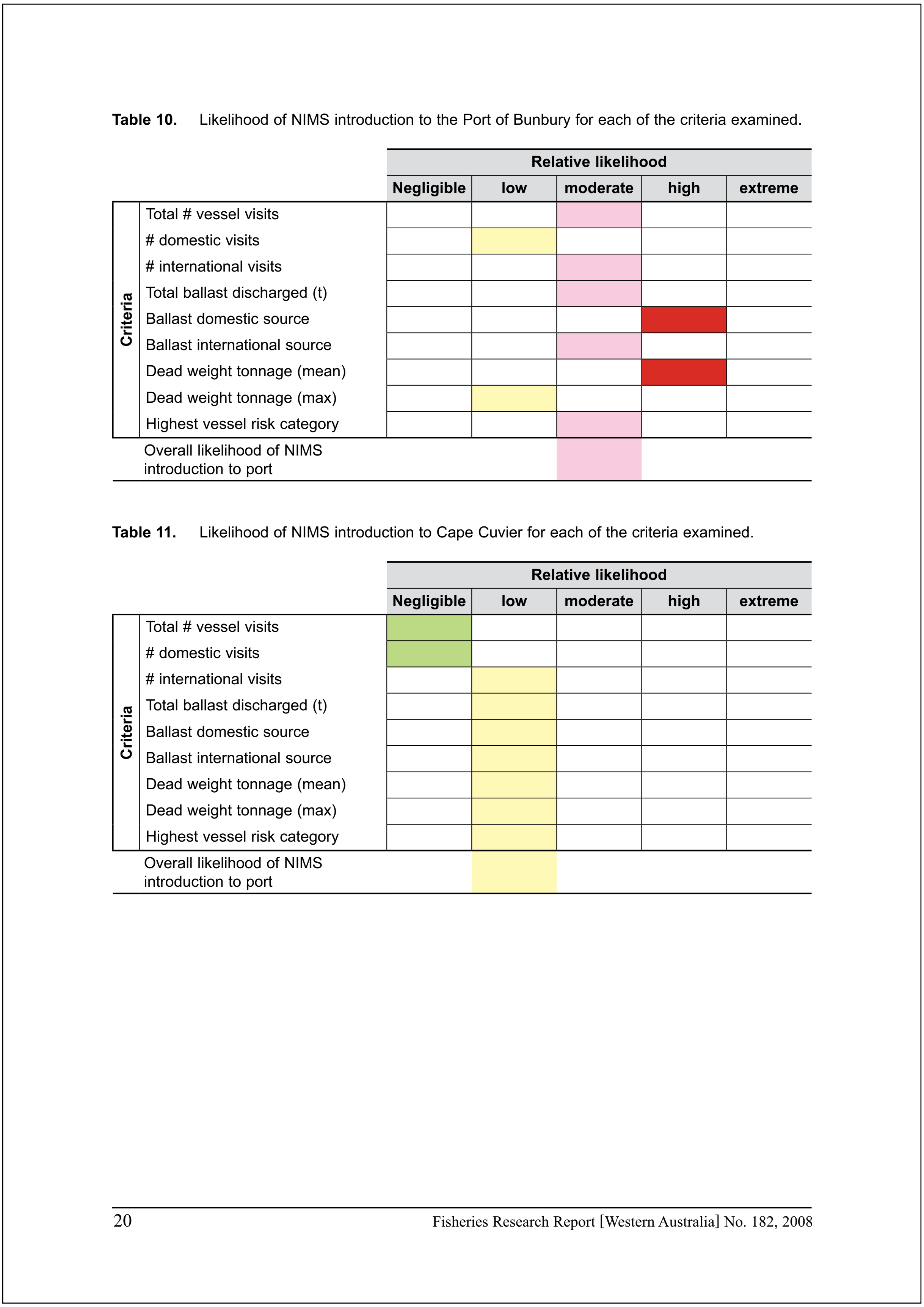


Table 10. Likelihood of NIMS introduction to the Port of Bunbury for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits			■		
	# domestic visits		■			
	# international visits			■		
	Total ballast discharged (t)			■		
	Ballast domestic source				■	
	Ballast international source			■		
	Dead weight tonnage (mean)				■	
	Dead weight tonnage (max)		■			
	Highest vessel risk category			■		
	Overall likelihood of NIMS introduction to port			■		

Table 11. Likelihood of NIMS introduction to Cape Cuvier for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits	■				
	# domestic visits	■				
	# international visits		■			
	Total ballast discharged (t)		■			
	Ballast domestic source		■			
	Ballast international source		■			
	Dead weight tonnage (mean)		■			
	Dead weight tonnage (max)		■			
	Highest vessel risk category		■			
	Overall likelihood of NIMS introduction to port		■			

Table 12. Likelihood of NIMS introduction to Cape Lambert for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits		🟨			
	# domestic visits	🟩				
	# international visits			🟪		
	Total ballast discharged (t)		🟨		🟥	
	Ballast domestic source		🟨			
	Ballast international source				🟥	
	Dead weight tonnage (mean)		🟨			🟫
	Dead weight tonnage (max)		🟨			🟫
	Highest vessel risk category		🟨			
	Overall likelihood of NIMS introduction to port		🟨			

Table 13. Likelihood of NIMS introduction to the Port of Dampier for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits					🟫
	# domestic visits					🟫
	# international visits					🟫
	Total ballast discharged (t)					🟫
	Ballast domestic source			🟪		
	Ballast international source					🟫
	Dead weight tonnage (mean)			🟪		
	Dead weight tonnage (max)					🟫
	Highest vessel risk category			🟪		
	Overall likelihood of NIMS introduction to port					🟫

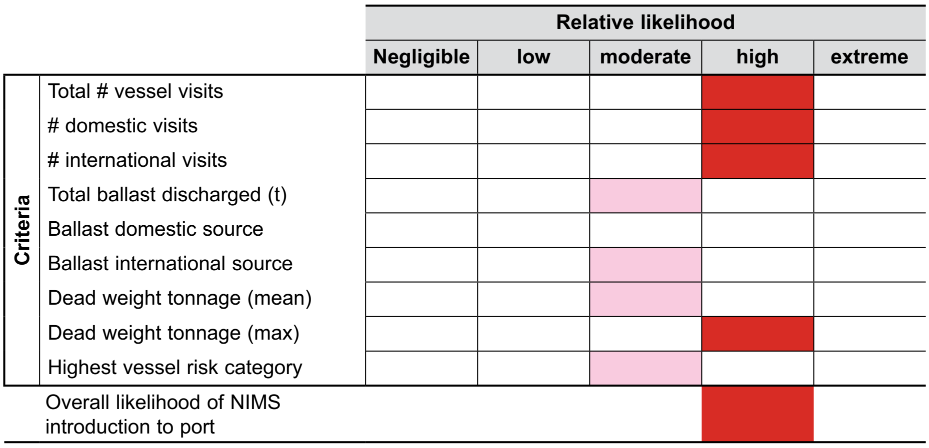
Table 14. Likelihood of NIMS introduction to the Port of Esperance for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits		🟨			
	# domestic visits		🟨			
	# international visits		🟨			
	Total ballast discharged (t)			🟥		
	Ballast domestic source		🟨			
	Ballast international source			🟥		
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)		🟨			
	Highest vessel risk category		🟨			
	Overall likelihood of NIMS introduction to port		🟨			

Table 15. Likelihood of NIMS introduction to Exmouth for each of the criteria examined.

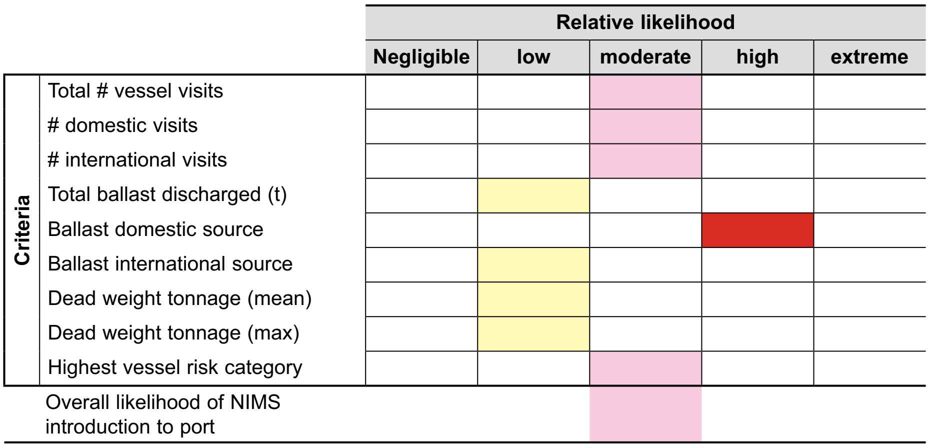
		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits	🟩				
	# domestic visits		🟨			
	# international visits	🟩				
	Total ballast discharged (t)	🟩				
	Ballast domestic source	🟩				
	Ballast international source	🟩				
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)	🟩				
	Highest vessel risk category		🟨			
	Overall likelihood of NIMS introduction to port		🟨			

Table 16. Likelihood of NIMS introduction to the Port of Fremantle for each of the criteria examined.



		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits				🟥	
	# domestic visits				🟥	
	# international visits				🟥	
	Total ballast discharged (t)			▨		
	Ballast domestic source					
	Ballast international source			▨		
	Dead weight tonnage (mean)			▨		
	Dead weight tonnage (max)				🟥	
	Highest vessel risk category			▨		
	Overall likelihood of NIMS introduction to port				🟥	

Table 17. Likelihood of NIMS introduction to the Port of Geraldton for each of the criteria examined.



		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits			▨		
	# domestic visits			▨		
	# international visits			▨		
	Total ballast discharged (t)		🟨			
	Ballast domestic source				🟥	
	Ballast international source		🟨			
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)		🟨			
	Highest vessel risk category			▨		
	Overall likelihood of NIMS introduction to port			▨		

Table 18. Likelihood of NIMS introduction to Port Hedland for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits			🟪		
	# domestic visits		🟨			
	# international visits				🟥	
	Total ballast discharged (t)				🟥	
	Ballast domestic source			🟪		
	Ballast international source				🟥	
	Dead weight tonnage (mean)				🟥	
	Dead weight tonnage (max)			🟪		
	Highest vessel risk category			🟪		
	Overall likelihood of NIMS introduction to port				🟥	

Table 19. Likelihood of NIMS introduction to Useless Loop for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits	🟩				
	# domestic visits	🟩				
	# international visits		🟨			
	Total ballast discharged (t)		🟨			
	Ballast domestic source	🟩				
	Ballast international source		🟨			
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)		🟨			
	Highest vessel risk category		🟨			
	Overall likelihood of NIMS introduction to port		🟨			

Table 20. Likelihood of NIMS introduction to Varanus Island for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits		🟨			
	# domestic visits			🟥		
	# international visits	🟩				
	Total ballast discharged (t)		🟨			
	Ballast domestic source		🟨			
	Ballast international source	🟩				
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)			🟥		
	Highest vessel risk category			🟥		
	Overall likelihood of NIMS introduction to port		🟨			

Table 21. Likelihood of NIMS introduction to the Port of Wyndham for each of the criteria examined.

		Relative likelihood				
		Negligible	**low**	**moderate**	**high**	**extreme**
Criteria	Total # vessel visits		🟨			
	# domestic visits		🟨			
	# international visits		🟨			
	Total ballast discharged (t)	🟩				
	Ballast domestic source		🟨			
	Ballast international source		🟨			
	Dead weight tonnage (mean)		🟨			
	Dead weight tonnage (max)	🟩				
	Highest vessel risk category			🟥		
	Overall likelihood of NIMS introduction to port	🟩				

7.2 Figures

Figure 1. Map of the Western Australian coastline showing the 15 ports evaluated in this assessment.

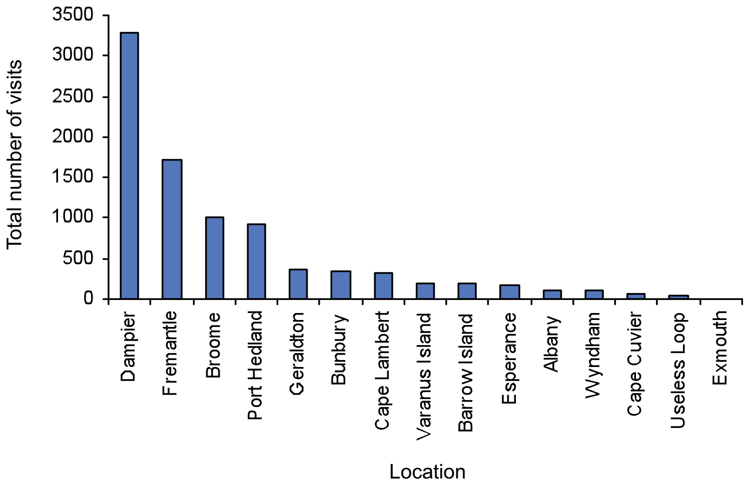


Figure 2. Total number of visits recorded for each port in 2006.

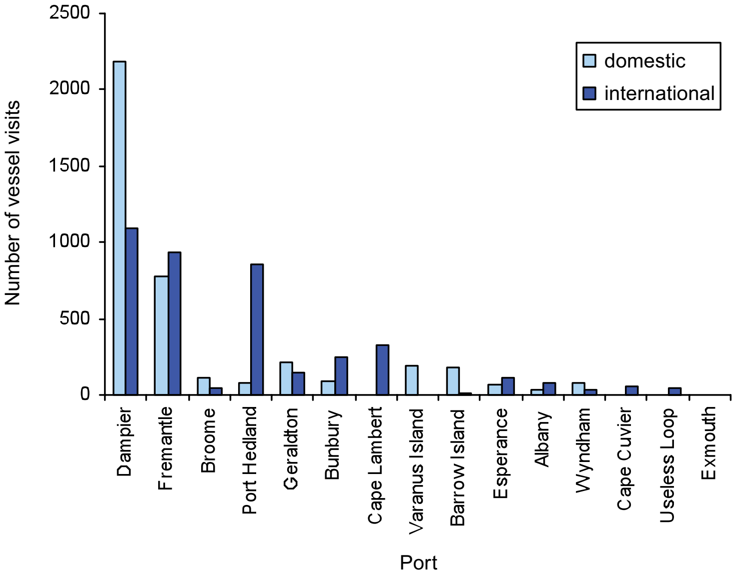


Figure 3. Number of international and domestic visits recorded for each port in 2006.

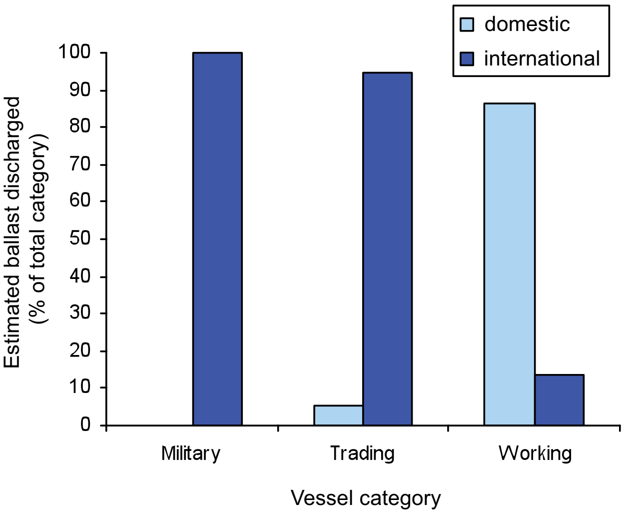


Figure 4. Amount of domestic or international sourced ballast water discharged from three vessel categories (as a percentage of total number) in 2006. Number of vessels per category and amount of ballast water discharged: Military vessels - 2 international vessels (450 tonnes); Trading vessels - 744 domestic vessels (6.6 million tonnes), 3,330 international vessels (116.8 million tonnes); Working vessels 4 domestic (3,150 tonnes), 1 international vessel (500 tonnes).

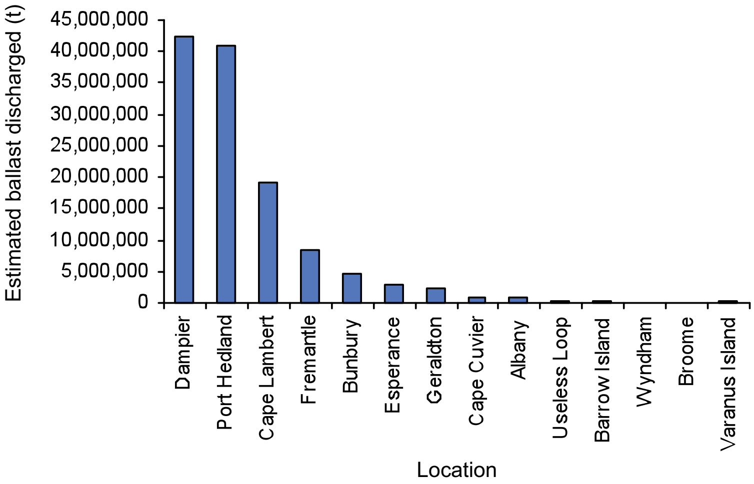


Figure 5. Total estimated ballast water discharged at each port in 2006.

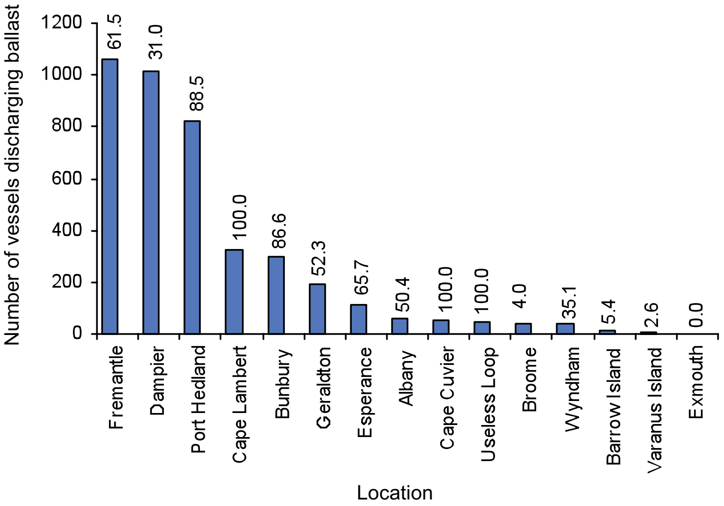


Figure 6. Number of vessels estimated to discharge ballast water at each port in 2006 (Values above bars represent the percentage of vessels estimated to discharge ballast water per port).

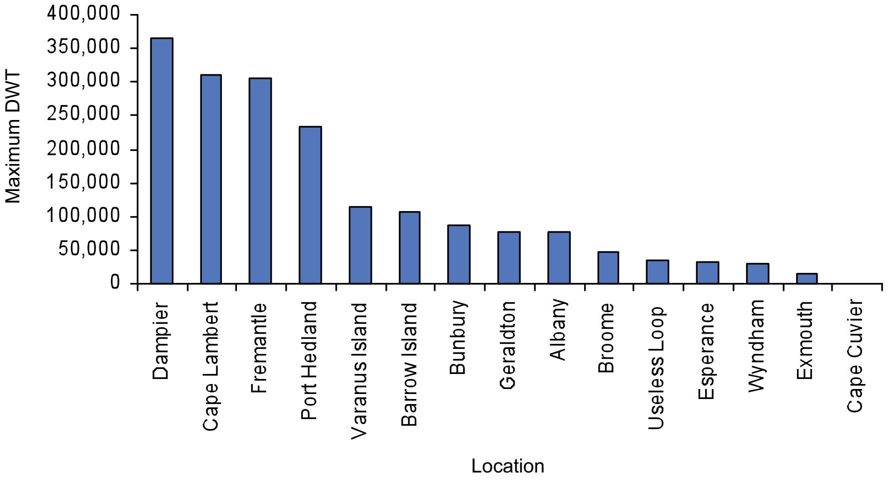


Figure 7. Maximum DWT for vessels visiting each port in 2006.

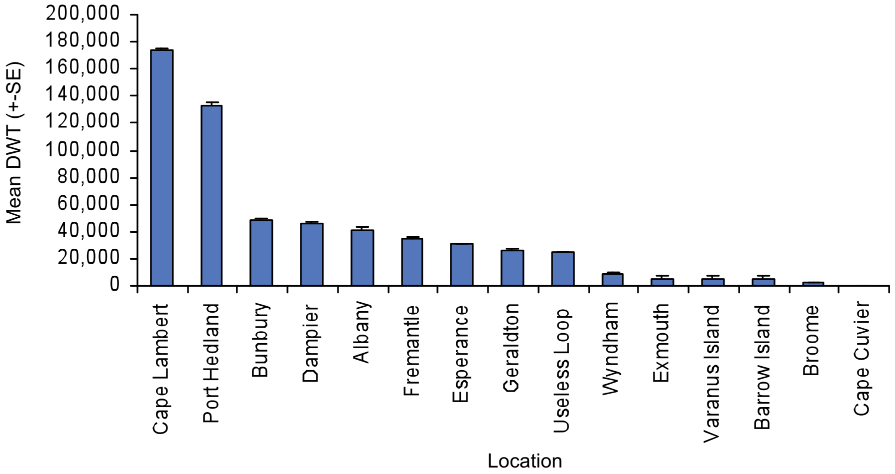


Figure 8. Mean (± SE) DWT for vessels visiting each port in 2006.

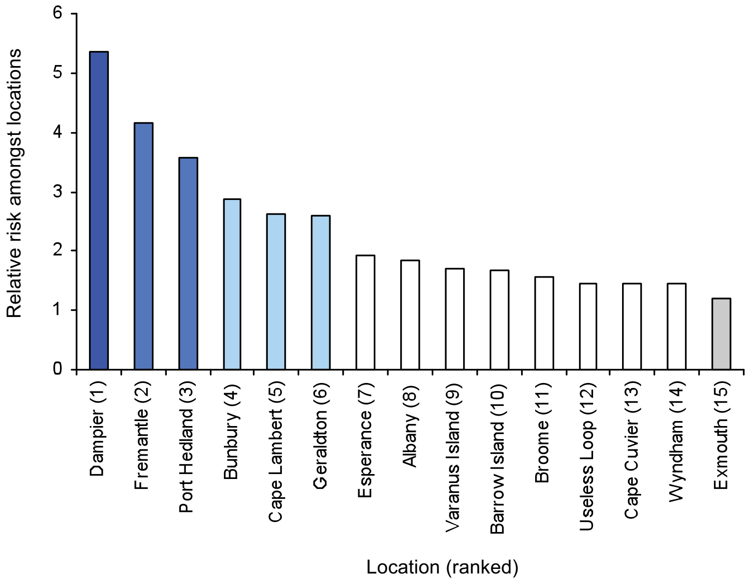


Figure 9. Relative likelihood of NIMS introduction amongst all ports evaluated. Values in brackets alongside location names indicate likelihood ranking from this study.

8.0 Appendices

Appendix 1. Vessel type and number of visits made to all ports in 2006.

Vessel type	# visits
Barge	36
Bitumen carrier	2
Cable laying vessel	4
Cement carrier	7
Chemical tanker	120
Container ship	491
Crude oil tanker	203
Cruise charter	325
Cruise ship	49
Customs	8
Dredge	8
Ferry	2
Fishing vessels	474
FPSO	1
Gas carrier	40
General bulk carrier	1294
General cargo	311
Government patrol	97
Grain carrier	116
Heavy lift	33
Ice breaker	1
Livestock carrier	135
LNG carrier	212
Military	64
MODU	12
n/a	49
Ore carrier	1658
OSV	2602
Pipe layer	2
Private patrol	1
Products tanker	253
Reefer	2
Research vessel	1
Ro-Ro	32
Sailing - training	5
Sailing vessel	2
Shuttle tanker	1
Special cargo carrier	5
Super yacht	1
Tug	38
Tug & barge combo	3
Vehicles carrier	145
WA police	5
Woodchip carrier	24
Total number of visits to all ports	8874

Appendix 2. Raw data for all ports showing number of visits (total and last port of call), amount of ballast water discharged (total and source - last port of call), and mean Dead Weight Tonnage (DWT) for all vessels entering that port in 2006.

Port	Vessel visits			Ballast			DWT		Vessel risk factor	
	total #	domestic	international	total	domestic	international	mean	max	low to moderate	moderate to high
Albany	115	41	74	873888	234299	639589	40927	77073	108	7
Barrow Island	186	180	6	254827	135873	118954	5346	107081	10	176
Broome	1017	975	42	45263	15483	29780	2390	47999	12	143
Bunbury	344	93	251	4503806	830297	3673509	48920	87052	343	3
Cape Cuvier	55	3	52	877188	40096	837092	0	0	55	0
Cape Lambert	325	2	323	19145624	82377	19063247	173454	310698	325	0
Dampier	3278	2188	1090	42406279	203966	42202313	46046	364767	1205	2068
Esperance	175	67	108	2787411	172235	2615176	31350	31350	174	0
Exmouth	6	5	1	0	0	0	5568	15521	6	0
Fremantle	1722	785	937	8532086	3876914	4655172	35076	306000	1650	67
Geraldton	369	217	152	2445824	528782	1917042	25657	77834	235	134
Port Hedland	930	77	853	40932681	268570	40664111	132667	233584	915	15
Useless Loop	47	3	44	368152	19314	348838	24278	35313	47	0
Varanus Island	193	190	3	176202	176202	0	5356	114809	9	184
Wyndham	114	83	31	72129	31451	40679	8756	29990	112	2
Total	8876	4909	3967	123421361	6615859	116805503			5206	2799

* The mean score of a port is determined by ranking each port for all variables shown in table from highest to lowest. Then taking the mean value of each ranking.

** Broome data – 860 of the 1017 visits had insufficient or no data provided on DWT, Ballast water etc… therefore are not included in these analyses.

Risk assessment of commercial fisheries introducing or transferring non-indigenous marine species (NIMS) in Western Australia

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Executive Summary

Western Australia has an extensive, variable coastline that extends from the tropical regions of the Kimberley to the temperate areas of the south coast. Three quarters of the State's 2.1 million people live in the Perth metropolitan area and most of the remainder live in the southwest. Outside the major towns and ports in other parts of the State, the marine environment is relatively pristine. Introduced marine pests are considered to be one of the critical threats to this pristine marine environment.

A recent analysis recorded 60 introduced marine species for which distributional data are available. Most (37 species) are temperate; 6 are tropical; and 17 occur in both areas. All 60 species are found in marine areas associated with harbours; 26 species occur on nearby open coasts. This strongly suggests species are being introduced to the State through major nodes of human activity, followed by some spread to nearby areas. However, it is acknowledged that surveys for introduced species have been concentrated in harbours and records from adjacent open shores are incidental.

A national port monitoring program is being established that targets 55 species known to be invasive in Australia or elsewhere, or are potentially invasive. In their analysis of marine species introduced into Western Australia, Huisman *et al.* (2008) found only three species on the national list: the dinoflagellate, *Alexandrium tamarense*, the polychaete *Sabella spallanzanii,* and the bivalve *Musculista senhousia.* The alga *Caulerpa taxifolia* occurs in WA, but it is not the invasive genetic strain. A single specimen of the invasive marine alga *Codium fragile fragile* was recently found in Albany. Investigations are underway to determine whether the species is actually present in the area. Overall only eleven of the 55 species occur in Australian waters. It is acknowledged that species not on the list may become invasive. Eighteen ports nationwide are in the national monitoring system, including three in Western Australia: Dampier, Port Hedland and Fremantle.

The present document was developed as a discussion paper for a workshop held in May 2008 to evaluate the risk of introduction of nonindigineous marine species into Western Australia by commercial fisheries and the risk of their spread by fisheries activities. The final document has been updated to incorporate the workshop results.

It is concluded that fishing boats operating in Western Australian managed fisheries could potentially introduce NIMS from other areas when they move from interstate or overseas into WA. However, this is a shipping issue common to all vessels moving from one location to another, and should be considered in the context of overall vessel movement.

As no boats in WA managed fisheries fish overseas, there is no risk of introductions through overseas fishing activities. A few boats in northern WA fisheries travel to Darwin, but at present no species on the NIMPCG (2006) list are known to occur there. Two boats in the

WA southern rock lobster fishery are based in Ceduna, South Australia, but again there are no known species on the NIMCGP (2006) list. There is some opportunity for boats to move the three species in already WA about in the southern half of the State, but to date no adverse effects from these species have been recorded. Overall, there is low risk at present of boats operating in WA managed fisheries introducing NIMS into the State, but the situation will be continually monitored.

The above assessment has been concerned with the movement of NIMS into Western Australia or movement of the few species already within the State into new areas. The assessment has placed the risks as low in view of the few species present in areas where WA fisheries operate that are on the NIMPCG target list. However, it must be recognised that if NIMS are introduced into an area where WA fisheries operate, there is a high potential for commercial fishing activities to spread the NIMS. This might well occur before the Department of Fisheries becomes aware of the presence of the marine pest. Accordingly, the recommendations of Summerson and Curran (2005) should be followed by all WA commercial fisheries. NIMPCG is currently developing national protocols for the operation of commercial fisheries vessels. When these protocols have been developed, they should be used in Western Australia.

Introduction

Non-indigenous marine species (NIMS) are organisms that have moved from their natural environment to an area where they can potentially threaten human health, economic values or the environment, thereby becoming introduced marine pests. Non-indigenous marine species are a global problem, and are second only to habitat change and loss in reducing global biodiversity (Millennium Ecosystem Assessment, 2005). Many of these species remain inconspicuous, however it is estimated that one in six to ten of non-indigenous marine species will become a pest. Most accidental introductions are due to shipping and recreational craft moving from country to country, with the pests being transported in ballast water, on ship hulls, or within a vessel's internal seawater pipes. There have been no successful deliberate introductions (for aquaculture, aquaria or recreational fishing) to the marine environment in WA. An attempt to introduce the Japanese oyster (*Crassostrea gigas*) at Albany in 1947 failed (Thomson 1959; Huisman *et al.* 2008). Non-indigenous marine species may also arrive naturally via marine debris and ocean currents (Wells and Kilburn 1986).

NIMS are perhaps the most important long-term threat to coastal ecosystems and commercial fisheries (Hayes *et al.* 2005). This is because non-indigenous species can spread widely, there is often limited chance of their complete eradication, and the impacts posed by these species are difficult to predict. Non-indigenous marine species are even capable of stressing or even destroying commercial fisheries. There is no way to determine the actual economic impact that marine introduced species have, however, the amount of money lost from the destruction of fisheries, the removal of fouling organisms can be enormous (Carlton 2001).

Other damage caused by NIMS includes predation on native and farmed species, prolific colonisation, increased competition for space and food, altered nutrient cycles, and a loss of diversity in local species. In addition to environmental consequences, some non-indigenous marine species have the potential to harm human health (e.g. cholera, paralytic shellfish poisoning), and increase fuel consumption in transport (hull fouling organisms). Aquarium species can become marine pests if dumped and may act as vectors for diseases harmful to native species.

Once a species becomes established in the marine environment, it is almost impossible to eradicate. Non-indigenous marine pests in Australia and overseas have caused many millions of dollars of damage to local economies and can require the expenditure of many more millions of dollars annually in control and remediation efforts. There has only been one non-indigenous marine species that has been successfully eradicated to date in Australia, the black striped mussel that was found in Darwin Harbour in 1999 (Willan *et al.* 2000).

There have been a number of studies which suggested fishing activities could potentially transfer marine pests from one area to another. Kinloch *et al.* (2003) examined 23 categories of nontrading vessels in Australian waters and ranked commercial fishing vessels as the greatest risk for moving marine pests from one part of Australia to another after they had been originally introduced. There are a large number of fishing vessels (estimated at nearly 12,000), which undertake a broad range of activities. Some vessels may move considerable distances from one port to another. Often the vessels remain in port for extended periods, allowing the development of fouling communities on the hulls. Fishing often occurs in shallow waters where marine pests are concentrated, with the gear often left in the water for 24 hours or more in close contact with the sea floor. Wet fishing nets and boat wells are potential transmission vectors (Hutchings *et al.* 1987), as are the fishing gear and anchors (Hough and Dommissee 2004) and sea chests (Coutts et al. 2003; Meinesz 2003). Fishing vessels have been implicated in moving the Japanese giant kelp *Undaria pinnatifolia* to new sites in New Zealand (Sinner et al. 2000), and the marine alga *Caulerpa taxifolia* has been spread widely in the Mediterranean Sea by entanglement in fishing gear (Meinesz et al. 2001).

Summerson and Curran (2005) recently analysed the risks of Australian commercial fisheries transferring introduced marine pests from one part of the coastline to another. They conducted risk assessments of four likely scenarios:

- Organism entrained in port and translocated to fishing ground;
- Organism present in one fishing ground and translocated to another fishing ground;
- Organism present in fishing ground and translocated back to port or to another port; and
- Organism entrained in one port and translocated to another port.

Summerson and Curran (2005) analysed fishing activities of fifteen fisheries in detail and another 132 were briefly discussed. Included in the assessment were 47 fisheries managed by the Western Australian Department of Fisheries, with the Kimberley prawn fishery being examined in detail.

The Summerson and Curran (2005) examined the potential for fisheries to transfer organisms from one area to another. If pests were present, they could be among the species transferred. Following the paper by Summerson and Curran (2005), Huisman *et al*. (2008) developed detained information on the location of introduced marine species in Western Australia, including pest species. The present paper examines the risk of commercial fisheries managed by the Western Australian Department of Fisheries in moving species into the state, or to different areas within Western Australia.

Marine Biogeography of Western Australia

As the largest State in Australia, Western Australia has a long and relatively pristine coastline that stretches over 12,500 km. The coast ranges over 20 degrees of latitude from 14°S in the most northerly parts of the Kimberley to 35°S on the south coast. The shallow waters of the WA coast can be divided into three distinct biogeographical regions (Figure 1). The tropical north coast extends northeastward from North West Cape to the Northern Territory Border. The north coast is part of the vast tropical Indo-West Pacific biogeographic region that stretches from the east coast of Africa to Hawaii. In Australia, the Indo-West Pacific reaches as far south as the southern limit of the Great Barrier Reef, Queensland. There are no major distributional barriers on the north coast. While there are some individual species that have shorter ranges, most taxa which occur on the north coast extend to North West Cape if the necessary habitat is available. The south coast is part of the Southern Australian Warm Temperate Region that extends east from Cape Leeuwin to New South Wales. Like the north coast, there are no major distributional barriers on the south coast. Most species on the south coast reach Cape Leeuwin if the correct habitat is available. The west coast, between North West Cape and Cape Leeuwin, is a region of biogeographical overlap, where the tropical and temperate biotas overlap. Tropical species predominate in the north and temperate species in the south. In addition, about 10% of the shallow water marine biota of WA is endemic to the State. The ranges of individual endemic species vary considerably: some occur on the north coast, others on the south, and many are wide ranging, but most WA endemic species occur on the west coast for at least part of their range. The WA endemics may be economically and/or ecologically important (Wells 1980; Wilson and Allen 1987).

Figure 1. Map of Western Australia showing the three major biogeographic zones.

The importance of Western Australian coral reefs was highlighted by a recent study published in *Science* (Roberts *et al.* 2002). The authors analysed the worldwide distributions of 3225 species of corals, fish, molluscs and rock lobsters that live on coral reefs throughout the world. Eighteen hotspots of coral reef biodiversity were found, including one on the west coast of Western Australia. The WA hotspot includes Ningaloo Reef, the outer islands of Shark Bay, the Houtman Abrolhos Islands, and Pocillopora Reef at Rottnest Island. The international significance of the hotspot is indicated by the fact that it ranks seventh in total diversity of the groups studied (768 species) among the 18, second (56) in the number of restricted range species and only 15th in terms of threats from human activities.

The Western Australian marine environment is unusual because of the Leeuwin Current, which forms in the open ocean north and east of North West Cape. It flows down the west coast of WA bringing warm, relatively low salinity tropical waters along the edge of the continental shelf. The current is strongest and closest to shore during autumn and winter; during spring and summer it is weaker and farther from the coast. The Leeuwin Current has a major influence on the biogeography of the State's marine flora and fauna and is responsible for the occurrence of tropical biota at latitudes where these species would not otherwise be found (Morgan and Wells, 1991). At Cape Leeuwin the current changes direction to the east and flows into the Great Australian Bight, dissipating as it heads east. Traces have been recorded as far east as Tasmania, making it the longest unidirectional current in the world.

Fisheries included in this assessment

One common misconception about the management of fisheries in Western Australia is that the Department of Fisheries is responsible only for State waters, which are generally three nautical miles out to sea from the baseline. While this is important for many areas, under the Offshore Constitutional Settlement between the Commonwealth and Western Australian governments the State of Western Australia is, in general, responsible for management of fisheries in both State and Commonwealth waters out to the 200 m isobath. The Commonwealth is responsible for management of fisheries in waters deeper than 200 m out to the limit of the Australian Exclusive Economic Zone, which in most areas is the 200 nautical mile (361 km) limit. The major exceptions are tuna, which are managed by the Commonwealth Australian Fisheries Management Authority (AFMA), and the Northern Prawn Fishery that operates in Queensland, the Northern Territory and the Kimberley region of Western Australia.

AFMA manages several small deepwater trawl fisheries off Western Australia: North West Slope Trawl Fishery, Western Deepwater Trawl Fishery and the Southern and East Coast Scalefish and Shark Fishery (SECSSF). The first two are located entirely off Western Australia, but the Great Australian Bight Trawl Sector of the SECSSF includes all of the waters off the south coast of WA and SA. Throughout its range the fishery operates in waters deeper than 200 m, with State fisheries working in shallower waters. In the middle of the fishery, in the unpopulated areas of the Great Australian Bight, the fishery also trawls on the shelf.

The vast majority of fisheries in Western Australia are managed by the Western Australian Department of Fisheries (DoF). The present assessment is limited to fisheries managed by DoF; it does not include Commonwealth managed fisheries nor entry to the State by illegal foreign fishers.

The DoF manages fisheries in Western Australia by biogeographical regions: north coast, south coast, west coast and Gascoyne coast bioregions (Figure 1). The division of the west coast into two bioregions reflects the differences between the area from Shark Bay north and the regions south of Shark Bay. In fact, there is division between marine scientists as to the southern limit of the Tropical Australian Province. For example, Wells (1980) divides the tropical and west coast overlap zones at North West Cape, while Wilson and Allen (1987) recognise Shark Bay as the southern limit of the tropical biota. For the purposes of this report, the following biogeographical regions are recognised:

- tropical north coast, from North West Cape to the Northern Territory border;
- temperate south coast, from Cape Leeuwin east to the South Australian border;
- southern west coast overlap zone, from Cape Leeuwin to 27ºS; and
- northern west coast overlap zone (Gascoyne region), from 27ºS to North West Cape.

These regions are similar to the fishery management zones but are considered to be more biologically meaningful. The marine bioregional boundaries used here are broadly consistent with those of the *Interim Marine and Coastal Regionalisation for Australia* report (IMCRA Technical Group 1997), except for the inclusion of the Gascoyne coast as a separate region. This reflects the nature of the Gascoyne as a permanent transition zone between tropical and temperate waters. The broad IMCRA regions are subdivided into smaller units, reflecting habitat distinctions within these broad regions.

The *Fish Resources Management Act, 1994* provides the legislative framework to implement management arrangements for fisheries in Western Australia. The FRMA and the specific management plans for individual fisheries adhere to arrangements established under relevant Australian laws with reference to international agreements. The objects of the FRMA are to conserve, develop and share the fish resources of the State for the benefit of present and future generations. In particular, this act has the following objects:

- to conserve fish and to protect their environment;
- to ensure that the exploitation of fish resources is carried out in a sustainable manner;
- to enable the management of fishing, aquaculture and associated industries and aquatic eco-tourism;
- to foster the development of commercial and recreational fishing and aquaculture;
- to achieve the optimum economic, social and other benefits from the use of fish resources;
- to enable the allocation of fish resources between users of those resources;
- to provide for the control of foreign interests in fishing, aquaculture and associated industries;
- to enable the management of fish habitat protection areas and the Abrolhos Islands reserve.

The first goal of the FRMA is to “conserve fish and to protect their environment”. The FRMA sets out the objects for the sustainable management of fish resources in WA, and provides the framework for developing and implementing management plans for the State’s fisheries. Thus the introduction of NIMS species into the Western Australian marine environment would pose a major threat not only to commercial fisheries but also to our marine biodiversity and ecosystem health. Not only is the management of NIMS in Western Australia in accord with the FRMA, the Department of Fisheries is the lead agency in the State government for the issue.

The present assessment is of the risk of introducing non-indigenous marine species into

Western Australia by Western Australian managed fisheries, or the transfer of such species already in the State from one area to another.

Non-Indigenous Marine Species in Western Australia

As a first step in developing management information on marine pests in Western Australia, Huisman *et al.* (2008.) compiled a comprehensive listing of species that have been reported as introduced to the State. Results of this study are summarised below.

A total of 102 species are discussed in the paper:

- seven have been reliably reported but are not presently known to occur here (four are natural introductions (Macpherson, 1953; Wells and Kilburn 1986);
- 26 species are considered to be cryptogenic or native;
- records of nine species are questionable or have been excluded;
- 60 species have been introduced and are currently living in Western Australia.

The 60 NIMS established in Western Australia are classified in a wide range of plant and animal taxa. The groups with the most introduced species are bryozoans (15), crustaceans (13) and molluscs (9). All 60 species occur in marine areas associated with harbours. Twenty-six species occur in nearby open coasts, including estuaries such as the mouth of Peel Inlet. This strongly suggests species are being introduced to the State through major nodes of human activity, followed by some spread to nearby areas. However, it should be noted that surveys for introduced species have been concentrated in harbours and the records from adjacent open shores are incidental. A targeted survey would be required to determine how widespread introduced species have become outside harbours. The most diverse groups on open coasts are bryozoans (7 species) and barnacles (5 species). The bryozoans were all recorded in Shark Bay (Wyatt *et al*. 2005).

Most of the NIMS in Western Australia are temperate species (37 species) that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 introduced species occur in both the southern and northern halves of Western Australia. Because of the preponderance of temperate species, southern marine areas have more introduced marine species than northern areas. The greatest concentration is in the southwest corner of Western Australia: Fremantle (including Cockburn Sound and the lower Swan River) has 46 introduced species. It is the largest port by vessel movements. Albany (25), Bunbury (24) and Esperance (15) are all smaller ports with less habitat diversity and fewer numbers of introduced marine species.

Huisman *et al.* (2008) searched the NIMPIS (2002) database by state or territory. The following numbers of NIMS were found: Victoria (57); New South Wales (55); Tasmania (45); Western Australia (44); South Australia (43); Queensland (26); and the Northern Territory (9). While the data are out of date, they confirm that on a nationwide basis there are more introduced marine species on the temperate south coast than in the tropical northern waters. With about a third of Australia's coastline, Western Australia ranks fourth of the six states in the number of introduced marine species, just one species ahead of South Australia. Huisman *et al.* (2008) recognise 60 species as introduced and 26 as cryptogenic in the entire state of Western Australia. Hewitt *et al.* (2004) report 99 species as introduced to Port Phillip Bay, Victoria alone, and an additional 61 cryptogenic species in the bay.

As yet there are no published data regarding adverse impacts of introduced species in Western Australia (Hass and Jones 1999), but several have been shown to have significant impacts in other areas, by competition for food and/or space. For example, no threats to Western Australian native species, fisheries or seagrass beds were identified through the introduction of *Sabella spallanzanii*, the European fan worm (Clapin and Evans 1995), although studies in Victoria have suggested that this species has the potential to compete with native filter feeders and change the structure of the benthic food web (Walters 1996). Adverse impacts may not occur until decades after the initial introduction and establishment (Courtnay 1990) and it would, therefore, be extremely shortsighted to assume that Western Australia's relatively unaffected marine environment is somehow immune to infestation by pest species.

While the number of known NIMS in Western Australia is relatively low, it should be remembered that there have been recent incursions of the black striped mussel *Mytilopsis sallei* on illegal Indonesian fishing boats in Broome and Port Hedland and the Asian green mussel *Perna viridis* on large ships entering Dampier. Whatever the current situation, there is still a great need for continued vigilance.

The National Monitoring Program

During the 1990s and early 2000s, the CSIRO Centre for Research into Introduced Marine Pests (CRIMP) developed a method for conducting baseline surveys of Australian ports for introduced marine species. The goal was to establish a national database of as a first step in addressing the problem. The hypothesis was that to understand if a species is introduced, there must first be a thorough understanding of what species occur naturally in an area. Baseline surveys were conducted by CRIMP, or other agencies using CRIMP methodology, of all of the major Australian ports, with the exception of Dampier. However, in late 2007, the Department of Fisheries made a submission that the extensive work of the partnership between the Australian Museum and Woodside Energy Limited be considered to be the equivalent of a CRIMP-type survey. While initial reactions have been favourable, no final decision has as yet been made.

Extensive risk analyses and other studies were conducted which resulted in 18 major ports, including Dampier, Port Hedland and Fremantle in Western Australia, being included on the National Monitoring Network. Targeted monitoring will concentrate on these ports in the future. The system is now being brought into effect, and the ports will be examined as soon as possible. Following the initial survey, each of the three ports will be surveyed every two years.

Now that the baseline surveys have been completed, there is a much better understanding of NIMS in Australia. With the broad surveys completed, the NIMPCG focus has changed to determining the presence/absence of 55 target species (Table 1). These are species that are known to be invasive in Australia, are invasive elsewhere, or are considered to be potentially invasive. The National Monitoring Network will target these species, acknowledging that other species might be detected by the surveys.

In their analysis of marine species introduced into Western Australia, Huisman *et al.* (2008) found only three species on the NIMPCG (2006) list: the dinoflagellate *Alexandrium minutum*); the polychaete *Sabella spallanzanii*; and the bivalve *Musculista senhousia* (Table 2). The alga *Caulerpa taxifolia* occurs naturally in WA, but it is not the invasive genetic strain. In addition, the dinoflagellate *A. tamarense,* which is on the list, was considered to be cryptogenic or native to WA. Recently a single specimen of the marine alga *Codium fragile fragile* was found in

Princess Royal Harbour, near Albany, but a survey for the species in June 2008 failed to record any individuals. The area will be resurveyed in the coming summer. Overall only eleven of the 55 species occur in Australian waters (Table 3).

While the list will inevitably be modified over time, it is important to recognise that future monitoring for NIMS in Western Australia will concentrate on the NIMPCG list.

Table 1. Target species of introduced and potentially introduced marine species on the national monitoring program (NIMPCG 2006).

Group	Species	Group	Species
BALLAST WATER			
Dinoflagellates	*Alexandrium catenella*	Diatoms	*Chaetoceros convolutus*
	Alexandrium minutum		Chaetoceros concavicornis
	Alexandrium monilatum		Pseudo-nitzschia seriata
	Alexandrium tamarense	Ctenophorans	*Beroe ovata*
	Dinophysis norvegica		Mnemiopsis leidyi
	Gymnodinium catenatum	Copepods	*Acartia tonsa*
	Pfiesteria piscicida		Pseudodiaptomus marinus
			Tortanus dextrilobatus
HULL FOULING			
Algae	*Bonnemaisonia hamifera*	Cnidarians	Blackfordia virginica
	Caulerpa racemosa	Polychaetes	*Sabella spallanzanii*
	Caulerpa taxifolia		Hydroides dianthus
	Codium fragile spp.		*Marenzelleria* spp.
	Grateloupia turuturu	Barnacles	*Balanus eburneus*
	Sargassum muticum		Balanus improvisus
	Undaria pinnatifida	Crabs	*Callinectes sapidus*
	Womersleyella setacea		*Carcinus maenus*
Bivalves	*Corbula amurensis*		Charybdis japonica
	Ensis directus		*Eriocheir* spp.
	Limnoperna fortunei		Hemigrapsus sanguineus
	Mya arenaria		*Hemigrapsus takanoi*
	Varicorbula gibba		Rhithropanopeus harrisii
	Musculista senhousia	Ascidians	*Didemnum* spp.
	Mytilopsis sallei	Starfish	*Asterias amurensis*
	Perna perna	Fish	*Neogobius melanostomus*
	Perna viridis		Siganus luridus
	Crassostrea gigas		*Siganus rivulatus*
Gastropods	*Crepidula fornicata*		Tridentiger barbatus
	Rapana venosa		Tridentiger bifasciatus

Table 2. NIMPCG target species recorded in Western Australian marine areas.

Group	Species	Areas inhabited
Dinoflagellates	*Alexandrium minutum*	Bunbury, Fremantle
Bivalves	*Musculista senhousia*	Fremantle
Polychaetes	*Sabella spallanzanii*	Esperance, Albany, Bunbury, Fremantle
Macroalga	*Codium fragile fragile*	Albany

Table 3. NIMPCG target species recorded in Australian marine areas.

Group	Species	Areas inhabited
Marina algae	*Caulerpa taxifolia*	Queensland to South Australia
	Undaria pinnatifida	Tasmania
	Grateloupia turuturu	Tasmania
	Codium fragile fragile	New South Wales
Dinoflagellates	*Alexandrium minutum*	Western Australia
Starfish	*Asterias amurensis*	Tasmania, Victoria
Crab	*Carcinus maenas*	Tasmania, New South Wales to South Australia
	Crassostrea gigas	Tasmania, New South Wales to South Australia
	Musculista senhousia	Tasmania, South Australia, Western Australia
	Perna viridis	Cairns, Queensland
Polychaetes	*Sabella spallanzanii*	Tasmania, New South Wales to Western Australia

In addition to the NIMPCG (2006) species listed above, the websites of the responsible state agencies list the additional species considered to pests in those areas: the fish *Tridentiger trigonocephalus* in New South Wales and the bivalve *Corbula gibba* in Tasmania. The polychaete *Hydroides santaecrucis* has been recorded in the Cairns area of Queensland (Lewis *et al*. 2006), but is considered to be a nuisance, not a pest.

Assessment of Wa Managed Fisheries

The present assessment is of the possibility for NIMS being introduced into Western Australia or moved about within the State specifically as a result of fishing activities.

Movement of any vessel from an overseas or interstate port into Western Australia can introduce NIMS into the State, regardless of whether the vessel is a large ship, private yacht, dredge, fishing boat, or any other type of vessel. Issues associated with vessel movements between ports are covered by the national plans for vessel movements between ports and are not considered here.

There are three potential issues for Western Australian managed fisheries with regard to introduction of non-indigenous marine species:

- introduction of NIMS into Western Australia from overseas;
- introduction of NIMS into Western Australia from interstate; and
- transport of NIMS within Western Australia.

Each of these is discussed below.

Introduction of NIMS into Western Australia from overseas

None of the Western Australian managed fisheries operate in overseas locations. Because of this, there is no possibility of introducing NIMS into WA from overseas. If a vessel is brought into WA to undertake fishing activities, risks are evaluated as a shipping activity.

Introduction of NIMS into Western Australia from interstate

The vast majority of Western Australian managed fisheries operate within the State, and thus cannot bring NIMS into WA as part of their fishing operations. As with overseas vessels, the initial movement of a fishing boat into WA would be considered a risk under vessel movements, not as a result of fishing activities.

North coast

There are four exceptions to this statement on the north coast:

- trawl fisheries;
- pearling;
- trap fisheries; and
- a mackerel boat.

There are a number of trawl fisheries in Western Australia (Table 4). They can be divided into three separate components: prawn fisheries; scallop fisheries; and scalefish fisheries, as are shown on the table. Although the fisheries are managed separately, there is considerable overlap as most boats are licenced to operate in more than one fishery. For example, the prawn trawlers in Shark Bay are licenced to also catch scallops. Similarly, the South Coast Trawl Fishery targets scallops in the occasional good year. In other years the boats fish initially for scallops, but if they are not abundant the boats concentrate on scalefish. While there is a clear distinction of fisheries on Table 4, many boats have multiple licences. They fish during the open season in a fishery then move to a different part of the coast when the season opens in a second area. Many of the boats thus move up and down the coast from Fremantle to the Kimberley, or south to Esperance. Some of the trawlers are also licenced to work in the Commonwealth managed Northern Prawn Fishery, and thus venture into Northern Territory waters as far east as the Gulf of Carpentaria, including Darwin.

Table 4. WA managed trawl fisheries in Western Australia.

Prawns
Northern Prawn Fishery
Kimberley Prawn Managed Fishery
Broome Prawn Managed Fishery
Nickol Bay Prawn Managed Fishery
Onslow Prawn Managed Fishery
Shark Bay Prawn Managed Fishery
Exmouth Gulf Prawn Trawl Managed Fishery
South West Trawl Managed Fishery
Scallops
Shark Bay Scallop Managed Fishery
Abrolhos Islands and Mid West Trawl Managed Fishery
South Coast Trawl Fishery
Finfish
Pilbara Fish Trawl (Interim) Managed Fishery

Trawlers are particularly susceptible to transporting NIMS from one area to another as their fishing gear is in close contact with the bottom, considerable material is caught in the trawls, and may be retained in nets. In addition, the trawlers can be in an area for a prolonged period and are relatively slow moving.

The major pearling companies in the *Pinctada maxima* fishery operate vessels of about 30 m. These boats catch broodstock in areas such as off Eighty Mile Beach and in other areas such as off the Pilbara coast. The boats remain in an area for several weeks catching pearl shell, cleaning the shells, allowing the pearl oysters to rest before a pearl nucleus is inserted, then a further period of rest. The boats then transport the pearl oysters to farms in northern Western Australia and the Northern Territory (Enzer 1998). Some of the boats are based in Darwin.

Similarly some of the vessels operating in the northern trap fishery travel into the Northern Territory. One of the boats licensed in the mackerel fishery is based in Darwin, but fishes wide areas of the Western Australian coast, and moves as far south as Fremantle.

All of these fishing boats are capable of transporting NIMS from Darwin into northern Western Australian waters. However, there are currently no NIMS on the NIMPCG (2006) list recorded in Darwin (H. Cribb pers comm., Feb 2008). The black striped mussel, *Mytilopsis sallei*, was introduced into three marinas in Darwin in 1999. The introduction is thought to have been through a yacht arriving in the Northern Territory. Fortunately, the species was restricted to the marina, and it was successfully eradicated (Willan *et al.* 2000).

The Asian green mussel, *Perna viridis*, has been introduced into Cairns, where it has apparently established a breeding colony (Stafford *et al.* 2007).

South coast

In general, boats in Western Australian managed fisheries on the south coast do not travel across to South Australia. There are two South Australian registered vessels in the Western Australian southern rock lobster fishery coast that enter WA waters to fish. The vessels are based in Ceduna, far to the west of the known distribution of the pest species in southeastern Australia, which get as far west as the Adelaide region. (Table 3).

Evaluation

Any of these species can be transported into Western Australia by any vessel arriving from an infected area. Plans are in effect to combat an outbreak of any pest species arriving in any area of Western Australia. However, it is only from Darwin that WA managed fishing vessels can introduce NIMS on the NIMPCG (2006) list into WA. Should an outbreak of a NIMS occur in Darwin, the fishing vessels would be treated in the same manner as other vessels.

Transport of NIMS within Western Australia

Western Australian managed fisheries operate in all parts of the State, with many operating in more than one of the State's four biogeographic regions outlined above. Some existing NIMS occur from Albany on the south coast to Dampier on the north coast, thus occurring in all four of these regions (Huisman *et al.* 2008). As described above, the trawl fisheries operate in all parts of the State from the Kimberley to Esperance, and so could transport NIMS throughout the four biogeographic regions. Many of the fisheries straddle the 26ºS parallel dividing the northern and southern parts of the west coast overlap zone. This includes the large and important western rock lobster fishery. There is thus a potential for movement of NIMS from one part of the State to another by fishing vessels.

At present, there are three introduced species on the NIMPCG (2006) target list present in Western Australia:

- the toxic dinoflagellate *Alexandrium minutum*;
- the European fanworm *Sabella spallanzanii*; and
- the Asian date mussel *Musculista senhousia.*

All of these three species can be moved about within Western Australia by vessel movements, including fishing boats. All three species are currently distributed in harbours, and are not known in the open sea. Thus, the risk is from fishing boats transporting the species from one harbour to another, not from fishing in the open sea.

The toxic dinoflagellate *Alexandrium minutum* has been recorded in Bunbury and Fremantle (Huisman *et al.* 2008). This species has two life stages, an active mobile stage that lives in the water column and a resting, or cyst, stage that lives on the surface of bottom sediments. Both life stages can be transported by fishing boats. The planktonic stage can be moved in water held in holding tanks or pools of water on the boat. The benthic cyst stage can be moved in any sediment inadvertently carried from one harbour to another, such as from Bunbury or Fremantle to Geraldton, Albany or Esperance. It is unlikely that the species would survive in ports north of Geraldton because of the higher seawater temperatures.

The European fanworm *Sabella spallanzanii* has been found in Esperance, Albany, Bunbury and Fremantle (Huisman *et al.* 2008). This species is most likely to be transported as clumps of individuals trapped in nets, pots, etc, and could probably not survive north of Geraldton.

The Asian date mussel *Musculista senhousia* has been found only in the lower Swan River and Cockburn Sound (Huisman *et al.* 2008). A survey conducted in October 2007 was unable to locate live individuals of this species. While its population has declined substantially, it is possible that there are still individuals in the area that could replenish the population. The taxonomy of this species is confused, as is shown by the NIMPIS (2002) distribution maps. These show *M. senhousia* as being cryptogenic in Indonesia, and introduced in southern WA. There may in fact be two species. The temperate species, which occurs in Fremantle, could probably survive in all of the major marine areas south of Geraldton.

Thus, the three introduced species on the NIMPCG (2006) list that occur in southern WA could all be distributed into the harbours from Geraldton south. However, there are no known adverse environmental effects of the three pest species in Western Australia. There have been no reports of human or animal health issues in WA due to *Alexandrium minutum.* A recent survey suggests that while populations of *Musculista senhousia* in the Fremantle marine area have declined, those of *Sabella spallanzanii* have spread.

A single specimen of a fourth species, *Codium fragile fragile*, was found in Albany in June 2007 and recently identified. The status of this species in Albany is currently being investigated. If the presence of *C. fragile fragile* is confirmed in Albany, it is another species that could be translocated in southern Western Australia by vessels.

Preventing the Spread of Nims

The above assessment has demonstrated that NIMS will not be introduced into WA from overseas or interstate by fishing activities. There are only three species on the NIMPCG (2006) list that could be spread further in the harbours south of Geraldton. While this is encouraging, it must be remembered that an outbreak of a single species in a single Western Australian harbour could be rapidly spread to other harbours and cause considerable economic and environmental damage.

There are a variety of programs being developed nationally to reduce the risk of NIMS being introduced into Australia, including Western Australia, for both ballast water and hull fouling.

Ballast water

Large ships use ballast water to maintain their correct position in the water. If a ship is lightly loaded it will be higher in the water, and thus more subject to wave and wind action, and be less manoeuvrable. This increases operational costs and reduces safety. The answer developed has been to install tanks in the vessel into which seawater can be pumped. The ballast tanks can be filled to the level necessary to lower the ship to the desired waterline.

Unfortunately, when vessels take on water they also take on whatever is in the water, including suspended sediment and organisms. Larvae of many coastal species can survive in the water column within the ship. When the vessel arrives in a new port to load a cargo, some or all of the ballast water is discharged into the new port. Entrained species can be introduced into the new environment in this way.

At the same time, during the voyage suspended sediment can settle to the bottom of the ballast water tank. Over time the sediment accumulates, forming an additional habitat in which species can survive.

The Australian Quarantine Inspection Service (AQIS) has a program to counteract this problem. If a vessel arrives in Australia from overseas, a risk analysis must be undertaken before any ballast water can be discharged. The analysis considers factors such as species known to be in the port of origin, comparative habitats in the two ports, temperature and salinity regimes and other factors. It the risk analysis indicates there is a low probability of species being introduced, then the ballast water can be discharged on arrival. If there is a high risk of introducing species, then ballast water must be exchanged in the open ocean where there are few larvae of coastal species, and thus low risk of the fresh ballast water containing pest species. There are exemptions from the requirement to exchange ballast water at sea when it would endanger the vessel and its crew.

The system is not perfect, but it has substantially reduced the risk of introducing marine pests through ballast water. Worldwide there are active programs aimed at developing mechanisms such as heating the water or using chemicals to further reduce the number of species being introduced.

The AQIS system currently operates only for vessels with ballast water from overseas. A national program is currently being developed to develop similar methods for handling ballast water being shipped interstate or even within a state.

Hull fouling

Any small boat owner is familiar with the fact that if a boat is left in the water for even a short period of time numerous plant and animal species start to grow on the hull. The longer the boat is in the water, the greater the amount of material that adheres to it. If the vessel moves from one port to another, it can transport marine pests into a new area. This is true of all vessels, regardless of their size.

The growth slows the boat's movement through the water, increasing operational costs. Such costs can be reduced by regular cleaning of the vessel and the use of paint with an antifoulant added to reduce growths on the hull of the vessel. Unfortunately, to be effective the antifoulant must be very toxic. Until recently, the primary chemical added was tributyltin (TBT), which first came into widespread use in the late 1960s. Soon after TBT came into use, there were an increasing number of reports on adverse impacts on the marine environment. The use of TBT in vessels smaller than 25 m was banned in Western Australia in 1991 and limits were placed on the rate at which TBT could leach out of the paint of larger vessels. TBT is now banned worldwide and antifoulants are being developed using copper compounds.

National guidelines are currently being developed for minimising hull fouling on large ships. However, the issue is not simply with large vessels, and small boat owners moving boats from one area to another should ensure there is no adhering growth, particularly in nooks and crannies where they tend to accumulate. Similarly, ropes, anchors, craypots and other items that have been in the sea should be fully dried and checked to ensure there are no organisms.

If an outbreak occurs

If an outbreak of a marine pest species occurs within Western Australia, the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) will be alerted by the Department of Fisheries. DoF remains in control of handling the emergency, but CCIMPE will provide advice and other support that may be required for a successful response. CCIMPE has developed protocols and a management plan for handling the emergency. The plan is available at:

http://adl.brs.gov.au/mapserv/marinepest/html/emerg.php

The plan has four stages:

- Investigation;
- Alert;
- Operation; and
- Stand-Down.

If the emergency is serious enough, there is a common funding pool developed by the Commonwealth, State and Territory governments that can be used to fund the costs of combating the emergency.

Commercial Fishers Code of Conduct

The above assessment has been concerned with the movement of NIMS on the NIMPCG (2006) target list into Western Australia or movement of the few species already within the State into new areas. The assessment has placed the risks as low in view of the few species present in areas where WA fisheries operate that are on the NIMPCG (2006) list. However, it must be recognised that if NIMS are introduced into an area where WA fisheries operate, there is a high potential for commercial fishing activities to spread the NIMS. This might well occur before the Department of Fisheries becomes aware of the presence of the marine pest. Accordingly, the recommendations of Summerson and Curran (2005) should be followed by all WA commercial fisheries.

The recommendations are:

- Bycatch should be disposed of as close to the fishing site as possible and in as deep water as possible;
- Decks should be kept clean;
- Plant fragments and any motile organisms discovered in nets and other gear away from the fishing site and during cleaning in port should be retained on board and disposed of in landfill;
- Anchors and warps, if used, should be cleaned and inspected before being stowed. Any organic matter found should be retained on board and disposed of in landfill;
- Guidelines for the management of fishing vessel hull cleanliness should be developed in conjunction with maritime safety agencies;
- Further research needs to be carried out to obtain empirical evidence or the risks of entrainment and translocation; and
- Measures similar to those being developed for the commercial fishing industry should also be developed for the recreational, charter boat and indigenous fishing sectors.

NIMPCG is currently developing national protocols for use by commercial fisheries to minimise the risks of commercial fishing activities introducing marine pests into Australia or translocating them within Australian waters. When the protocols are available, they should be used by all Western Australian commercial fisheries.

Conclusions

The introduction of non-indigenous marine species (NIMS) into new marine areas has had serious consequences worldwide, including in eastern Australia. Western Australia has been fortunate to date that while 60 foreign species have been introduced into the State, only three are on the NIMPCG (2006) list of 55 species of concern: the toxic dinoflagellate *Alexandrium minutum,* the European fanworm *Sabella spallanzanii* and the mussel *Musculista senhousia.* The status of *Codium fragile fragile* in Albany is currently being investigated. Eight additional species on the NIMPCG (2006) list have been introduced into eastern Australia but are not present in Western Australia.

Fishing boats operating in Western Australian managed fisheries could potentially introduce NIMS from other areas when they move from interstate or overseas into WA. However, this is a shipping issue common to all vessels moving from one location to another, and should be considered in the context of overall vessel movement.

As no boats in WA managed fisheries fish overseas, there is no risk of introductions through overseas fishing activities. A few boats in northern WA fisheries travel to Darwin, but at present no species on the NIMPCG (2006) list are known to occur there. Two boats in the WA southern rock lobster fishery are based in Ceduna, South Australia, but again there are no known species on the NIMCGP (2006) list. There is some opportunity for boats to move the three species in WA about in the southern half of the State, but to date no adverse effects from these species have been recorded.

Overall, there is low risk at present of boats operating in WA managed fisheries introducing NIMS into the State, but the situation will be continually monitored.

It must be realised that the above assessment has been concerned with the movement of NIMS into Western Australia or movement of the few species already within the State into new areas. The assessment has placed the risks as low in view of the few species present in areas where WA fisheries operate that are on the NIMPCG (2006) list. However, it must be recognised that if NIMS are introduced into an area where WA fisheries operate, there is a high potential for commercial fishing activities to spread the NIMS. This might well occur before the Department of Fisheries becomes aware of the presence of the marine pest. Accordingly, the recommendations of Summerson and Curran (2005) should be followed by all WA commercial fisheries until national protocols for commercial fisheries are agreed. Once this is done the protocols should be used by all WA commercial fisheries.

Acknowledgements

The Department of Fisheries initiated a project *Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia* in October 2006. The present report is part of the project. It is funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State government. This component was funded through the W.A. Strategic Reserve Fund (project no. 053085). Richard Stoklosa of E-Systems Pty Ltd, and Dr Justin McDonald and Dr Stephanie Turner of WA Fisheries provided considerable input into the development of this discussion paper. The assistance of the technical panel and other participants in the risk assessment workshop is also very much appreciated.

Environmental, Social and Economic Risk Assessment

Threat of Introducing Marine Species from Commercial Fisheries Activities in Western Australia

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Executive Summary

The Western Australian Department of Fisheries (the Department) has undertaken a consultative project to identify and assess the risk of introducing marine pest species to State Ports and coastal waters under the Natural Heritage Trust Strategic Reserve Fund Project No. 053085 (NHT Project). As part of the public consultation process, stakeholders identified a potential threat of introducing or translocating non-indigenous marine species (NIMS) through the activities of commercial fishing vessels operating in State waters and visiting interstate ports and fishing grounds.

The threat of introducing or translocating NIMS exists through potential biofouling of vessel hulls and other wetted surfaces, biofouling of fishing gear, infection of target species, storage and handling of marine fishing bait which is transported outside its natural range, and fouling of water carried in ballast or holding tanks on vessels (recognising that most fishing vessels do not carry significant ballast or holding tanks, if any). Of particular interest are the more severe consequences of introducing a known invasive marine species, or ‘marine pest’.

In the event that a fishing vessel visits or operates in waters infected with marine pests, there is the potential for the vessel or its fishing gear to become infected with one or more pest species. When fishing vessels move between ports and fishing grounds, an infected vessel might spread the distribution of a pest species, causing undesirable impacts in the new environment if conditions are favourable for survival and establishment.

The Department engaged E-Systems Pty Limited to provide advice on an appropriate methodology to formally assess the risk of introducing NIMS (and in particular marine pests) as a result of commercial fishing activities in State waters, to assist with preparation for a consultative workshop, and to facilitate the risk assessment. Richard Stoklosa of E-Systems performed these tasks.

This document is the report of the 23 May 2008 Risk Assessment Workshop. The outcome of the qualitative risk assessment was a transparent classification of marine pest risks associated with commercial fishing activities in State waters, and identification of possible management strategies to reduce risk.

Eleven threats of introduction or translocation were identified and assessed, involving movements of fishing vessels between ports and fishing grounds within Australia (including vessels calling into interstate ports). No threats of introduction or translocation were identified from outside of Australian waters, as only Patagonian toothfish vessels in Western Australian managed fisheries reportedly operate overseas in deep water fishing grounds.

In general, it was recognised that most listed marine pests are temperate species, generally viewed to have a low likelihood of survival and establishment in tropical waters. The three

listed marine pest species which have been detected to date in Western Australian waters are temperate species. For fishing vessels visiting interstate waters, it was recognised that there are currently no listed marine pests which have been detected in the Port of Darwin (subject to two-yearly survey findings), which is visited by a small number of vessels associated with Western Australian managed fisheries. As such, the exposure of fishing vessels operating in tropical waters to tropical marine pests is hypothetical. There are some temperate species which exist in South Eastern Australian waters, but these are rarely visited by vessels associated with Western Australian managed fisheries.

Of the eleven threat scenarios that were identified, seven were ranked ‘medium’ or ‘high’. In all cases, infection presumed the existence of a marine pest in a Western Australian port or interstate fishing ground, which could have been introduced from any number of maritime activities. For purposes of the risk assessment, the presumption of vessel exposure to marine pests was made in tropical waters, although no known pests have been detected in surveyed tropical ports in Western Australia, or the one interstate tropical port (Darwin) visited by commercial fishing vessels operating from Western Australian managed fisheries.

Only the known temperate marine pests which have been detected in the southern Western Australian ports and coastal areas may be potentially translocated by fishing vessels at present. However, the translocation risk is not unique to the commercial fishing industry, as there are more frequent users of port facilities which are vectors for translocation, some of which are not subject to the same management controls to prevent translocation (e.g. recreational and tourism vessels). The risk of translocation by fishing vessels is therefore a small subset of the risk of translocation posed by all users of the marine environment.

Notwithstanding the un-assessed risk of introduction and translocation of marine pests by all users of the marine environment, the medium and high risks identified in this assessment were subject to consideration of planned commitments for risk management, and recommended control measures suggested by workshop participants. As a common theme for every medium and high risk, the *Biosecurity and Agriculture Management Act 2007* (BAM Act) and the planned national biofouling guidelines and regulations were cited as important and effective State and Commonwealth commitments for reducing the risk of introducing and translocating marine pests. Workshop participants also noted the development of a ‘communications package’ to develop awareness of biofouling risk and methods to avoid infection of vessels and fishing gear.

Control measures suggested for consideration by workshop participants reflected the robust biosecurity practices adopted by the pearling industry for its operations in Western Australia, the development of industry-specific codes of practice, and guidance for self-assessment of vessel risk.

Except for the difficulty of preventing the translocation of temperate species from one temperate port to another in the Southern region of Western Australia (by fishing vessels and other more frequent users of marine ports), all of the potentially high risks for fishing activities were reduced to medium risks with the planned and recommended risk control measures taken into consideration.

The workshop results are presented to the Department for consideration to inform its efforts to prevent the introduction and spread of NIMS, and in particular listed marine pests, in Western Australian waters. These findings and recommendations also respond to issues arising from stakeholder consultation for the NHT Project, and will be communicated to the wider stakeholder group.

Introduction

A need for a consultative, expert-based qualitative risk assessment was identified (Wells 2008) to evaluate the risk of introducing non-indigenous marine species (NIMS) into Western Australia by commercial fisheries and the risk of their spread by fisheries activities. Of particular interest is the threat of introducing or translocating recognised marine pests which could have environmental or socio-economic impacts in the marine environment.

The Western Australian Department of Fisheries (the Department) engaged E-Systems Pty Limited to develop a fit-for-purpose risk assessment procedure and to facilitate a workshop of stakeholders and technical experts to undertake the risk assessment. Results of the risk assessment are to be reported back to the wider stakeholder group for the Department's Natural Heritage Trust project: *Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia* (Strategic Reserve Fund project no. 053085) (NHT Project).

Western Australian surveys of NIMS have identified 60 species to date, mainly focusing on marine areas associated with harbours. Incidental surveys of open coastal areas have detected the presence of 26 of these species. Of the 60 NIMS which have been identified to date in Western Australia, three 'potentially invasive species' have been discovered from the 'national list' of 55 species known to be invasive in Australia or elsewhere (NIMCPG 2006). Overall, there are eight species on the national list which have been discovered in Australian waters.

Commercial fisheries managed by the Department have the potential to introduce NIMS to State waters, or translocate NIMS within State waters as a result of the following pathways suggested by Summerson and Curran (2005):

- NIMS infects a vessel or fishing gear in a port, and is translocated to a fishing ground;
- NIMS present in one fishing ground infects fishing gear or vessel, and is translocated to another fishing ground;
- NIMS present in a fishing ground infects fishing gear or vessel, and is translocated to a port; and
- NIMS present in one port infects vessel or fishing gear, and is translocated to another port.

Interested stakeholders were invited to participate in a risk assessment workshop, forming a Stakeholder Working Group, which included persons nominated for a Technical Panel to analyse the risk of introduce or translocate NIMS from commercial fisheries managed in State waters, and to consider risk reduction measures which may be proposed to manage risk.

A workshop procedure was developed in consultation with the Department (Stoklosa 2008), and distributed widely to stakeholders in April 2008 whilst canvassing the availability of independent experts for the risk assessment workshop. Five independent marine scientists formed a Technical Panel to assist with expert qualitative judgements for risk analysis.

The risk assessment workshop was undertaken on 23 May 2008, and resulted in detailed outcomes which were documented in the risk assessment workshop record prepared by the facilitator on behalf of all participants.

Consultation and Workshop Participants

E-Systems developed a risk assessment *Workshop Procedure* (Stoklosa 2008) in consultation with the Department, which was distributed to all stakeholders four weeks prior to the workshop date. The purpose of the *Workshop Procedure* was to inform all stakeholders of the proposed methodology and invite participation in the workshop.

The *Workshop Procedure* contains risk analysis criteria which allow independent experts (the 'Technical Panel') to making qualitative judgements of consequences. During the risk assessment workshop, additional criteria were proposed for economic consequences to fishing industry operators and service providers as a result of introducing NIMS, in the event that such judgements would be necessary. The criteria for consequences of introduced marine species included a range of environmental, social and economic receptors (Stoklosa 2008):

- Target species for fishery activities in fishing grounds;
- Non-target species in fishing grounds and ports;
- Threatened, endangered and protected (TEP) species;
- Benthic habitats;
- Ecological communities;
- Marine infrastructure;
- Public amenity;
- Food security of indigenous cultures; and
- Economic viability of fishing industry operators and service providers.

It was accepted that listed marine pests would be expected to have greater consequences than non-invasive NIMS if introduced to ecological receptors (target species, non-target species, TEP species, benthic habitats, ecological communities).

The likelihood of a consequence scenario eventuating was also estimated on a qualitative scale by independent experts in the risk analysis. The combinations of consequences and likelihood judgements were used to classify risk as 'high', 'medium', or 'low' (Stoklosa 2008).

Stakeholder Working Group

A Stakeholder Working Group was invited by the Department from the wider NHT Project to participate in the risk assessment workshop. Stakeholders included individuals, organisations, companies, government agencies and research scientists having an interest and/or technical expertise. Five stakeholders expressed an interest in attending, and were informed of preparations for the workshop.

The Stakeholder Working Group was provided with the *Workshop Procedure* and the Wells (2008) background paper. There was an opportunity for stakeholders to propose other published information to the Department for consideration by all participants prior to the workshop.

The number of 'observers' (non-participating management officers and non-technical officers) invited to the workshop was limited, to allow for efficient consideration of technical issues by participants, whilst ensuring that all stakeholder views were appropriately represented. However, special efforts were made to invite non-participating observers from special interest groups.

Stakeholders represented the Department of Fisheries, Ocean Watch Australia (nominated by the Western Australian Fishing Industry Council), Pearl Producers Australia and URS.

Technical Panel

A Technical Panel was convened for the risk assessment workshop with the support of a range of stakeholders, as a subset of the Stakeholder Working Group. The Technical Panel encompassed a range of scientific disciplines relevant to the fishery assessment and marine science.

Although there is no formula to obtain a 'perfect' mix of unbiased expert representation, the goal was to represent the range of stakeholder interests with persons who demonstrate recognised experience and qualifications in the subject matter, and have the capacity to provide high quality technical expertise for risk analysis. Stakeholders were given the opportunity to nominate appropriately qualified scientists for participation in the Technical Panel. Non-government organisations declined to nominate experts to the Technical Panel; however, the names of eminently qualified persons nominated to the Technical Panel were communicated to stakeholders for information in advance of the workshop.

The persons serving on the Technical Panel were:

- Dr. Lynda Bellchambers, Senior Research Scientist, Western Australian Department of Fisheries
- Dr. John Huisman, School of Biological Sciences and Biotechnology, Murdoch University
- Dr. John Keesing, Stream Leader, Western Australian Coasts, CSIRO Marine and Atmospheric Research
- Dr. Chris Simpson, Program Leader, Marine Science Program, Western Australian Department of Environment and Conservation
- Dr. Di Walker Professor, School of Plant Biology, University of Western Australia

The Technical Panel's role in the workshop was to participate in the identification of potential threats, to develop descriptive scenarios articulating the circumstances of introduction or translocation, to select the appropriate consequence table, and to assess the risk for these threats under existing fisheries management controls.

In many cases, the presence of a marine pest was presumed to enable experts to develop meaningful threat scenarios, even though no tropical pest species are currently known to be present in warm water regions visited by Western Australian managed fisheries. Otherwise, many of the potential threats in tropical regions would have been ranked 'low' for non-pest infection threats. Assessment was based on full consideration of the management actions formally adopted by specific fishing industry sectors or committed to by the government.

The Technical Panel also re-assessed the 'treated risk' level for new or alternative management actions that were suggested by the Stakeholder Working Group.

Workshop proceedings

The risk assessment workshop convened on 23 May 2008. A workshop agenda (Attachment 1) was distributed to all participants and adopted by the group. All persons attending the workshop were invited to introduce themselves and area of expertise or interest. A full list of participants and observers who were present on the workshop date is presented in Attachment 2.

The starting point for the workshop was the information contained in the Wells (2008) background paper, prepared from stakeholder consultation on the NHT Project. In general, it was recognised that most listed marine pests are temperate species, generally viewed to have a low likelihood of survival and establishment in tropical waters. The three listed marine pest species which have been detected to date in Western Australian waters are temperate species. For fishing vessels visiting interstate waters, it was recognised that there are currently no listed marine pests which have been detected in the Port of Darwin (subject to two-yearly survey findings), which is visited by a small number of vessels associated with Western Australian managed fisheries. As such, the exposure of fishing vessels operating in tropical waters to tropical marine pests is hypothetical. There are some temperate species which exist in South Eastern Australian waters, but these are rarely visited by vessels associated with Western Australian managed fisheries.

Industry was represented by Pearl Producers Australia and Ocean Watch Australia (nominated by the Western Australian Fishing Industry Council. For pearl producers, whose vessels and gear regularly transit from harvesting grounds to culture farms and ports, the industry procedures for preventing the spread of marine fouling organisms were explained for workshop participants. A schematic diagram of general fishing vessel movements through Western Australian waters, with indications of interstate movements, was also presented.

Discussion of the industry presentations by the Stakeholder Working Group assisted a shared understanding of fishing vessel activities. Several additional vessel movements not depicted on the schematic diagram were also identified for consideration in the workshop (e.g. scallop vessel movements between Fremantle and Albany, a few vessels visiting Dampier and Port Hedland, and the potential for fishing vessels to be chartered as offshore supply vessels during the closed portions of fishing seasons).

Following the Department and fishing industry discussions, threats of introduction or translocation of NIMS were identified and assessed. The ‘live’ recording of workshop proceedings in a structured risk assessment template was digitally projected, to enable all workshop participants to observe the information that was captured from the discussions. All participants had the opportunity to clarify the technical record during the workshop to ensure accuracy.

The identification and assessment of potential threats considered each of the pathways described above, (port to fishing ground, fishing ground to fishing ground, fishing ground to port, port to port). As a check on the progress of the workshop, a helpful diagram was constructed by a Technical Panellist to expand on these pathways, so that workshop participants could systematically consider permutations of translocations between ports and fishing grounds in the context of tropical and temperate waters. The diagram can be represented by the following logic tree, enabling workshop participants to consider one of two outcomes for each decision node:

Is the source port or fishing ground in WA waters or interstate waters?

- Is the source port or fishing ground infected with marine pest species or NIMS?
- Is the source port or fishing ground tropical or temperate?
- Is the destination in WA tropical or temperate?

- Is the destination in WA a port or a fishing ground?

Figure 1. Logic tree to systematically consider potential pathways of translocating NIMS.

A record of the threat identification and risk assessment is presented in Attachment 3 for reference.

Workshop findings and recommendations

Eleven threats of introduction or translocation were identified and assessed, involving movements of fishing vessels between ports and fishing grounds within Australia (including vessels calling into interstate ports). No threats of introduction or translocation were identified from outside of Australian waters, as only Patagonian toothfish vessels in Western Australian managed fisheries reportedly operate overseas in deep water fishing grounds.

Of the eleven threat scenarios that were identified, seven were ranked 'medium' or 'high'. In all cases, infection presumed the existence of a marine pest in a Western Australian port or interstate fishing ground, which could have been introduced from any number of maritime activities. For purposes of the risk assessment, the presumption of vessel exposure to marine pests was made in tropical waters, although no known pests have been detected in surveyed tropical ports in Western Australia, or the one interstate tropical port (Darwin) visited by commercial fishing vessels operating from Western Australian managed fisheries.

Only the known temperate marine pests which have been detected in the southern Western Australian ports and coastal areas may be potentially translocated by fishing vessels at present. However, the translocation risk is not unique to the commercial fishing industry, as there are more frequent users of port facilities which are vectors for translocation, some of which are not subject to the same management controls to prevent translocation (e.g. recreational and tourism vessels). The risk of translocation by fishing vessels is therefore a small subset of the risk of translocation posed by all users of the marine environment.

Notwithstanding the un-assessed risk of introduction and translocation of marine pests by all users of the marine environment, the medium and high risks identified in this assessment were subject to consideration of planned commitments for risk management, and recommended control measures suggested by workshop participants. As a common theme for every medium and high risk, the *Biosecurity and Agriculture Management Act 2007* (BAM Act) and the planned national biofouling guidelines and regulations were cited as important and effective State and Commonwealth commitments for reducing the risk of introducing and translocating marine pests. Workshop participants also noted the development of a 'communications package' to develop awareness of biofouling risk and methods to avoid infection of vessels and fishing gear.

Control measures suggested for consideration by workshop participants reflected the robust biosecurity practices adopted by the pearling industry for its operations in Western Australia, the development of industry-specific codes of practice, and guidance for self-assessment of vessel risk.

Except for the difficulty of preventing the translocation of temperate species from one temperate port to another in the Southern region of Western Australia (by fishing vessels and other more frequent users of marine ports), all of the potentially high risks for fishing activities were reduced to medium risks with the planned and recommended risk control measures taken into consideration.

The workshop results are presented to the Department for consideration to inform its efforts to prevent the introduction and spread of NIMS, and in particular listed marine pests, in Western Australian waters. These findings and recommendations also respond to issues arising from stakeholder consultation for the NHT Project, and will be communicated to the wider stakeholder group.

Agenda

Appendix 1

Date	Friday, 23rd May 2008
Location	Western Australian Fisheries and Marine Research Laboratories (08) 9203-0111 39 Northside Drive (north side of Hillarys Boat Harbour) Hillarys WA
Facilitator	Richard Stoklosa, E-Systems
Purpose	Risk Assessment Workshop—Threat of Introducing/Translocating Marine Species from Commercial Fishing Activities

09:00	Welcome and introductions	Richard Stoklosa
09:10	Opening remarks by the WA Department of Fisheries / NHT Project Leader	Fred Wells
09:20	Adoption of workshop agenda and procedure	Richard Stoklosa
09:40	Clarification of consequence/likelihood scoring criteria	Technical Panel and Stakeholders
10:00	Overview of commercial fishing activities in Western Australia	WAFIC/Pearl Industry
10:30	Morning tea	
10:45	Threat identification and risk analysis: NIMS infects a vessel or fishing gear in port, and is translocated and introduced to a fishing ground	Group discussion/ Technical Panel
12:30	Lunch	

3:15	Threat identification and risk analysis: NIMS present in one fishing ground infects fishing gear or vessel, and is translocated and introduced to another fishing ground	Group discussion/ Technical Panel
14:00	Threat identification and risk analysis: NIMS present in a fishing ground infects fishing gear or vessel, and is translocated and introduced to a port	Group discussion/ Technical Panel
15:00	Afternoon tea	
15:15	Threat identification and risk analysis: NIMS present in one port infects fishing gear or vessel, and is translocated and introduced to another port	Group discussion/ Technical Panel
16:45	Review risk assessment results and forward plan for communication to the Department of Fisheries and Stakeholders	Richard Stoklosa
17:00	Closing remarks by the Department of Fisheries	Fred Wells

Appendix 2

e-systems

Threat of Introducing/Translocating Marine Species—Commercial Fishing Activities Workshop Participants, 23 May 2008

Name	Organisation / company affiliation	Title / position / area of expertise	e-mail
Technical Panel			
Lynda Bellchambers	WA Dept of Fisheries	Senior Research Scientist	Lynda.Bellchambers@fish.wa.gov.au
John Huisman	Murdoch University	School of Biological Sciences and Biotechnology	J.Huisman@murdoch.edu.au
John Keesing	CSIRO Marine and Atmospheric Research	Stream Leader, WA Coasts	John.Keesing@csiro.au
Chris Simpson	WA Dept of Environment and Conservation	Program Leader, Marine Science Program	chris.simpson@dec.wa.gov.au
Di Walker	University of Western Australia	Professor, School of Plant Biology	diwalker@cyllene.uwa.edu.au
Stakeholders			
Carl Bevilacqua	Ocean Watch Australia (nominated by WAFIC)	WA SeaNet Extension Officer	carl@oceanwatch.org.au
Brett McCallum	Pearl Producers Australia	Executive Officer	Brett.McCallum@pearlproducersaustralia.com
John Polglaze	URS	Principal Environmental Scientist	John_Polglaze@URSCorp.com
Observers			

Justin McDonald	WA Dept of Fisheries	Research Scientist	Justin.McDonald@fish.wa.gov.au
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Facilitator			
Richard Stoklosa	E-Systems Pty Limited	Consultant, Ecological Risk Assessment	r.stoklosa@e-systems.com.au

Appendix 3

Risk Assessment of Commercial Fisheries Introducing or Translocating Non-indigenous Marine Species in Western Australia State Waters

Workshop Procedure

Revision 0 22 April 2008
Distributed to stakeholders for information.

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Introduction

A need for a consultative, expert-based qualitative risk assessment has been identified (Wells 2008) to evaluate the risk of introducing non-indigenous marine species (NIMS) into Western Australia by commercial fisheries and the risk of their spread by fisheries activities.

The Western Australian Department of Fisheries (the Department) engaged E-Systems Pty Limited to develop a fit-for-purpose risk assessment procedure and to facilitate a workshop of stakeholders and technical experts to undertake the risk assessment. Results of the risk assessment are to be reported back to the wider stakeholder group for the Department's Natural Heritage Trust project: *Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia* (Strategic Reserve Fund project no. 053085) (NHT Project).

Western Australian surveys of NIMS have identified 60 species to date, mainly focusing on marine areas associated with harbours. Incidental surveys of open coastal areas have detected the presence of 26 of these species. Of the 60 NIMS which have been identified to date in Western Australia, three 'potentially invasive species' have been discovered from the 'national list' of 55 species known to be invasive in Australia or elsewhere (NIMCPG 2006). Overall, there are eight species on the national list which have been discovered in Australian waters.

Commercial fisheries managed by the Department may introduce NIMS to State waters, or translocate NIMS within State waters as a result of the following pathways suggested by Summerson and Curran (2005):

- NIMS infects a vessel or fishing gear in a port, and is translocated to a fishing ground;
- NIMS present in one fishing ground infects fishing gear or vessel, and is translocated to another fishing ground;
- NIMS present in a fishing ground infects fishing gear or vessel, and is translocated to a port; and
- NIMS present in one port infects vessel or fishing gear, and is translocated to another port.

The Department proposes to invite interested stakeholders to participate in the risk assessment workshop, forming a Stakeholder Working Group, which will include persons nominated for a Technical Panel to analyse the risk of NIMS from commercial fisheries managed in State waters, and to consider risk reduction measures which may be necessary to reduce risk to acceptable levels.

This document describes the procedure for conducting a risk assessment workshop with persons having specialised expertise in the subject matter, facilitated by E-Systems.

Stakeholder Working Group

The Department has engaged a broad range of stakeholders for consultation on the NHT Project. Persons interested in participating in the NIMS risk assessment workshop will be invited by the Department to join a Stakeholder Working Group. Stakeholders may include individuals, organisations, companies, government agencies and research scientists with an interest and/or technical expertise.

The Stakeholder Working Group will receive background information from the Department prior to the workshop. There will be an opportunity for any member of the Stakeholder

Working Group to propose other published information to the Department for review by all participants prior to the workshop. Documents will need to be received by the Department in digital format, at least three weeks prior to the workshop date for distribution.

The total number of persons attending the workshop should be limited to allow for efficient consideration of technical issues, whilst ensuring that all stakeholder views are appropriately represented. It would also be appropriate to include non-participating observers from special interest groups and other stakeholder organisations (observers include persons with management roles and officers of organisations).

Technical Panel

A Technical Panel should be identified with the support of stakeholders, as part of the Stakeholder Working Group. The Technical Panel will encompass appropriate scientific disciplines, with a balanced representation of government, industry, non-government organisation and independent conservation specialists. Although there is no formula to use to obtain a 'perfect' mix of representation, the goal should be to represent the range of stakeholder interests with persons who demonstrate recognised experience and qualifications in the subject matter, and have the capacity to provide high quality technical expertise for risk analysis. Stakeholders should therefore nominate appropriately qualified scientists for participation in the Technical Panel, limiting the panel size to four to eight scientific experts.

The Technical Panel's role in the workshop is to perform the qualitative risk analysis in the presence of the Stakeholder Working Group, using the criteria for likelihood and consequences to categorise risk. Expert judgements will be based on full consideration of published information and the management actions formally adopted by the commercial fishing industry, management actions required by existing regulations, and management actions committed to by the government.

The Technical Panel should also re-assess the treated risk level for any management actions that might be suggested by the Stakeholder Working Group to reduce the likelihood or consequences of significant risks. Significant risks which cannot be mitigated by existing or proposed management actions are subject to further analysis.

Workshop procedure

There are limited examples of very rigorous risk assessment methodologies for NIMS (Hayes and Hewitt 2000, Hayes 2002a and 2002b, Stoklosa 2005), and more narrative approaches (Russell et al. 2003). Rigorous risk assessment methods could be adapted to the present task of risk assessment for NIMS as a result of commercial fishing activities in State waters; however, they require significant resources and time to implement. In the first instance it is desirable to undertake a qualitative screening-level risk assessment process for NIMS, to determine if there are any risks that appear to be significant before engaging in more rigorous, detailed analysis.

A qualitative, screening-level risk assessment will be undertaken using the guidelines of AS/NZS 4360 for risk management (Standards Australia 2004a) and AS/NZS HB 203 for environmental risk management (Standards Australia 2004b). The criteria to be used for qualitative risk analysis and risk classification are presented in subheadings below.

Risk (or threat) identification

The starting point for the subject workshop is the information contained in the background paper (Wells 2008) and any other relevant technical documents that will be provided to workshop participants at least four weeks prior to the workshop date. These documents identify threats to be considered in the NIMS risk assessment workshop.

Prior to commencing assessment of threats identified in the background paper, stakeholders present at the workshop should be given the opportunity to propose any other threats that should be considered.

Risk analysis

The risk analysis relies on expert judgment, in this case a Technical Panel, to make qualitative estimates of the consequences of an introduction or translocation of NIMS from commercial fishing activities in State waters, and the likelihood of those consequences eventuating.

The consequences of an introduction are not straightforward to predict, as a successful establishment of NIMS may require specific temperature, light and salinity tolerances/triggers; disturbance of the receiving environment to provide a niche; lack of natural predators or competition for habitat; and/or may be related to the frequency of repeated inoculations of the receiving environment.

To keep the consequences of an introduction simple for this screening analysis, we can use the invasiveness of NIMS as a proxy for the severity of potential consequences, recognising that some species may be non-indigenous but non-invasive, whilst other non-indigenous species are known to be invasive elsewhere (the NIMPCG national list of 55 species) and are therefore more of a potential threat. Threats identified in the risk assessment should distinguish between non-invasive species and known invasive species whenever possible.

The Technical Panel is to make informed judgements of the potential consequences and likelihood of hazards associated with the introduction or translocation of NIMS, with respect to adopted assessment criteria. It is the role of the facilitator to guide the process and maintain the integrity of the approach. The main focus of the workshop is to assess credible threats to ecological and socio-economic components — based on available expert knowledge, technical documentation and any data that may exist.

The ecological and socio-economic components which may be considered for the consequences of an introduction of NIMS are:

- Ecological components
    - Commercial fishery target species (different for each fishery);
    - Indigenous marine (non-target) species;
    - Threatened, endangered or protected (TEP) marine species;
    - Benthic habitats; and
    - Ecological communities.
- Socio-economic components
    - Marine infrastructure;
    - Public amenity; and
    - Food security (implications for indigenous cultures relying on traditional marine sources of food).

The criteria for qualitative judgments of consequences are presented for these components in Tables 1-8. The criteria used to assign a consequence category distinguishes between NIMS which are not listed as invasive with NIMS which are known to be invasive and included in the national list (NIMPCG 2006). Each threat identified for risk assessment will be subject to at least one of the consequence tables. Not all tables will be necessarily used, but are presented to allow the Technical Panel to focus on criteria for specific ecological and socio-economic components threatened by introductions or translocations of NIMS.

Further clarification of consequence categories may be necessary with the advice of the Technical Panel, and the definitions contained in Tables 1–8 should be discussed with stakeholders attending the workshop, prior to commencing the risk analysis to ensure a common understanding and usage of terms.

Table 1. Consequence categories for commercial fishery target species.

Category	Rating	Description of consequences to target species
Minor	1	Threshold of detectable change against background variability for this population, but minimal or acceptable impact on population size and none on dynamics.
Moderate	2	Long-term recruitment/dynamics not adversely impacted by introduction of NIMS.
Major	3	Invasive NIMS affect recruitment levels of stocks, or their capacity to increase.
Extreme	4	Invasive NIMS cause imminent collapse of the fishery.

Table 2. Consequence categories for indigenous (non-target) marine species.

Category	Rating	Description of consequences to indigenous (non-target) species
Minor	1	Relative area of, or susceptibility to displacement/predation by NIMS is suspected to be less than 10 percent.
Moderate	2	Relative area of, or susceptibility to displacement/predation by NIMS is suspected to be less than 50 percent.
Major	3	Relative area of, or susceptibility to displacement/predation by invasive NIMS are suspected or known to be greater than 50 percent.
Extreme	4	Invasive NIMS cause widespread extinctions of indigenous species.

Table 3. Consequence categories for TEP species.

Category	Rating	Description of consequences to TEP species
Minor	1	Some are impacted by displacement/predation of NIMS, but there is no impact on stock.
Moderate	2	Levels of impact are at the maximum acceptable level to maintain stock.
Major	3	Invasive NIMS affect local recruitment levels of TEP populations, or their capacity to increase.
Extreme	4	Invasive NIMS cause local extinctions of TEP species.

Table 4. Consequence categories for benthic habitats.

Category	Rating	Description of consequences to benthic habitats
Minor	1	NIMS cause measurable impacts on habitats, but these are very localised compared to total habitat area. *(For example, impacts affecting <5% of the original habitat area)*
Moderate	2	NIMS cause more widespread impacts on the habitat, but the levels are still acceptable given the area affected, the types of impact occurring, and the recovery capacity of the habitat if the NIMS was eradicated or if indigenous species adapted to compete with NIMS. *(For example, impact on non-fragile habitats may be up to 50%—but for more fragile habitats, the percentage area affected may need to be <20%, and for critical habitats <5%)*
Major	3	Invasive NIMS cause impacts to habitats which will not be able to recover adequately, or it will result in substantial loss of function. *(For example, the activity makes a significant impact in the area affected, and >25-50% of habitat is being affected—for critical habitats <10%)*
Extreme	4	Invasive NIMS cause loss of entire habitats. *(For example, >90% of the habitat area being affected—for fragile habitats >50%, and for critical habitats >30%)*

Table 5. Consequence categories for ecological communities.

Category	Rating	Description of consequences to ecological communities
Minor	1	Ecosystem consequences: NIMS impact species which do not play a keystone role. Only minor changes in the relative abundance of other constituents.
Moderate	2	Ecosystem consequences: NIMS cause measurable changes to the ecosystem components without there being a major change in function (eg no loss of components).
Major	3	Ecosystem consequences: Ecosystem function altered measurably by invasive NIMS, and some function or components are locally missing/ declining/increasing outside of historical range, and/or have allowed/ facilitated the appearance of new species. If eradication of invasive NIMS is possible, recovery measured in years to decades.
Extreme	4	Ecosystem consequences: Invasive NIMS cause total collapse of ecosystem processes. If eradication of invasive NIMS is possible, recovery period may be greater than decades.

Table 6. Consequence categories for marine infrastructure.

Category	Rating	Description of consequences to marine infrastructure
Minor	1	Threshold of detectable change in performance or maintenance costs of marine infrastructure.
Moderate	2	Measurable loss of performance and increase in maintenance costs of marine infrastructure.
Major	3	Significant impact to marine infrastructure, requiring capital works to replace infrastructure before its planned design life. Recovery cost on the order of $1 million plus.
Extreme	4	Rapid and irreversible damage to marine infrastructure, resulting in log-term loss of industrial productivity or municipal services. Recovery cost on the order of $10 million plus.

Table 7. Consequence categories for public amenity.

Category	Rating	Description of consequences to public amenity
Minor	1	Threshold of impacts to public amenity associated with the marine environment (eg coastal recreation, odours, public safety hazards).
Moderate	2	Some direct impacts to public amenity which do not threaten local community use of the marine environment. Some adaptation for social use of the marine environment may be necessary.
Major	3	Significant impact to public amenity at a local level, resulting in localised loss of community use of the marine environment, or decreased property value in an isolated area.
Extreme	4	Widespread impacts to public amenity, resulting in a regional loss of community use of the marine environment, or decreased property value in multiple coastal communities.

Table 8. Consequence categories for food security of indigenous cultures.

Category	Rating	Description of consequences to food security of indigenous cultures
Minor	1	Threshold of impacts to food security (eg no tainting of food supply, background non-toxic levels of marine organisms).
Moderate	2	Some direct impacts to food security (eg tainting of food supply, localised but not continuous toxic levels of marine organisms).
Major	3	Significant loss of local food resources, or potential for community human health problems.
Extreme	4	Widespread loss of food resources within a region, leading to dietary/nutritional problems or requiring economic aid.

For each threat, the likelihood of the threat occurring and having the predicted consequences is qualitatively estimated by the Technical Panel using Table 9, with judgments supported by any data that may be available.

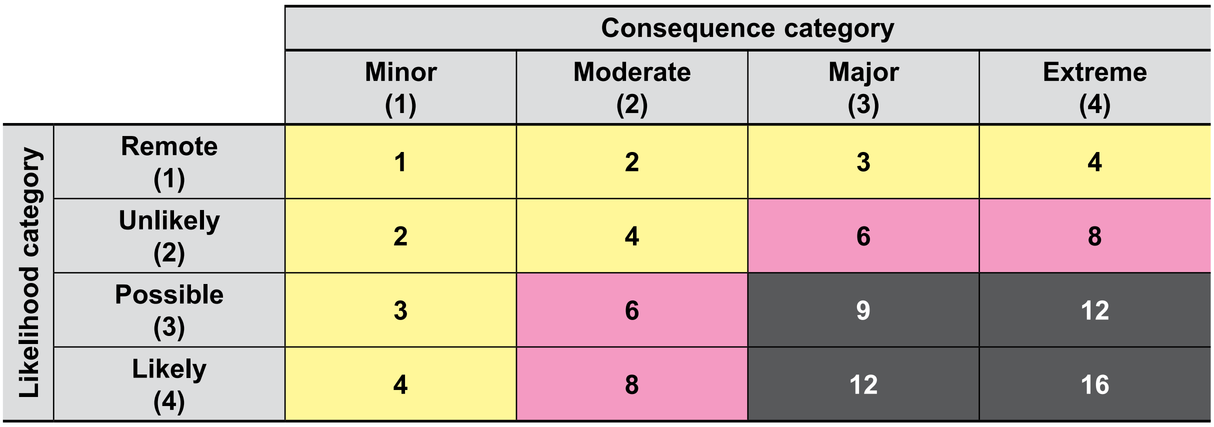
Table 9. Likelihood categories for risk analysis.

Category	Rating	Description
Remote	1	Never heard of, but not impossible.
Unlikely	2	Uncommon, but has been known to occur elsewhere.
Possible	3	Some evidence to suggest this is possible and will occur occasionally.
Likely	4	Expected to occur.

Risk classification

Using the Technical Panel judgments of consequence and likelihood categories, the risk is ranked as the product of the two ratings, as illustrated in the risk matrix in Figure 1. This is not to imply that the judgements of consequences and likelihood have a quantitative meaning; rather, it is a shorthand method of noting the relative contributions of consequences and likelihood to risk. The risk matrix is used to rank risk in one of three levels, consistent with the ESD Reporting Framework used by the Department (Fletcher, R, personal communication).

An explanation of the required management response and reporting requirements is summarized in Table 10.



		Consequence category			
		Minor (1)	Moderate (2)	Major (3)	Extreme (4)
Likelihood category	Remote (1)	1	2	3	4
	Unlikely (2)	2	4	6	8
	Possible (3)	3	6	9	12
	Likely (4)	4	8	12	16

Figure 1. Risk classification matrix.

Table 10. Risk rankings and expected action.

Risk ranking	Qualitative risk score	Management response	Reporting requirements
Low	1–4	No specific response required.	Full justification needed.
Medium	6–8	Specific management and monitoring needed.	Full performance report.
High	>8	Additional management activities needed.	Full performance report.

Risk treatment

For any activities which result in higher levels of risk, workshop participants are asked to suggest risk treatment measures which might reduce the consequences and/or likelihood scores. These risk treatment measures are recorded as important advice to the Department for consideration, but may not necessarily be adopted by the fishing industry or government to manage risk of NIMS.

For each risk treatment measure, the risk analysis is repeated for the 'treated risk' by the Technical Panel, as a reflection of the residual level of risk if the risk treatment measures were in fact adopted. The treated risk is documented as part of the workshop record.

Risk management

The results of the risk assessment will be documented to inform the NHT Project of the potential risks of introducing or translocating NIMS to Western Australian State waters from commercial fishing activities. In the event that any medium or high risks are identified, the management responses specified in Table 10 should be undertaken to control risk, and further analysis of risk beyond this screening-level risk assessment may be considered.

Expected outcomes

The desired outcomes of the NIMS risk assessment workshop are:

- Identification of all relevant technical documents and data underpinning the risk analysis of threats of introducing or translocating NIMS to State waters as a result of commercial fishing activities. The status of the technical information should be documented as peer reviewed, otherwise published, or unpublished work or data.

- Identification of threats, risk analysis, classification of risk and suggested risk treatment options to manage threats of introducing or translocating NIMS for consideration.
- Full documentation of the proceedings of the workshop for stakeholder communication and input to the NHT Project.

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Is there a need for monitoring of environmentally sensitive areas in Western Australia for non-indigenous marine species?

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Executive Summary

Western Australia has an extensive, variable coastline that extends from the tropical regions of the Kimberley to the temperate areas of the south coast. Three quarters of the State's 2.1 million people live in the Perth metropolitan area and most of the remainder live in the southwest. Outside the major towns and ports in other parts of the State, the marine environment is relatively pristine. Introduced marine pests are considered to be one of the critical threats to this pristine marine environment.

A recent analysis recorded 60 introduced marine species for which distributional data are available. Most (37 species) are temperate; 6 are tropical; and 17 occur in both areas. All 60 species are found in marine areas associated with harbours where there are commercial trading ports; 26 species occur on nearby open coasts. This strongly suggests species are being introduced to the State through major nodes of human activity, followed by the spread of some species to nearby areas. However, it is acknowledged that surveys for introduced species have been concentrated in harbours and records from adjacent open shores are incidental.

A National Monitoring Network at 18 ports around Australia is being established that targets 55 species known to be invasive in Australia or elsewhere, or are potentially invasive. In their analysis of marine species introduced into Western Australia, Huisman *et al*. (2008) found only four species on the national list: the dinoflagellates, *Alexandrium tamarense* and *A. minutum* (considered to be cryptogenic or native), the polychaete *Sabella spallanzanii,* and the bivalve *Musculista senhousia.* The alga *Caulerpa taxifolia* occurs in WA, but it is not the invasive genetic strain. Several specimens of the invasive marine alga *Codium fragile* subsp. *fragile* were recently found in Albany. The status of this species is currently being checked. Overall only eleven of the 55 species occur in Australian waters. The National System acknowledges that there may be invasive species not on the list, and incorporates this consideration into the monitoring program.

Eighteen locations nationwide are included in the National Monitoring Network, including three WA commercial trading ports: Dampier, Port Hedland and Fremantle. The present document considers whether environmentally sensitive areas in WA should be monitored for introduced marine species, and if so, where such monitoring should occur.

Over the last 20 years, the WA Department of Environment and Conservation has been developing a Statewide representative system of marine parks and reserves. These are considered here, along with the Houtman Abrolhos Islands Fish Habitat Protection Area (FHPA), as a proxy for the State's 'environmentally sensitive marine areas'. A separate analysis is planned to consider high value aquaculture areas.

It is concluded that there is low threat of non-indigenous marine species (NIMS) being introduced directly into an environmentally sensitive area from overseas. Vessels entering Australian waters must report to an Australian 'first port of call' for customs and quarantine clearance. Such introductions are most likely to occur in a major harbour where a variety of possible introduction mechanisms occur, or alternative NIMS can be introduced indirectly as a translocation from an eastern Australian locality.

There are four possible conclusions for the question of whether additional monitoring of marine parks and FHPAs for introduced marine species is required in additional to the National Monitoring Network:

- Monitoring requirements in marine parks and FHPAs will be adequately covered by the developing National Monitoring Network that will monitor primarily for the presence of 55 species on the NIMPCG target list;
- Monitoring using the methods and species list of the developing National Monitoring Network should be undertaken in one or more of the marine parks and FHPAs;
- An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using the NIMPCG target list;
- An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using an alternative list of target species.

Consultation with independent scientific experts identified a need for monitoring of marine parks and FHPAs in Western Australian waters. Further consultation with a panel of experts that examined the issue resulted in a collective **recommendation that a future project should initially select at least one tropical and one temperate environmentally sensitive area for monitoring, using the methods and species list of the developing National Monitoring Network**. Such a project should be designed to validate its scientific value, and inform the approach for continuing and/or expanding the program to other areas.

Introduction

As the largest State in Australia, Western Australia has a long and relatively pristine coastline that stretches over 12,500 km. The coast ranges over 20 degrees of latitude from 14°S in the most northerly parts of the Kimberley to 35° S on the south coast. There are a wide variety of coastal marine habitats in this vast area. The south coast has extensive white sandy beaches interspersed with granite headlands. Diverse species of temperate marine algae occur on the south coast. With 26 species, the seagrasses of the State are the most extensive in the world, covering an estimated 20,000 km^2. There is a rich diversity of fauna, both invertebrates and fish, associated with these plant communities. A number of species of whales, dolphins and sea lions occur on the south coast.

The extensive north coast also has a wide variety of habitats. Foremost of these is Ningaloo Reef, the largest fringing reef in the world. It stretches from the tip of North West Cape 300 km south to Red Bluff. In recent years, Ningaloo has become famous as one of the best places in the world to see whale sharks during their seasonal migration northward in April—May. In addition, there is a fantastic variety of reef life, including large fish, which are very accessible as the reef is close to shore. There are smaller coral reefs in the coastal areas of the Pilbara and Kimberley. On the edge of the continental shelf, open ocean atolls are found at Rowley Shoals, Scott Reef, Seringapatam Reef and Ashmore Reef. In open oceanic waters, these reefs have a very different biota from that which occurs in the more turbid waters of the inshore continental coastline (Berry 1986; 1993; Wells 1986). The Pilbara has extensive mangroves, with eight species of mangrove plants and many associated animals. Further north there are much larger mangrove forests, with a total of 16 species (Semeniuk *et al.* 1978).

The west coast also has a wide range of marine habitats. Shark Bay is on the World Heritage List as one of the most important marine sites in the world. The 12,000 km^2 of the bay has the largest population of dugongs in the world. The arid coastline has an unusual hypersaline setting where the heads of the bays reach salinities of up to 70‰, approximately double that of normal seawater. The bay has extensive seagrass meadows, mangroves along the eastern shore, a wide variety of fish, and the dolphins that come to the shore at Monkey Mia are world famous. Further south, the 122 islands of the Houtman Abrolhos are one of the key marine areas of Western Australia. Closer to Perth, Rottnest Island is a favourite among West Australians. The beaches and fishing at Rottnest are a major attraction. Further south the Capes to Capes region is a national park with a beautiful open coastline and extensive rocky shores.

This coastline is relatively pristine. The human population of the 2.5 million square kilometres of Western Australia is only 2.1 million people, three quarters of whom live in the Perth metropolitan area. Perth and the southwest have high human population density, but away from these areas there are vast parts of the coast where there are few people. The Western Australian marine environment is highly valued. There is a high level of boat ownership. About a third of the population goes fishing at least once a year, and water sports are favourite past times. The tourism industry depends heavily on the marine environment as attractants for intrastate, interstate and overseas visitors.

The importance of Western Australian coral reefs was highlighted by a study published in *Science* (Roberts *et al.* 2002). The authors analysed the worldwide distributions of 3225 species of corals, fish, molluscs and rock lobsters that live on coral reefs throughout the world. Eighteen hotspots of coral reef biodiversity were found, including one on the west coast of Western Australia. The WA hotspot includes Ningaloo Reef, the outer islands of Shark Bay, the Houtman Abrolhos Islands, and Pocillopora Reef at Rottnest Island. The international significance of the hotspot is indicated by the fact that it ranks seventh in total diversity of the groups studied (768 species) among the 18, second in the number (56) of restricted range species and only 15th in terms of threats from human activities.

The Western Australian marine environment is even more unusual because of the Leeuwin Current, which forms in the open ocean north and east of North West Cape. It flows down the west coast of WA bringing warm, relatively low salinity tropical waters along the edge of the continental shelf. The current is strongest and closest to shore during autumn and winter; during spring and summer it is weaker and farther offshore (Cresswell 1991). The Leeuwin Current has a major influence on the biogeography of the State's marine flora and fauna and is responsible for the occurrence of tropical biota at latitudes where these species would not otherwise be found (Morgan and Wells 1991). At Cape Leeuwin the current changes direction to the east and flows into the Great Australian Bight, dissipating as it heads east. Traces of the current have been recorded as far eastward as Tasmania, making it the longest unidirectional current in the world.

It is critical that we maintain the Western Australian marine habitat in its present excellent condition for the present and future generations. The introduction of non-indigenous marine species (NIMS) into new marine areas is second only to habitat change and loss in reducing global marine biodiversity (Millennium Ecosystem Assessment 2005). This is a worldwide issue, not one unique to Western Australia. Many introduced species cause no apparent harm, but some become serious pests. Among other problems, these pests can cause diseases in humans and native species, disrupt ecosystems, and/or cause industrial problems such as fouling, with significant economic implications.

In October 2006, the Western Australian Department of Fisheries initiated a project on introduced marine pests in Western Australia. One of the major components of the project is to determine whether there should be monitoring of high value areas in WA for marine pest species. The present publication provides background information for analysis of this question. For the purposes of this report, "high value areas" have been defined as environmentally important areas, such as declared marine parks and reserves. Aquaculture sites and potential aquaculture sites are another type of high value area. A separate proposal is currently being developed for submission to the Fisheries Research and Development Corporation (FRDC) to examine the impact of introduced marine pests in these areas.

The examination of environmentally sensitive areas is the third risk assessment to be undertaken as part of the Natural Heritage Trust project on marine pests in Western Australia. McDonald (2008) recently updated information on the risks of shipping in 15 Western Australian commercial trading ports introducing marine pests into the State. The report demonstrated that Dampier, Fremantle and Port Hedland are the highest risk commercial trading ports, confirming the results of NIMPCG (2006). These three commercial trading ports will be part of the developing National Monitoring Network that will underpin the National System. Wells (2008) examined the risks of commercial fisheries managed by the WA Department of Fisheries introducing or translocating marine pests into WA. As commercial fisheries (except for the Patagonian tooth fish fishery) are limited to Australian waters, there is little chance of species being introduced from overseas. Most WA managed fisheries are confined to Western Australia, though some vessels enter Northern Territory or South Australian waters. As there are few marine pests in these areas, there is little chance for introduction into WA. Similarly, there are few pests in WA and little chance for translocation within the State. However, fishing vessels are high risk because of factors such as their close contact with the bottom, extensive time in port, wet nets, and holding areas. If pests were introduced into areas where the fisheries operate, fisheries vessels could transfer the pests rapidly from one area to another. This might happen before the pest was actually detected. Because of this, commercial fishers must maintain a high level of vigilance and adopt procedures to minimise the risk of moving introduced marine pests from one part of the coast to another.

Non-Indigenous Marine Species in Western Australia

As a first step in developing management information on marine pests in Western Australia, Huisman *et al.* (2008) compiled a comprehensive listing of species that have been reported as introduced to the State. Results of this study are summarised below.

A total of 102 species are discussed in the paper:

seven have been reliably reported but are not presently known to occur here (four are natural introductions (Macpherson, 1953; Wells and Kilburn 1986);

26 species are considered to be cryptogenic or native;

records of nine species are questionable or have been excluded; and

60 species have been introduced and are currently living in Western Australia.

The 60 species regarded as having have been introduced and presently living in Western Australia are classified in a wide range of plant and animal taxa. The groups with the most introduced species are bryozoans (15), crustaceans (13) and molluscs (9). All of the 60 species occur in marine areas associated with harbours. Twenty-six species occur in nearby open coasts, including estuaries such as the mouth of Peel Inlet. This strongly suggests species are being introduced to the State through major nodes of human activity, followed by some spread to nearby areas. However, it should be noted that surveys for introduced species have been concentrated in harbours and the records from adjacent open shores are incidental. A targeted survey would be required to determine how widespread introduced species have become outside harbours. The most diverse groups on open coasts are bryozoans (7 species) and barnacles (5 species). The bryozoans were all recorded in Shark Bay (Wyatt *et al*. 2005).

Most of the NIMS in Western Australia are temperate species (37 species) that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 introduced species occur in both the southern and northern halves of Western Australia. Because of the preponderance of temperate species, southern marine areas have more introduced marine species than northern areas. The greatest concentration is in the southwest corner of Western Australia: Fremantle (including Cockburn Sound and the lower Swan River) has 46 introduced species. It is the largest port by vessel movements. Albany (25), Bunbury (24) and Esperance (15) are all smaller ports with less habitat diversity and fewer numbers of introduced marine species.

Huisman *et al.* (2008) searched the Hewitt *et al.* (2002) database by state or territory. The following numbers of introduced species were found: Victoria (57); New South Wales (55); Tasmania (45); Western Australia (44); South Australia (43); Queensland (26); and the Northern Territory (9). While the data are out of date, they confirm that on a nationwide basis there are more introduced marine species on the temperate south coast of the continent than in the tropical northern waters. With about a third of Australia's coastline, Western Australia ranks fourth of the six states in the number of introduced marine species, just one species ahead of South Australia. Huisman *et al.* (2008) recognise 60 species as introduced and 26 as cryptogenic in the entire state of Western Australia. Hewitt *et al.* (2004) report 99 species as introduced to Port Phillip Bay, Victoria alone, and an additional 61 cryptogenic species in the bay.

The National Network Monitoring Program

During the 1990s and early 2000s, the CSIRO Centre for Research into Introduced Marine Pests (CRIMP) developed methods for conducting baseline surveys of Australian ports for introduced marine species. The goal was to establish a national database of the distribution of NIMS a first step in addressing the problem. The basis was that to understand if a species is introduced, there must first be a thorough understanding of what species occur naturally in an area. Baseline surveys were conducted by CRIMP, or other agencies using CRIMP methodology, of all of the major Australian commercial trading ports, with the exception of Dampier. Although Dampier was not surveyed, there has been considerable biodiversity work undertaken in the Dampier region by the Western Australian Museum. The resulting publications (Wells *et al.* 2003; Jones 2004) make this the best-known area of Western Australia in terms of marine biodiversity.

NIMPCG (2006) undertook an analysis of all of the major commercial trading ports in Australia, including the number of ships entering a port, size of the vessels, types of vessels and similarity of the marine environment between the departure ports and the Australian arrival ports. These studies resulted in 18 major commercial trading ports, including Dampier, Port Hedland and Fremantle in Western Australia, being included on the National Monitoring Network. Targeted monitoring will concentrate on these ports in the future.

Table 1. Relative risk rankings of commercial trading ports in Western Australia for the introduction of NIMS.

Port	Rankings		
	Original study		McDonald (2008)
	WA	National	
Dampier	2	6	1
Fremantle	1	2	2
Port Hedland	3	9	3
Bunbury	4	24	4
Cape Lambert	Not included	Not included	5
Geraldton	5	27	6
Esperance	7	37	7
Albany	6	34	8
Varanus Island	11	59	9
Barrow Island	12	76	10
Broome	9	43	11
Useless Loop	14	81	12
Cape Cuvier	10	46	13
Wyndham	8	41	14
Exmouth	13	79	15

As part of the present Department of Fisheries program on NIMS, McDonald (2008) conducted an independent analysis of Western Australian commercial trading ports. The same three ports (Dampier, Port Hedland and Fremantle) again topped the list of ports in terms of the relative risk of introducing NIMS (Table 1). These three ports are all clumped together as high risk, with Dampier at the top. The risk drops to Fremantle then Port Hedland, at which point a plateau is reached for the ports of Bunbury, Cape Lambert and Geraldton, indicating little difference in the relative risk amongst these ports. The risk is reduced once more and again plateaus out for the remaining nine ports (McDonald, 2008). The three top ports in WA all ranked in the top nine nationally. Bunbury (24) and Geraldton (27) were next, with the remaining ports ranking well down on the national list.

Now that the baseline surveys of ports on the national monitoring system have been completed, there is a much better understanding of NIMS in Australia. It is important to note that with the broad surveys completed, the NIMPCG (2006) focus has changed to determining the presence/absence of 55 target species (Table 2). These are species that are known to be invasive in Australia, are invasive elsewhere, or are considered to be potentially invasive. The National Monitoring Network will target these species, acknowledging that other species might be detected by the surveys.

In their analysis of marine species introduced into Western Australia, Huisman *et al.* (2008) found only four species on the NIMPCG list: the dinoflagellates *Alexandrium minutum* and *A. tamarense* (considered by Huisman *et al.* (2008) to be cryptogenic or native) (Table 3); the polychaete *Sabella spallanzanii*; and the bivalve *Musculista senhousia.* The alga *Caulerpa* *taxifolia* occurs in WA, but it is not the invasive genetic strain. More recently, several specimens of the marine alga *Codium fragile* subspecies *fragile* were collected in Princess Royal Harbour and King George Sound at Albany. This subspecies was previously known as *C. fragile tomentosoides,* but Maggs and Kelly (2007) synonymised the subspecies with *C. fragile* subsp. *fragile*. The green alga *Caulerpa racemosa* var. *cylindracea*, a major pest in the Mediterranean and introduced to South Australia, is native to southwestern Australia (Verlaque *et al*., 2003) Overall only 11 of the 55 species occur in Australian waters (Table 4). Additional species occurring outside WA are the invasive strain of *C. taxifolia,* the macroalga *Grateloupia turuturu,* the kelp *Undaria pinnatifida,* the starfish *Asterias amurensis,* the crab *Carcinus maenas,* the oyster *Crassostrea gigas,* and the mussel *Perna viridis.*

Table 2. Target species of introduced and potentially introduced marine species on the national monitoring program (NIMPCG 2006).

Group	Species	Group	Species
BALLAST WATER			
Dinoflagellates	*Alexandrium catenella*	Diatoms	*Chaetoceros convolutus*
	Alexandrium minutum		*Chaetoceros concavicornis*
	Alexandrium monilatum		*Pseudo-nitzschia seriata*
	Alexandrium tamarense	Ctenophorans	*Beroe ovata*
	Dinophysis norvegica		*Mnemiopsis leidyi*
	Gymnodinium catenatum	Copepods	*Acartia tonsa*
	Pfiesteria piscicida		*Pseudodiaptomus marinus*
			Tortanus dextrilobatus
HULL FOULING			
Algae	*Bonnemaisonia hamifera*	Cnidarians	*Blackfordia virginica*
	Caulerpa racemosa	Polychaetes	*Sabella spallanzanii*
	Caulerpa taxifolia		*Hydroides dianthus*
	Codium fragile subspecies fragile		*Marenzelleria* spp.
	Grateloupia turuturu	Barnacles	*Balanus eburneus*
	Sargassum muticum		*Balanus improvisus*
	Undaria pinnatifida	Crabs	*Callinectes sapidus*
	Womersleyella setacea		*Carcinus maenus*
Bivalves	*Corbula amurensis*		*Charybdis japonica*
	Ensis directus		*Eriocheir* spp.
	Limnoperna fortunei		*Hemigrapsus sanguineus*
	Mya arenaria		*Hemigrapsus takanoi*
	Varicorbula gibba		*Rhithropanopeus harrisii*
	Musculista senhousia	Ascidians	*Didemnum* spp.
	Mytilopsis sallei	Starfish	*Asterias amurensis*
	Perna perna	Fish	*Neogobius melanostomus*
	Perna viridis		*Siganus luridus*
	Crassostrea gigas		*Siganus rivulatus*
Gastropods	*Crepidula fornicata*		*Tridentiger barbatus*
	Rapana venosa		*Tridentiger bifasciatus*

Table 3. NIMPCG (2006) target species recorded in Western Australian marine areas.

Group	Species	Areas inhabited
Dinoflagellates	*Alexandrium minutum*	Bunbury, Fremantle
Bivalves	*Musculista senhousia*	Fremantle
Polychaetes	*Sabella spallanzanii*	Esperance, Albany, Bunbury, Fremantle

Table 4. NIMPCG (2006) target species recorded in Australian marine areas.

Group	Species	Areas inhabited
Marine algae	*Caulerpa taxifolia*	Queensland to South Australia
	Undaria pinnatifida	Tasmania
	Grateloupia turuturu	Tasmania
	Codium fragile fragile	New South Wales to Western Australia
Dinoflagellates	*Alexandrium minutum*	Western Australia
Starfish	*Asterias amurensis*	Tasmania, Victoria
Crab	*Carcinus maenas*	Tasmania, New South Wales to South Australia
	Crassostrea gigas	Tasmania, New South Wales to South Australia
	Musculista senhousia	Tasmania, South Australia, Western Australia
	Perna viridis	Queensland
Polychaetes	*Sabella spallanzanii*	Tasmania, New South Wales to Western Australia

In addition to the NIMPCG (2006) species listed above, the websites of the responsible state agencies list additional species considered to pests in those areas: the fish *Tridentiger trigonocephalus* in New South Wales and the bivalve *Corbula gibba* in Tasmania. The polychaete *Hydroides sanctaecrucis* has been recorded in the Cairns area of Queensland (Lewis *et al*. 2006), but is considered to be a nuisance, not a pest.

Potential Sources of Introductions

There are three potential sources for the introduction of NIMS into Western Australian environmentally sensitive areas:

- introduction of NIMS into Western Australia from overseas;
- introduction of NIMS into Western Australia from interstate; and
- translocation of NIMS within Western Australia.

Each of these is discussed below.

Introduction of NIMS into Western Australia from overseas

Clearly there is a potential for NIMS to come into Western Australia from overseas. The most likely sources would be vessels, primarily ships, entering directly into Western Australian ports. A second potential source would be private yachts entering the ports for customs clearance before moving along the coast.

Introduction of NIMS into Western Australia from interstate

There is less potential for NIMS to come into the State from eastern Australia, simply on the basis that there are only eight species on the NIMPCG list in the east that are not in WA.

Two tropical species on the NIMPCG list are of particular concern: the black striped mussel, *Mytilopsis sallei*, and the Asian green mussel, *Perna viridis*. *Mytilopsis sallei*, was introduced into three marinas in Darwin. The introduction is thought to have been through a yacht arriving in the Northern Territory. Fortunately, the species was restricted to the marinas, and it was successfully eradicated (Willan *et al.* 2000). However, there is considerable potential for the species to be re-introduced into Darwin. The Asian green mussel, *Perna viridis*, has been introduced into Cairns, where it has apparently established a small breeding colony (Stafford *et al.* 2007), though the evidence of this is equivocal.

The invasive marine alga *Caulerpa taxifolia* and the Pacific oyster *Crassostrea gigas* have been established in the Adelaide area (Table 4). *Crassostrea gigas* and the European shore crab *Carcinus maenas* extend eastwards along the coast to New South Wales and Tasmania, while the North Pacific seastar *Asterias amurensis* is found in Tasmania and Victoria. *Codium fragile fragile* has been found in several areas of New South Wales, Victoria, and South Australia and has spread to southwestern Australia at Albany. The marine algae *Grateloupia turuturu* and *Undaria pinnatifida* are established in Tasmania.

All of these species can be transported into Western Australia by any vessel arriving from an infected area.

Transport of NIMS within Western Australia

At present, there are four introduced species on the NIMPCG (2006) target list present in Western Australia:

- the toxic dinoflagellate *Alexandrium minutum*;
- the European fanworm *Sabella spallanzanii*; and
- the Asian date mussel *Musculista senhousia.*
- the green alga *Codium fragile* subsp. *fragile*

All of these four species can be moved about within Western Australia by vessel movements and potentially through other mechanisms. All four species are currently distributed in harbours, and are not known on open coasts.

The toxic dinoflagellate *Alexandrium minutum* has been recorded in Bunbury and Fremantle (Huisman *et al.* 2008). This species has two life stages, an active mobile stage that lives in the water column and a resting, or cyst, stage that lives on the surface of bottom sediments. Large ships that use ballast water can transport both life stages. The planktonic stage can be moved in water held in holding tanks or pools of water on the boat. The benthic cyst stage can be moved in any sediment inadvertently carried from one marine area to another, such as from Bunbury or Fremantle to Geraldton, Albany or Esperance. It is unlikely that the species would survive north of Geraldton because of the higher seawater temperatures.

The European fanworm *Sabella spallanzanii* has been found in Esperance, Albany, Bunbury and Fremantle, including Cockburn Sound, and also Warnbro Sound (Huisman *et al.* 2008). This species is most likely to be transported as clumps of individuals, or parts of individuals, trapped in nets, pots, etc or on drift material. *Sabella spallanzanii* is a temperate species and could probably not survive in the warmer sea temperatures north of Geraldton. It could also be transported as planktonic larvae via the ballast water of large ships.

The Asian date mussel *Musculista senhousia* has been found only in the lower Swan River and Cockburn Sound (Huisman *et al.* 2008). A survey conducted in October 2007 did not collect any individuals, though there may still be residual populations in the Swan River or Cockburn Sound. The species could be carried as planktonic larvae via the ballast water of ships or as hull fouling on any vessel. The published literature cited by NIMPIS (2006) suggests the species has a wide temperature tolerance that would include virtually all of Western Australia. However, there may be more than one species in what is presently considered to be one species (K. Chalermwat, Burapha University, Thailand, pers. comm. 2003).

The green alga *Codium fragile* subsp. *fragile* has recently been found in Princess Royal Harbour and King George Sound at Albany. This taxon has been present for some time in the east, but projections indicated its temperature tolerances would allow to it survive in southwestern Australian waters (Trowbridge, 1999). There appears to have been a step-wise progression westward, as *C. fragile* subsp. *fragile* appeared in South Australia in 2002 and subsequently in Western Australia in 2007.

Sources Of NIMS

There are two major sources of NIMS entering Western Australia:

- shipping from international and domestic sources; and
- private yachts visiting the State.

The patterns of each of these are discussed below.

Shipping from international and domestic sources

Of the two major potential sources of NIMS entering the State, international and domestic shipping is by far the larger. McDonald (2008) presents information on movements into 15 Western Australian commercial trading ports during 2006. These data are summarised in Table 5. These data capture all visits to the commercial trading ports surveyed during the year, and include all types of vessels: a wide variety of commercial ships, research vessels, charter boats, cruise ships, fishing vessels, and military ships. The fishing vessels included are those that used the port facilities, including the arrivals from international ports. It does not include local fishing boats using fishing harbours in areas such as Fremantle and Geraldton.

Table 5 shows there are considerable differences between commercial trading ports in terms of all characteristics measured: number of shipping visits, both domestic and international, and ballast water discharge, both domestic and international. Dampier had the greatest number of visits (3278) and the greatest ballast water discharge (42,406,279 tonnes). Port Hedland (930) and Cape Lambert (325) had lower numbers of visits, but very high volumes of ballast water discharge (40,932,681 and 19,145,624 tonnes respectively). Over 99% of the ballast water from these three ports was international. Fremantle had the second highest number of visits (1722), but was relatively low on ballast water (8,532,086 tonnes). Ballast water discharge into Fremantle was split between international (4,655,172 tonnes) and domestic (3,876,914 tonnes). Together these four ports had 6255 visits (70.5% of the total) and 111,016,670 tonnes of ballast water discharged (89.9% of the total).

Broome ranked high in terms of visits (1017). This was because 850 of the movements were vessels were operating out of Broome and returning to Broome without entering another port. These vessels include charter boats operating to Rowley Shoals and the Kimberley, and service boats operating to offshore petroleum reserves, etc.

At the other end of the scale, eight ports had less than 200 ship visits in 2006, with the total for the eight being only 891 visits, 319 of which were international. This is approximately one-fourth of the ship visits into the Port of Dampier alone, and only 10.9% of the ballast water discharged.

Table 5. Shipping movements and release of ballast water into Western Australian ports in 2006 (From McDonald 2008).

Port	Number of visits			Ballast water discharge (tonnes)		
	Total	Domestic	International	Total	Domestic	International
Dampier	3278	2188	1090	42,406,279	203,966	42,202,313
Fremantle	1722	785	937	8,532,086	3,876,914	4,655,172
Broome	1017	975	42	45,263	15,483	29,780
Port Hedland	930	77	853	40,932,680	268,570	40,664,111
Geraldton	369	217	152	2,460,606	528,782	1,917,042
Bunbury	344	93	251	4,503,806	830,297	3,673,509
Cape Lambert	325	2	323	19,145,624	82,377	19,063,247
Varanus Island	193	190	3	176,202	176,202	0
Barrow Island	186	180	6	254,827	135,873	118,954
Esperance	175	67	108	2,787,411	172,235	2,615,176
Albany	115	41	74	873,888	234,299	639,589
Wyndham	114	83	31	72,129	31,451	40,679
Cape Cuvier	55	3	52	877,188	40,096	837,092
Useless Loop	47	3	44	368,152	19,314	348,838
Exmouth	6	5	1	n/a	n/a	n/a
Totals	8876	4909	3967	123,421,361	6,615,858	116,805,502

Private yachts visiting the State

URS (2007) undertook a nationwide analysis of private yachts entering Australian waters during the period of 2000-2005. The results of this study are summarised in this section.

Cruising yachts less than 25 m in length can pose a high risk of introducing biofouling species because of:

- Extended periods spent in overseas ports or marinas;
- Slow cruising speeds that allow biofouling species to adhere to the hull;
- Low economic benefit of regular cleaning and haul out, and the accompanying lack of regulatory or insurance requirements to do so; and
- Lack of international requirements and guidelines on ways to reduce biofouling risk.

URS (2007) concluded the key to reducing the risk of introductions through biofouling was to undertake thorough and regular cleaning of the vessel and the application of appropriate antifoulant to the vessel. Since 1 October 2005, AQIS has been operating the *National Border Protocol for Apprehended and International Vessels Less than 25 m in Length* on a voluntary basis in selected ports. Under the National System, NIMPCG is currently developing National

Guidelines for management of biofouling for each of the key sectors, including recreational vessels.

URS (2007) analysed the commercial trading ports of entry of 4620 yachts entering Australia from overseas during the six-year period of January 2000 through December 2005. Nine of the 58 ports analysed accounted for 4026, or 87% of the arrivals. The leading ports were: Brisbane (965), Bundaberg (819), Cairns (641), Darwin (379), Port Jackson (Sydney (309), Thursday Island (293), Mackay (216), Coffs Harbour (210), and Townsville (194). None of these ports were in Western Australia.

The 13 Western Australian commercial trading ports recorded a total of 117 arrivals in six years. The leading port for the State was Fremantle, with 48 arrivals. Other ports near marine parks had the following total number of arrivals in the six years studied: Dampier (19), Carnarvon (11) and Exmouth (8).

Yachts arriving in Australia must proceed directly to an approved boarding station (Australian Customs Service 2008). Approved boarding stations in Western Australia are at: Broome, Port Hedland, Dampier, Carnarvon, Geraldton, Fremantle, Bunbury, Albany, and Esperance. Customs, quarantine, and immigration formalities must be completed before any person goes ashore (Australian Customs Service 2008). This means that yachts must proceed directly to a major port and are not allowed to visit a marine park before undertaking arrival clearance.

PREVENTION OF INTRODUCTIONS OF NIMS

There are two major methods by which NIMS can be introduced by vessels:

- in ballast water; and
- through hull fouling.

It is estimated that three quarters of the introduced marine species in Australia were brought in through hull fouling (URS 2007). There are very different methods employed to prevent NIMS through these two methods.

Ballast water

As shown on Table 5, vessels visiting Western Australian commercial trading ports discharged 123,421,361 tonnes of ballast water in 2006. Of this, 94.6% was international ballast water and 5.4% was domestically sourced. Vessels entering a Western Australian port (and other ports in Australia except for Victoria, which has its own regulations for handling of domestic ballast water) that plan to discharge ballast water must undertake a risk assessment of their ballast water using Australian Quarantine and Inspection Service (AQIS) guidelines. Ballast water assessed as high risk cannot be discharged in Australian waters. Exchange at sea in the open ocean is required to lower the risk. This is based on the fact that most of the larvae of species on the NIMPCG (2006) list have short-term planktonic larvae that are concentrated in coastal areas. Replacing the coastal water from a port with water from the open ocean greatly reduces the concentration of larvae in ballast water tanks.

Open sea exchange can be done by completely emptying a ballast water tank and replacing the water. An alternative is to run the ballast water pumps long enough to pump three times the volume of the tank, progressively decreasing the concentration of larvae as the pumps run. Exemptions are allowed for storms and other situations when ballast water exchange would endanger the vessel. On entry to port, AQIS inspects the pump records to ensure that ballast water exchange has actually occurred.

With the implementation of a nationally consistent management regime for the regulation of ballast water (which it is currently anticipated will be implemented in 2009) the same ballast water management arrangements will apply to domestically sourced ballast water. In addition, there are methods being developed to treat ballast water to further reduce the introduction of NIMS.

Hull fouling

At present management of hull fouling on ships is largely left up to the company, and is undertaken through regular cleaning programs and the use of antifoulants. Movement of a vessel through the water is slowed by hull fouling organisms, so it is in the operator's interest to ensure the hull is as clean as possible. In general, major companies ensure their vessels are as clean as possible, though it is recognised that this system is far from perfect.

However, there are a wide variety of vessels and not all pose the same risks. Vessels such as dredges and jack-up rigs are in close association with the bottom, slow moving, remain in an area for prolonged periods, and have numerous nooks and crannies where NIMS can settle and grow. These vessels are considered to represent high risk.

Many such vessels enter WA as part of major development programs for ports and other facilities. As part of the environmental assessment process, Ministerial Conditions are set by the WA Minister for the Environment. Increasingly these Ministerial Conditions require vessels to be inspected for marine pests before, or immediately after, they enter WA waters. If they are not clean, the vessels can be requested to remove the biofouling material, which because of the shortage of facilities in WA that can deal with these vessels, may mean the vessel has to go offshore for dry-docking and cleaning. In 2007 the WA Parliament passed the *Biosecurity and Agriculture Management* (BAM) *Act*. When it becomes operational, this Act will provide the WA Department of Fisheries with substantially enhanced capabilities for the management of the introduction of NIMS.

In addition, NIMPCG is in the process of developing national guidelines for the management of hull fouling by the different sectors.

Environmentally Sensitive Areas in WA

As one part of the task of protecting the marine environment, the Marine Parks and Reserves Selection Working Group (MPRSWG) examined the entire coastline of Western Australia in detail and selected 72 areas for further consideration for development as marine parks or reserves (MPRSWG 1994). At the time the report was released there were already several marine parks in Western Australia, such as the Ningaloo Marine Park and the Marmion Marine Park. A number of parks have been developed since then, and others are currently being developed.

The intention is to develop a representative system of marine reserves and marine parks in the various parts of the State, based on the CAR principles of comprehensive, adequate and representative for every region. In the 14 years since the report was published, a number of marine parks and reserves have been developed. The present paper uses the extensive analysis behind the selection of marine parks and reserves as the basis for selecting environmentally sensitive marine areas in terms of the possible introduction of marine pests.

The Minister for Fisheries also has the ability to declare Fish Habitat Protection Areas (FHPA) under the *Fish Resources Management Act 1994.* One of the key areas determined by the MPRSWG (1994) was the Houtman Abrolhos Islands off Geraldton. The Abrolhos is unusual in that it is vested in the Minister for Fisheries. In 1999 the Abrolhos was the first part of the State to be declared as an FHPA. It remains the largest and most important of the FHPAs and is included here as an environmentally sensitive area.

The environmentally sensitive areas considered in this analysis are, in geographical order from north to south (Figure 1):

- Rowley Shoals Marine Park
- Dampier Marine Park and Regnard Marine Management Area
- Montebello/Barrow Island Marine Management Area
- Ningaloo Marine Park
- Shark Bay Marine Park (including the Hamelin Pool Marine Nature Reserve)
- Houtman Abrolhos Islands Fish Habitat Protection Area
- Jurien Bay Marine Park
- Marmion Marine Park (including the Cottesloe Fish Habitat Protection Area)
- Swan Estuary Marine Park
- Shoalwater Islands Marine Park
- Southwest Capes Marine Park
- Walpole and Nornalup Inlets Marine Park

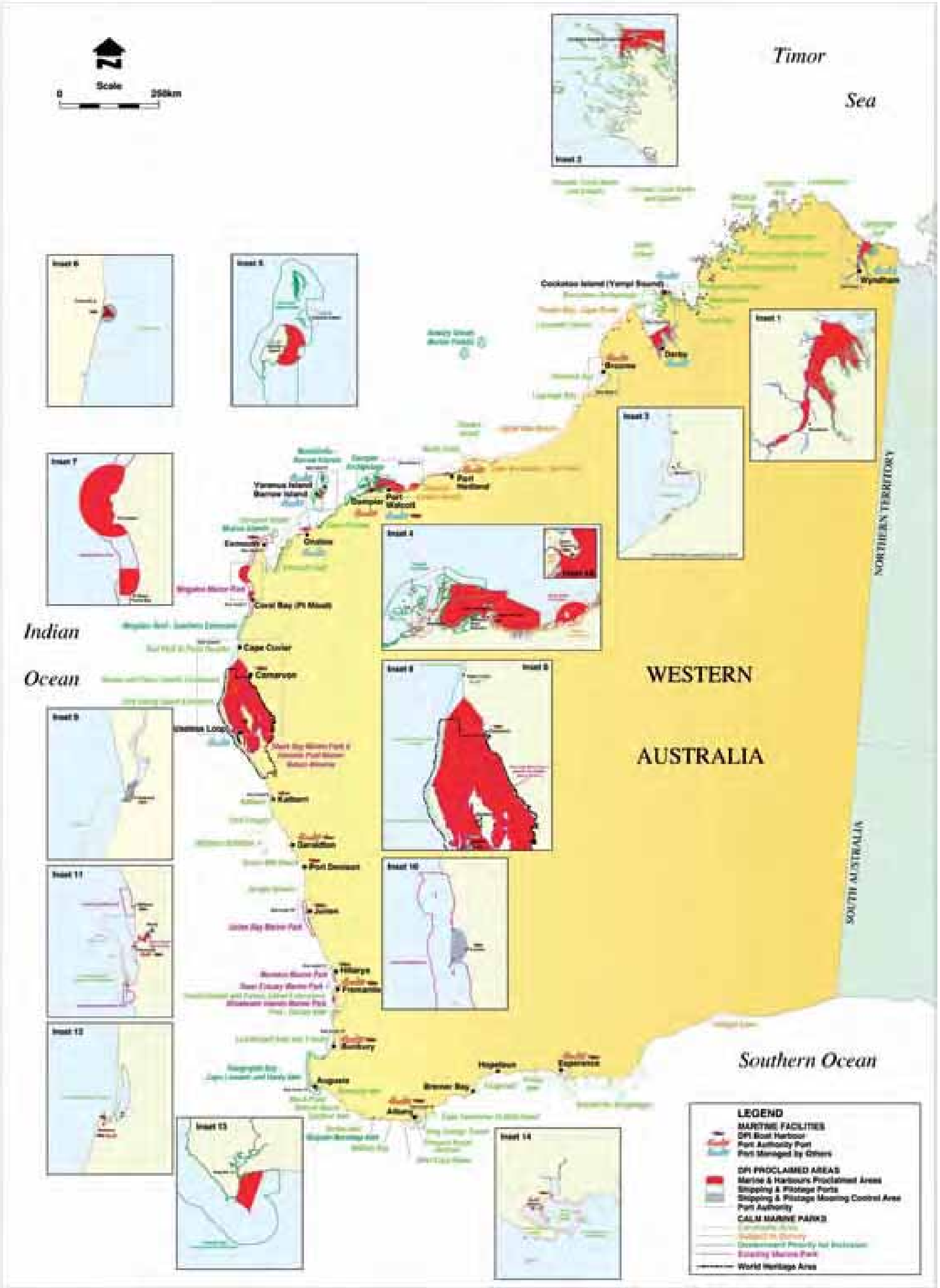

Figure 1. Map of Western Australia showing the locations of marine parks (map provided courtesy of the WA Department of Environment and Conservation).

Management Plans have been developed by the Department of Environment and Conservation for all of the marine parks and for the Fish Habitat Protection Areas by the Department of Fisheries. The Management Plans should be examined in detail for descriptions of the areas, their environmental values, zoning, regulations, etc.

Rowley Shoals Marine Park

The Rowley Shoals Marine Park is located nearly 300 km west-northwest of Broome on the edge of the Australian continental shelf. Rowley Shoals is comprised of three oceanic atolls (Mermaid, Clerke and Imperieuse Reefs) that are 30-40 km apart. They lie between the coordinates of 17°07'S, 119°36'E and 17°35'S, 118°56'E. The atolls are uninhabited, remote, and well away from shipping lanes. As offshore atolls, their biota is very different from that of coral reefs along the continental mainland. About one quarter of the species of a wide variety of phyla studied in the first survey of Rowley Shoals by the WA Museum in 1982 were new records for WA. Being so far offshore, the reefs are in nearly pristine condition.

Primary access to the Rowley Shoals is via charter vessels operating from Broome, and to a lesser extent via private yachts. There may also be some visits by Indonesian fishermen poaching in the area, but this is likely to be low. The primary threat of introductions to Rowley Shoals is translocation by vessels that originated in Broome. While the port of Broome has not been surveyed for NIMS, no species on the NIMPCG (2006) list are known to have established populations on the north coast. Three species of barnacles are known to have been introduced to Broome (Huisman *et al.* 2008).

Dampier Marine Park and Regnard Marine Management Area

The Dampier Archipelago Marine Park includes the marine waters of the Dampier Archipelago, Burrup Peninsula, and the eastern part of the peninsula. For the purposes of this discussion, the area also includes the region west to Cape Preston, which is proposed as the Regnard Marine Management Area. The Dampier Archipelago has received the most intense biodiversity survey in WA, with the presence of over 3,000 species published (Wells *et al.* 2003; Jones 2004). An additional volume with 1,500 species is currently being published (Jones 2008).

The Port of Dampier, one of the two largest commercial trading ports in Australia by tonnage of shipping, is adjacent to the Dampier Marine Park, but is not included in the Park boundaries. The Port of Dampier is included as one of 18 locations in the National Monitoring Network, which will include sites in the marine park, so the Dampier Marine Park is covered by the existing monitoring program.

Montebello/Barrow Island Marine Area

The Montebello/Barrow Island Marine Area is located off the Pilbara coast between Dampier and North West Cape. There are three components to the management area: Montebello Islands Marine Park, which includes the waters of the Montebello Islands and covers the entire island area; Barrow Island Marine Park on the western side of Barrow Island; and the Barrow Island Management Area (including the Barrow Island Marine Park). Despite the intensive petrochemical activity in the area, it is actually relatively remote and the marine waters are pristine. The diffuse Indonesian Through Flow begins to form the Leeuwin Current in the region, providing a source of larvae of tropical species from the north. This, plus the considerable habitat diversity, has led to the development of a very diverse marine biota.

For example, the 265 low-lying islands in the Montebello Islands Marine Park contain extensive lagoons, channels, intertidal embayments, intertidal platforms, and dunes. The benthic habitats include coral, limestone and exposed reef systems, sand patches and seagrass meadows providing a considerable range in habitat diversity. There are 141 species of scleractinian corals, 170 echinoderms, 633 molluscs, 123 crustaceans, and 456 fish known from the Montebello Islands alone. Turtles (five species), whales (seven species of toothed and five species of baleen whales) and dugongs are common. Seabirds (15 species) use extensively the islands as rookeries.

The primary threat of introduction of NIMS to the Montebellos is translocation of species from Dampier, which is part of the National Monitoring Network. Two smaller parts occur in the area (Table 5, Figure 1). The commercial trading port at Varanus Island handled 193 vessels, three of which were international, in 2006 and Barrow Island had 186 vessels, six of which were international, so the risk of a direct introduction from overseas is small. In addition, the vessels remained in port for only short periods of time.

Ningaloo Marine Park

Ningaloo Marine Park is one of the icon marine areas of Western Australia, and one that it is critical to protect from NIMS. The marine park extends from Bundegi Reef, just north of Exmouth down the west side of North West Cape to Red Bluff. It is regarded as the largest fringing reef in Australia. Recently it was extended to include the Muiron Islands. Ningaloo Reef has a lagoon near the shore, which makes the reef very accessible. There are a wide variety of different ecosystems and habitats in the region, including macroalgal meadows, mangroves, sand, and intertidal habitats. The reef itself has a variety of forms, including sections of limestone, coral and exposed intertidal reefs. Sandy and muddy bottoms and macroalgal communities provide habitat for many invertebrate groups that are poorly known in the region. There is high species richness within the management areas. Known diversity includes 217 species of coral, 600 molluscs, 500 finfish at Ningaloo Reef (393 species at the Muiron Islands). There are also 144 bird species, some of which are protected by international treaties. There are also 13 species of toothed whales and dolphins, and seven species of baleen whales. Ningaloo Reef is well known as one of the best places in the world to see the largest extant fish, the whale shark. Ningaloo Reef is the northern limit of the coral reef biodiversity hotspot described by Roberts *et al.* (2002), and has the greatest diversity in the hotspot of species examined: corals, molluscs, fish, and rock lobsters.

The Ningaloo Marine Park includes the areas in WA State waters. Offshore the park is continuous with the Commonwealth component of the park. The only commercial trading port in the area is Exmouth, which handled only six vessels in 2006, one of which was international.

It should be noted that there is a proposal for development of a major salt works on the east side of Exmouth Gulf. Should the proposal gain environmental approvals, it is likely that the approvals will include Ministerial Conditions for the management of NIMS. There will also be increased shipping in Exmouth during the operational phase of the salt works. However, these changes to shipping patterns near the Ningaloo Marine Park may require a re-evaluation of the potential introduction of NIMS in future. It should also be noted that vessels associated with the offshore oil and gas developments come into Exmouth Gulf for various reasons and potentially present a risk.

Shark Bay Marine Park (including the Hamelin Pool Marine Nature Reserve)

Like Ningaloo, the Shark Bay Marine Park (including the Hamelin Pool Marine Nature Reserve) is one of the environmentally critical areas of Western Australia, with a substantial requirement for protection from NIMS.

Shark Bay is the largest enclosed embayment in the world. While largely tropical, the marine biota of the bay includes a mixture of temperate Australian and endemic Western Australian species. Shark Bay has been called a “reverse estuary”. Salinities at the mouth are normal marine salinities of about 35‰. Salinity gradually increases to about 70‰ at the southern ends of the inner and outer gulfs. There are ancient stromatolite systems in Hamelin Pool and massive deposits of coquina shell, particularly at Shell Beach.

Faure Sill, just north of Hamelin Pool, has the largest seagrass meadow in the world, the Wooramel seagrass bank, which has an area of 1,030 km^2 and 12 species of seagrass. Overall there is about 4,000 km^2 of seagrass that forms the basis of productive marine ecosystems. In contrast to most of the biota of the bay, which is tropical, the seagrasses are dominated by the temperate genera *Posidonia* and *Amphibolis.* The seagrasses support one of the largest populations of dugongs in the world. There are also many other species of charismatic megafauna, including whales, dolphins, turtles, sharks, and rays. Resident dolphins at Monkey Mia regularly venture near the shore and interact with people. There are also many species of migratory birds. The coral reefs of the outer islands of Shark Bay are part of the coral reef biodiversity hotspot described by Roberts *et al*. (2002).

Two small commercial trading ports occur in the area. The salt works at Useless Loop had 47 vessel movements in 2006, only three of which were international. Another salt works at Cape Cuvier, just north of Shark Bay had 55 vessel movements, three of which were international. There is also a small commercial trading port at Carnarvon that primarily handles fishing boats.

Wyatt *et al.* (2005) recorded seven species of introduced bryozoans in Shark Bay, and suggested they could have been brought into the State by cruising yachts. Huisman *et al.* (2008) found that all seven species occur in other parts of Western Australia, and equally could have been secondary translocations from other WA areas.

Houtman Abrolhos Islands Fish Habitat Protection Area

The Houtman Abrolhos Islands Fish Habitat Protection Area is located in the State waters of the Abrolhos Islands, 64 km to the west of Geraldton. The Abrolhos is another of the icon marine areas of the State. The 122 islands and islets are the centre of the WA western rock lobster industry, with 22 islands or parts of islands inhabited by fishers during the season of 15 March to 30 June each year. There are extensive coral reefs that are essentially a veneer over the underlying limestone. The marine biota is a unique mixture of tropical, temperate and WA endemic species. Known biodiversity includes 184 species of corals, 172 echinoderms, 492 molluscs, and 234 marine benthic algae. The Abrolhos is one of the most important breeding sites for seabirds in the world. There are over one million pairs of Wedge-Tailed Shearwaters (*Puffinus pacificus*). In addition, the islands are the largest known WA habitat for breeding colonies of another nine species.

International vessels may transit close to the islands, and occasionally between the island groups, but there is no port in the islands. It is likely that any introduced species would first be introduced into the Port of Geraldton and then trans-located to the islands. In 2006, the Port of Geraldton handled 369 vessels, including 152 from international ports. No species on the NIMPCG (2006) list are known to occur in Geraldton harbour. A possibility is that private yachts and fishing boats moving directly from Fremantle to the Abrolhos could introduce NIMS to the islands. However, only three species on the NIMGPG (2006) list are known from the Fremantle marine area, and recent attempts to collect *Musculista senhousia* in the Fremantle area were unsuccessful (see above). Further, *M. senhousia* lives in protected bays and estuaries, and the Abrolhos habitat is probably not suitable for this species. While some vessels going to the Abrolhos originate in Dongara and others in Kalbarri, most come from Geraldton. In particular, many of the fishing boats, rock lobster carrier boats and Department of

Fisheries boats originate from the fishing boat harbour, located close to the shipping port. If a pest species became established in Geraldton, it could be readily introduced to the Abrolhos by vessels moving from Geraldton to the islands, so vigilance must be maintained. The Abrolhos is a key part of the coral reef biodiversity hotspot described by Roberts *et al*. (2002). The reefs of the Abrolhos have the greatest number of restricted range species in the hotspot.

Jurien Bay Marine Park

The Jurien Bay Marine Park is 200 km north of Perth, between Wedge Island and Green Head, and extends westward to the western limit of State waters. Located on the central west coast of WA, the park has an essentially temperate biota with strong elements of tropical and west coast endemic species. The Jurien Bay region is representative of this area of the WA coastline. Dominant marine habitats are seagrass meadows; sand; intertidal reef platforms along the shoreline and on offshore islands; subtidal limestone reefs; and reef pavement. Combined, these habitats provide for a relatively high marine diversity for this part of the coast. The region is in essentially pristine condition.

Marine mammals include eight species of baleen whale, six of toothed whales, several dolphin species, and sea lions. In addition, there are three species of turtles, and numerous species of sea and shore birds nesting on the islands. Sea lion populations on the west coast are small, and individuals in the Jurien Bay area are genetically distinct from populations further south.

There are no major commercial trading ports in the area. The closest ports are Fremantle to the south (part of the National Monitoring Network) and Geraldton to the north.

Marmion Marine Park (including the Cottesloe Fish Habitat Protection Area), Shoalwater Islands Marine Park and Swan Estuary Marine Park

All of these areas are located in close proximity to the Fremantle marine area. The Marmion Marine Park (and the Cottesloe Fish Habitat Protection Area) is just to the north, the Shoalwater Marine Park is just to the south, and the small sites of the Swan Estuary Marine Park are just up the river from Fremantle. All of these marine parks are in close proximity to the Perth metropolitan area and have heavy usage from the Perth population.

Fremantle is one of the locations included in the National Monitoring Network, so there is no requirement for a separate survey of these areas.

Southwest Capes Marine Park

The proposed Southwest Capes Marine Park is located offshore of the extreme southwest corner of the continent. It includes the region between Cape Naturaliste and Cape Leeuwin and also Hardy Inlet. Much of the exposed coastline is rocky shore, and the sea bottom is inhabited by a wide variety of macroalgae, seagrass and associated invertebrate communities. The region is at the southern limit of the west coast biogeographic overlap zone, so the biota is primarily temperate, with some WA endemic species and a few tropical species that are carried south on the Leeuwin Current. The extent of the tropical component varies between years depending on the strength of the Leeuwin Current.

The Southwest Capes Marine Park is closest to the port of Bunbury, which is 60 km to the northeast. Bunbury has 24 known introduced species, only two of which are on the NIMPCG (2006) target list (Huisman *et al.* 2008).

Walpole and Nornalup Inlets Marine Park

The Walpole and Nornalup Inlets Marine Park is in the south coast bioregion, 450 km south of Perth. It is an estuarine system that includes Walpole and Nornalup Inlets and the Frankland, Deep and Walpole Rivers. Unlike many estuaries in the southwest, Walpole and Nornalup Inlets are permanently open to the sea and are not separated by a sandbar. There is moderate habitat diversity, with mud and sand flats and rocky shallows. Polychaetes, crustaceans, molluscs dominate the invertebrates. There are also 40 species of finfish and a variety of seagrasses and macroalgae. Water birds, shore birds, and seabirds frequent the area, including species that must be protected because of treaties that Australia has signed.

Albany, 140km to the west, is the closest port to the Walpole and Nornalup Inlets Marine Park. Albany has 25 known introduced species, only two of which are on the NIMPCG (2006) target list (Huisman *et al.* 2008). The recent discovery of *Codium fragile* subsp. *fragile* has added to that list, however.

CONCLUSIONS

The introduction of non-indigenous marine species (NIMS) into new marine areas has had serious consequences worldwide, including in eastern Australia. Western Australia has been fortunate to date that while 60 foreign species have been introduced into the State, only four are on the NIMPCG (2006) list of 55 species of concern: the toxic dinoflagellate *Alexandrium minutum,* the European fanworm *Sabella spallanzanii*, the mussel *Musculista senhousia*, and the green alga *Codium fragile* subsp. *fragile.* Seven additional species on the NIMPCG (2006) list have been introduced into eastern Australia but are not present in Western Australia.

NIMPCG (2006) undertook an extensive analysis of the risks of marine pests being introduced into Australian commercial trading ports and is developing a National Network Monitoring Program of 18 locations that have been determined to have the highest risk for introducing marine pests. Three of these are in Western Australia: Dampier, Port Hedland and Fremantle. McDonald (2008) recently re-examined Western Australian commercial trading ports and concluded there has been no change in the risk profile in WA as a result of increased shipping due to the current resources boom.

The key question posed in the present document is whether there is a need for separate monitoring, over and beyond the National Network Monitoring Program that is required to be implemented by WA at three locations, of environmentally sensitive areas. Two types of areas are present: commercially valuable areas, such as aquaculture leases, and Marine Parks and Fish Habitat Protection Areas. Aquaculture leases will be examined separately in a project currently being proposed to the Fisheries Research and Development Corporation. The current document deals with marine parks and FHPAs (Advice provided by a team of technical panellists to the Department of Fisheries is included as Attachment 1).

A separate analysis of the risks of commercial fishing vessels introducing marine pests into WA from overseas or interstate, or translocating them within WA, was recently completed (Wells 2008). The report concluded the risks are low at present. However, if other vectors introduced a species, it could be spread rapidly by commercial fishing activities, even before authorities were alerted to the incursion. Because of this, procedures must be developed to ensure the commercial fishing fleet does not inadvertently translocate newly arrived pests.

Two primary sources of introduced marine pests are examined in the present document: ballast water and hull fouling (including niches, internal water systems, on or in the vessel). Ballast water is used only in ships coming into commercial trading ports. Hull fouling can be introduced both by ships and smaller vessels, largely private yachts. The overwhelming international vessel traffic into WA is ships entering WA commercial ports. In the year 2006 examined by McDonald (2008), there were 3,967 international ship movements into WA ports, but only an average of 19.5 visits by international yachts in the six year period between 2000-2005. Under Australian requirements, the yachts must enter Australia through customs facilities that are located in commercial trading port areas before moving along the coast, so their entry point is also ports. The high-risk ports are included in the National Monitoring Network. In 2006, there were 4,909 domestic shipping movements in WA ports (McDonald, 2008).

There are four possible conclusions for the question of whether additional monitoring of marine parks and FHPAs for introduced marine species is required in additional to the National Monitoring Network:

- Monitoring requirements in marine parks and FHPAs will be adequately covered by the developing National Monitoring Network that will monitor primarily for the presence of 55 species on the NIMPCG target list;
- Monitoring using the methods and species list of the developing National Monitoring Network should be undertaken in one or more of the marine parks and FHPAs;
- An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using the NIMPCG target list; and
- An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using the an alternative list of target species;

Acknowledgements

The Department of Fisheries initiated a project *Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia* in October 2006. The present report is part of the project, which is funded by the Australian Government’s Natural Heritage Trust, delivered in Western Australia in partnership with the State government. This component was funded through the W.A. Strategic Reserve Fund (Project No. 053085). I thank Richard Stoklosa of E-Systems for assisting with the risk analysis, and Drs Stephanie Turner and Justin McDonald of the WA Department of Fisheries, and Dr John Huisman of Murdoch University for commenting on a draft report and Dr Chris Simpson of the WA Department of Environment and Conservation for commenting on the draft and providing the map of marine parks in WA.

Attachment 1

Is there a need for monitoring of environmentally sensitive areas in Western Australia for non-indigenous marine species?

Advice to the Western Australian Department of Fisheries

Introduction

The Western Australian Department of Fisheries (the Department) has undertaken a consultative project to identify and assess the risk of introducing marine pest species to Western Australia under the Natural Heritage Trust Strategic Reserve Fund Project No. 053085 (NHT Project). One of the key questions posed at the start of the project was: *'Is there a need for monitoring of environmentally sensitive areas in Western Australia for non-indigenous marine species?'*

The Department previously engaged E-Systems Pty Limited to provide advice on an appropriate methodology to formally assess the risk of introducing NIMS (and in particular marine pests) as a result of commercial fishing activities in State waters, to assist with preparation for a consultative workshop, and to facilitate the risk assessment. E-Systems completed these tasks and published a report: *Environmental, social and economic risk assessment—Threat of introducing Marine Species from commercial fisheries activities in Western Australia* (E-Systems 2008). A key aspect of this assessment was to convene a Technical Panel of independent experts to consider the technical information available, and identify and analyse the risks of introduction.

The Department subsequently prepared a paper (Question of Monitoring Paper) addressing the question of monitoring environmentally sensitive areas for the presence of non-indigenous marine species (Wells 2008, attached for reference). This paper provided background on the potential threats of introducing NIMS to environmentally sensitive areas, and posed four possible strategies to address the question of monitoring (numbered for reference):

1. Monitoring requirements in marine parks and Fish Habitat Protection Areas (FHPAs) will be adequately covered by the developing National Monitoring Network [18 locations around Australia, including the WA Ports of Dampier, Port Hedland and Fremantle] that will monitor primarily for the presence of 55 species on the NIMPCG target list.
2. Monitoring using the methods and species list of the developing National Monitoring Network should be undertaken in one or more of the marine parks and FHPAs.
3. An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using the NIMPCG target list.
4. An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using an alternative list of target species.

As an alternative to convening a workshop to discuss the alternatives, the Question of Monitoring Paper was provided to the experts involved in the Technical Panel for the recent risk assessment of commercial fisheries activities. Advice was sought from the Technical Panelists to identify the alternatives considered to be the preferred approach. Although advice was sought from each Panelist individually, without the advantage of debate in a workshop setting, the purpose was to gauge the Panelists' responses in the first instance to assess whether some clear advice could be obtained.

Of the Technical Panelists convened in the previous workshop, three of the original five experts were available to respond (J. Huisman of Murdoch University, J. Keesing of CSIRO, and D. Walker of the University of Western Australia). Two were on extended leave (L. Bellchambers of the Department of Fisheries, and C. Simpson of the Department of Environment and Conservation). Two experts from the DEC offered advice on behalf of their colleague on leave (A. Kendrick and K. Waples for C. Simpson).

Results of consultation with Technical Panelists

Four responses to the Department's request for advice were received, with regard to the nomination of a preferred strategy from the Question of Monitoring Paper. The responses of the Technical Panel are summarized as follows (in alphabetical order of respondents):

- Dr John Huisman School of Biological Sciences and Biotechnology, Murdoch University

  Support for strategy 2: Monitoring using the methods and species list of the developing National Monitoring Network should be undertaken in one or more of the marine parks and FHPAs.

  This Panelist advised that '…environmentally sensitive areas are at low risk, the implication being we should be concentrating on the high risk areas [the 18 ports included in the national system] and then only looking more broadly if a truly 'invasive' species arrives…' However, putting cost and resource issues aside, monitoring of environmentally sensitive areas is a preferred scientific strategy for gaining knowledge of marine flora and fauna as a first priority, which would include the detection of any marine pest species that might be present in any case.

- Dr John Keesing Stream Leader, Western Australian Coasts, CSIRO Marine and Atmospheric Research

  Support for strategy 2: Monitoring using the methods and species list of the developing National Monitoring Network should be undertaken in one or more of the marine parks and FHPAs.

  This Panelist recommended consideration of climate change impacts in the Wells (2008) paper, in view of the potential for change in environmental conditions along the WA coastline, particularly latitudinally, that may affect the distribution and abundance of native flora and fauna and their resilience to the effects of invasive organisms.

- Dr Alan Kendrick and Dr Kelly Waples (on behalf of Dr Chris Simpson) Marine Science Program, Dept of Environment and Conservation

  Support for strategy 2: Monitoring using the methods and species list of the developing National Monitoring Network should be undertaken in one or more of the marine parks and FHPAs.

  These Panelists suggested that the term 'environmentally sensitive areas' could be defined in a manner that considers candidate marine reserve areas listed in the 1994 'Wilson Report', and 'terrestrial' CALM Act reserves which include intertidal areas (eg. Great Sandy Islands Nature Reserve, Scott Reef).

  It was proposed that priorities for including conservation estates in the National Monitoring Network could be established; however, this proposal goes beyond the scope of the question posed for advice, and was not considered by other Panelists who provided advice.

It was further noted that the potential for increased shipping activity in existing ports, and the potential for new ports may change the risk of introducing NIMS in WA. '…The monitoring of environmentally sensitive areas should include the capacity for regular review in relation to such changes'.

- Professor Di Walker Professor, School of Plant Biology, University of Western Australia:

  Support for strategies 2 (as a minimum), 3 (a preferred approach) and 4 (to be considered):

  2. Monitoring using the methods and species list of the developing National Monitoring Network should be undertaken in one or more of the marine parks and FHPAs.
  3. An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using the NIMPCG target list.
  4. An alternative method of monitoring should be undertaken in one or more of the marine parks and FHPAs, using an alternative list of target species.

The support for strategy 2 as a minimum included a recommendation to undertake surveys in at least one tropical and one temperate environmentally sensitive area.

This Panelist recommended consideration of '…introduced marine pests as uninvited 'passengers' on yachts…'

Advice to the Department of Fisheries

The advice presented here is for consideration by the Department, to inform its efforts to prevent the introduction and spread of NIMS, and in particular introduced marine pests, in Western Australian waters.

Consultation with independent scientific experts has identified a need for monitoring of marine parks and FHPAs in Western Australian waters. Further consultation with the Panel of experts resulted in a collective **recommendation that a future project should initially select at least one tropical and one temperate environmentally sensitive area for monitoring, using the methods and species list of the developing National Monitoring Network**. Such a project should be designed to validate its scientific value, and inform the approach for continuing and/or expanding the program to other areas.

The quality of this advice is unlikely to be improved with additional effort to undertake technical workshops, although such a discussion may be an option in the future, when data from port surveys undertaken through the National Monitoring Network, and data from monitoring of environmentally sensitive areas become available.

Part 2 Communication of the results

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Introduced marine species in Western Australia

Department of Fisheries

INTRODUCED MARINE SPECIES IN WESTERN AUSTRALIA

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Introduction

As the largest State in Australia, Western Australia (WA) has a long and relatively pristine coastline that stretches over 12,500 km, or over 20,700 km if the State's 3,747 islands are included. The coast ranges over 20 degrees of latitude from the temperate south coast to the northern tip of the tropical Kimberley. There are a wide variety of coastal marine habitats in this vast area. The south coast has extensive white sandy beaches interspersed with granite headlands. A diverse range of nearly 800 species of temperate marine algae, or seaweeds, occurs in the area. With 26 species, the seagrasses of the State are the most extensive in the world, covering an estimated 20,000 square kilometres. There is a rich diversity of fauna species, both invertebrates and fish, associated with these plant communities. Numerous species of whales, dolphins and sea lions live on the south coast.

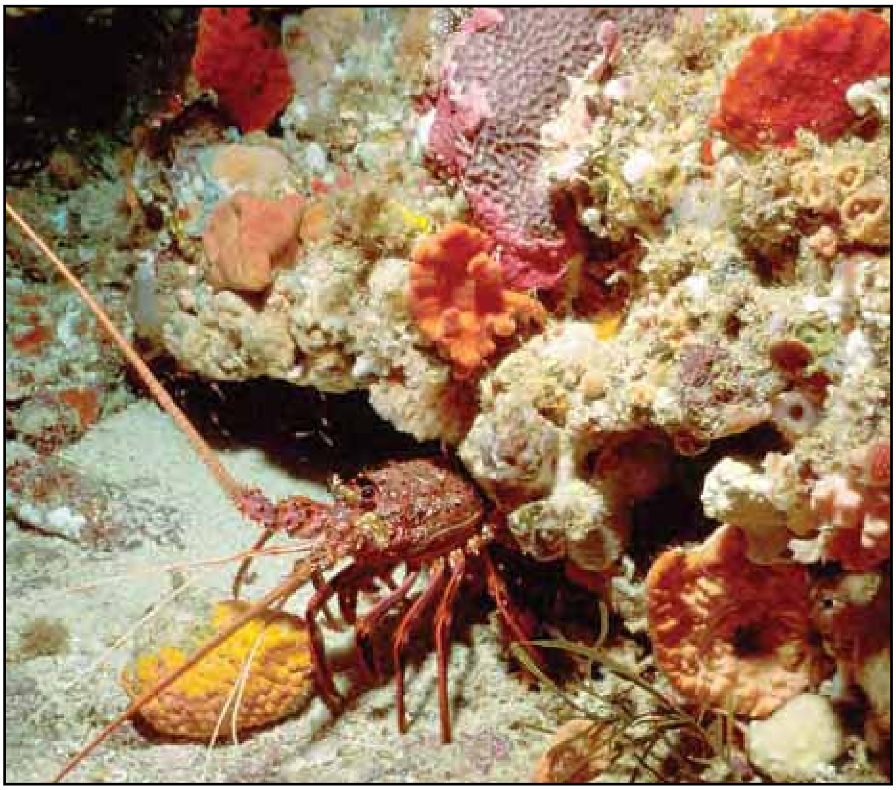
Foremost among the habitats on the north coast is Ningaloo Reef, the largest fringing reef in the world. It stretches from the tip of North West Cape 300 km south to Red Bluff. In recent years, Ningaloo has become famous as one of the best places in the world to see whale sharks. In addition, there is a fantastic variety of reef life, including large fish, which are very accessible as the reef is close to shore. There are other coral reefs in the coastal areas of the Pilbara and Kimberley. On the edge of the continental shelf, open ocean atolls are found at Rowley Shoals, Scott Reef, Seringapatam Reef, and Ashmore Reef. These reefs have a very different biota from that which occurs inshore along the continental coastline. The Pilbara has extensive mangroves, with eight species of mangrove plants and many associated animals. Further north there are much larger mangrove forests, with a total of 16 plant species.

The west coast also has a wide range of marine habitats. Shark Bay is on the World Heritage List as one of the most important marine and terrestrial areas in the world. The 12,000 square kilometres of the bay has the largest remaining population of dugongs in the world. The arid coastline has an unusual hypersaline setting where the heads of the bays reach salinities of up to 70 parts per thousand, approximately double that of normal seawater. The bay has extensive seagrass meadows, a wide variety of fish, and the dolphins that come to the shore at Monkey Mia are world famous. Closer to Perth, Rottnest Island is a favourite among West Australians. The beaches and fishing at Rottnest are a major attraction. Further south the Capes to Capes region is a national park with a beautiful open coastline. Plans are in place to develop a marine park in the area.

The population of the 2.5 million square kilometres of Western Australia has recently passed two million, 75% of whom are in the Perth metropolitan area. Perth and the southwest have high human population density, but away from these areas there are vast parts of the coast where there are very few people. Those that live outside the metropolitan area are clustered together in small towns such as Karratha, Dampier, Port Hedland, and Broome on the north coast, Albany and Esperance on the south coast, and Bunbury and Geraldton on the west coast. While activities in these marine areas, particularly large scale shipping, have increased tremendously with the recent economic boom, it is still true that human impacts on the WA marine environments largely occur near the settlements, and open areas are relatively untouched.

The importance of Western Australian marine environments was highlighted by a recent study published in *Science*. The authors analysed the worldwide distributions of 3,225 species of corals, fish, molluscs and rock lobsters that live on coral reefs throughout the world. Eighteen hotspots of coral reef biodiversity were found, including one on the west coast of Western Australia. The WA hotspot includes Ningaloo Reef, the outer islands of Shark Bay, the Houtman Abrolhos Islands and Pocillopora Reef at Rottnest Island. The international significance of the hotspot is indicated by the fact that it ranks seventh in total diversity (768 species) among the 18, second in the number of restricted range species (56) and only 15th in terms of threats from human activities.

Many of the open water habitats in Western Australia, such as this coral scene in the Houtman Abrolhos, are in excellent condition.



The western rock lobster, *Panulirus cygnus*, is the most valuable commercial and recreational species in Western Australia.

Commercial fisheries are a key component of the Western Australian economy, particularly in regional areas. The western rock lobster fishery for *Panulirus cygnus* is the largest single wild caught species fishery in Australia, with an average annual value to the fishermen of approximately $ 300 million. Many of the coastal towns on the west coast, such as Lancelin, Jurien Bay, Cervantes and Dongara originally started as fishing towns and still depend heavily on the rock lobster industry. In the north of the State, growing and harvesting the south sea pearl, *Pinctada maxima,* is one of the largest aquaculture industries in Australia. There are also valuable commercial fisheries for prawns, scallops, scalefish, and other species. Overall, commercial fisheries contribute about a half a billion dollars to the Western Australian economy.

It is critical that we maintain the Western Australian marine habitat in excellent condition for the present and future generations. Introduced marine species are a global problem, and are a serious threat to global biodiversity. Many introduced species cause no apparent harm, but some become serious pests. Among other problems, these pests can cause diseases in humans and native species, disrupt ecosystems, damage fisheries and aquaculture activities, and cause industrial problems such as fouling.

This book brings together our present knowledge of introduced marine species in Western Australia, including pest species, to provide information to anyone interested in this issue. We hope that by doing so, people will be better informed about marine pests and what we can do to minimise the risk of further introductions and their spread.


Photo: Rod Knight

The Northern Pacific Sea star, *Asterias amurensis*, has devastated the seafloor in Port Phillip Bay, Victoria.

Marine biogeography of Western Australia

Distribution patterns

Covering nearly a third of the continent, Western Australia is by far the largest state of Australia. The coastline can be divided into three biogeographical regions that are susceptible to very different threats from possible introductions of marine species.

The shallow, coastal waters of the north coast of Western Australia, from about North West Cape to the Northern Territory border, are part of the vast Indo-West Pacific marine biogeographic region. Species that occur along our north coast tend to be widely distributed. While some species occur only in a small part of this area, such as the Kimberley, most occur along the entire coastline of northern Australia to the southern end of the Great Barrier Reef in Queensland. Many of the species also occur in tropical countries to our north such as Indonesia, Papua New Guinea, Thailand, Malaysia, and the Philippines. In fact, the Indo-West Pacific Province stretches across the warm, tropical parts of the Indian and Pacific Oceans from the east coast of Africa through Southeast Asia and southern Japan as far east as the Hawaiian Islands and the South Pacific. Some individual species, such as the money cowry *Cypraea moneta,* occur over this entire range. A few Indo-West Pacific species have even been occasionally recorded along the west coast of the Americas!

A key feature of any biogeographic region is that while a species may occur in the region, it will live only in habitats that are suitable to the biology of that species. Because of this there are significant differences between species that occur along the continental coastline of the WA north coast and those that live on the coral reef atolls along the edge of the continental shelf, areas such as the Rowley Shoals, Scott Reef, Seringapatam Reef, and Ashmore Reef. Mangroves and bays with muddy bottoms are abundant along the inshore continental coastline and the water has high silt concentrations. Species living in this area are very different from those that live on the coral reefs of the offshore atolls where the ocean water is much cleaner.

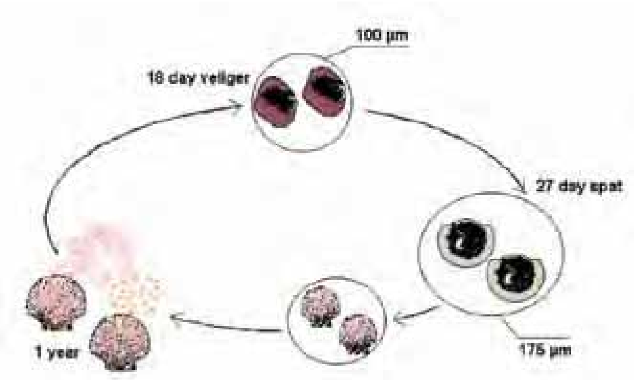
Map of Western Australia showing the shallow water marine biogeographic regions (after Wilson and Allen, 1987).

In contrast to the tropics, the shallow waters of the south coast of Western Australia are part of the Southern Australian Temperate Zone. The biota of southern Australia is almost different from that of the tropics, with a very small proportion occurring in both areas. While a few species are shared with New Zealand or southern Africa, the vast majority of south coast species are restricted to Australia. For example, about 85% of the 600 species of inshore fish are restricted to the south coast; 11% are shared with New Zealand, and 4% are a combination of circum-Australian, circum-temperate or are shared with other southern continents. The Southern Australian Temperate Zone extends from Cape Leeuwin at the southwestern tip of Western Australia across the southern shores of the continent to New South Wales. Most of the temperate species which occur along the south coast of Western Australia are distributed across the entire coastline from the South Australian Border to Cape Leeuwin. There are no major distributional barriers along the south coast. However, a few species do occur from southeastern Australia along the southern Australian coastline and have their western distributional limits in the area between Esperance and Albany.

The west coast of Western Australia, between Cape Leeuwin and North West Cape, is the Western Overlap Zone. There is a change in the shallow water biota that inhabits the Western Overlap Zone proceeding from south to north. The southern portion of the zone is inhabited by temperate species that decrease in diversity to the north. In contrast, the northern part of the zone is inhabited by tropical species that decrease going south. A key feature is the shallow water species that are endemic to Western Australia, occurring nowhere else in the world. The proportion of such species varies between taxonomic groups, being low in fish and high in echinoderms, but averaging about 10% across a wide variety of plants and animals. The ranges of individual endemic species differ: some occur on the north coast and some on the south coast; others occur from the south coast, along the entire west coast, and onto the north coast. Despite these differences, most of the species have at least some of their distribution on the west coast. Shallow water endemic species, such as the western rock lobster, can be ecologically and/or economically important. one of

Distribution mechanisms

If marine species are so widely distributed, the question is how do they do this? The answer lies in the planktonic larval stage, which occurs in the vast majority of marine animals. In its simplest form, males and females respectively spawn sperm and eggs into the water column. Fertilisation is external, and takes place in the water. The developing larvae go through a planktonic stage where they remain in the water and are carried about by of ocean currents. More advanced species have internal fertilisation. They produce fewer eggs, but there is a higher survival rate because a greater percentage of the eggs are fertilised and develop into planktonic larvae. The time spent in the plankton varies considerably. Many species live in the water for only a few days to a week. They are dependent on yolk from the egg for nutrition and do not feed in the plankton. Other species may live in the water for a year or more, providing extensive dispersal capabilities. For example, the western rock lobster goes through 15 life stages during an 11-month journey in the plankton, before the final puerulus stage settles to the bottom and moults into the juvenile form.



Life cycle of the commercial scallop *Amusium balloti*, showing the planktonic larval stage.

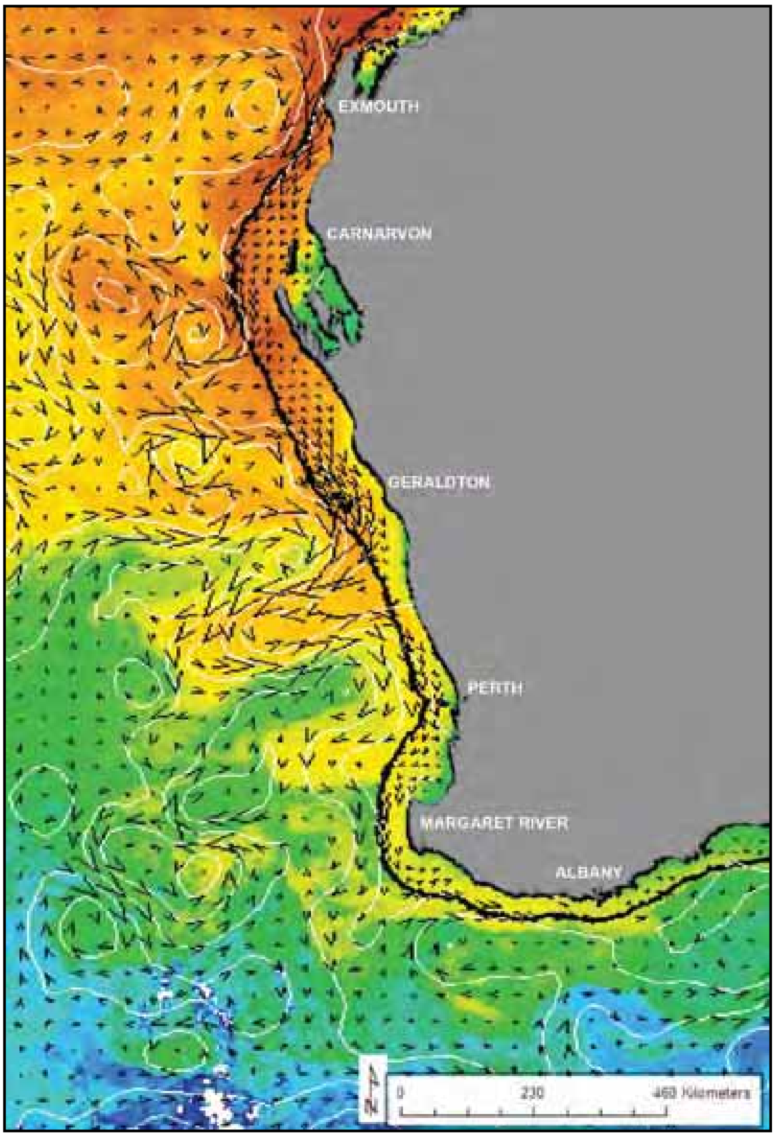
Most marine species that lack a planktonic larval stage have other means of distributing themselves over a wide area. Marine plants, such as species of the brown alga *Sargassum,* can be torn from the sea bottom during storms and then carried about by currents. The plant continues to live in the water column. Any species that is attached to the plant is also carried away. Small fish are attracted to the floating plants as they provide hiding places from predators. The fish then swim wherever the *Sargassum* is carried, and both the plant and its associated animals broaden their range. Other marine invertebrates may be attached to large mobile species such as whales and turtles. It is important to remember that a species does not have to be distributed over its entire range in the lifetime of a single individual. All that is required is that there is sufficient genetic exchange between the various populations for them to remain in contact with each other and not diverge into separate forms.

The Leeuwin Current

The famous Australian naturalist Saville Kent reported in 1897 that winter sea surface temperatures at Geraldton were several degrees cooler that those at the Houtman Abrolhos Islands to the west. He speculated that there was a south flowing current that keeps temperatures on the islands warmer than would otherwise be the case, and that the current does not reach the continental coastline at Geraldton. It was more than 80 years later, in 1980, that George Cresswell and T. J. Golding described the Leeuwin Current.

As we understand it now, the South Equatorial Current flows west from South America as part of the huge gyre that moves water about the margins of the South Pacific Ocean. As it nears Australia, the South Equatorial Current turns southward and flows down the east coast of Australia as the East Australian Current. Some of the water from this massive current flows through the Indonesian Archipelago to an area off northern Western Australia. This Indonesian through flow is thought to be the key driving force for the Leeuwin Current.

The Leeuwin Current forms north of North West Cape and flows south along the outer continental shelf of the west coast. It is strongest in winter, maintaining sea surface temperatures higher than they would otherwise be in areas such as the Abrolhos, the western end of Rottnest Island and other offshore islands. The current is a key mechanism for the distribution of tropical species down the west coast of the State.



Satellite photograph of the Leeuwin Current. Areas in red are where sea surface temperatures are greatest; those in blue are the coolest waters.

Naturally changing distributions

The distributions of individual species are not constant. Instead they vary over time. In recent geological history distributions changed with the ice ages. There are also significant variations over shorter time frames. The strength of the Leeuwin Current varies from year to year. In years when it is stronger, larvae of tropical species are distributed further down the coast than they are in years with weaker Leeuwin Currents. The mangrove crab, *Scylla serrata,* provides an excellent example of this. The crab is a tropical species that is abundant in mangroves and coastal muddy areas along our north coast as far south as Shark Bay. A strong Leeuwin Current in 1999/2000 brought larvae farther south than usual and a population developed in the Moore River at Guilderton. Suddenly fishers were collecting mangrove crabs in an area where they had never been found before. Over the next year or two crabs were also found further south, with some being caught as far south as Wilson Inlet on the south coast. These crabs reached full legal size and were fished, but conditions were not suitable for them to spawn and the population was not replenished. Over time they were fished out and the southern populations disappeared.

Another example is that in recent years the western rock lobster, *Panulirus cygnus,* has been more abundant than usual in the area near Cape Naturaliste. The enhanced catches have attracted larger numbers of rock lobster fishers to the area, creating conflicts with local surfers when the two groups are operating in the same waters.

In this time of climate change, there will be a tendency for water temperatures along the west coast to increase. As this happens, the ranges of more tropical marine species will be extended to the south, along with a contraction of temperate species.

On a larger scale, shells of three species of marine snails, *Bullia annulata, Cymatium cutaceum africanum* and *Nassarius kraussianus* were found at beaches near Augusta in the southwestern corner of the State during the 1980s. These are common South African species that had never before been found in Australian waters. Apparently they had been carried as larvae across the southern Indian Ocean to Augusta where they settled from the plankton and survived. While the animals lived, they did not reproduce, and no populations were formed.

Introduced marine species

Difficulties in identifying species

The marine flora and fauna of Australia is highly diverse with tens of thousands of species spread across dozens of phyla of marine plants and animals. Nobody knows exactly how many species occur either in Australian or Western Australian waters.

The most detailed species list for any area of Western Australia has been developed for the Dampier Archipelago and the nearby Burrup Peninsula by the WA Museum. A number of surveys have been conducted by the Museum in the Dampier region. Over 80 scientists from throughout the world, all specialists in different groups, have examined the specimens collected during these surveys. Together, they have found over 4,500 species of marine flora and fauna in the Dampier Archipelago. Many have been previously unknown to science or are new records for Australia or Western Australia.

A series of six marine biological workshops organised by the WA Branch of the Australian Marine Sciences Association in different areas of the State, including one in Dampier, have discovered more than 300 new species and 20 new genera. Many groups of animals have never been scientifically studied in the State. Two groups were examined in detail for the first time in WA at the workshops: marine mites and marine oligochaetes, the group to which terrestrial earthworms belong. Over 70 species were found in each group, most new to science. Clearly, no one person or group of people can be familiar with all these organisms. This has a significant impact on the recognition of introduced species, as the first step in establishing whether a species is introduced is to know what marine species occur naturally in an area. For most of our coastline we have little understanding of the 'naturally' occurring marine flora and fauna present.

Albany, on the south coast of Western Australia, has long been known for oysters, as indicated by the name Oyster Harbour being given to one of the three marine embayments in the area. One of the local oysters in the region is *Ostrea angasi*, which has been farmed commercially for years. A recent study, which included DNA analyses, demonstrated that in fact two species are present where it was thought there was only one! The presence of the second species, the European oyster *Ostrea edulis* had gone undetected for an unknown period.

How the European oyster arrived in Albany has not been determined, but early colonists could have brought it in as an aquaculture species shortly after the colony of Western Australia began. In the poor record keeping of the colonial days the fact that it was introduced was forgotten until the recent rediscovery. Although the two species are genetically distinct, they cannot be easily separated on external shell morphology.

On the botanical side, the marine alga *Codium fragile* ssp. *fragile* has been introduced around the globe through shellfish aquaculture, recreational boating, and transport on ship hulls. *Codium fragile* ssp. *fragile* has serious economic implications for aquaculture industries. Indeed, the tendency of this species to overgrow and smother oyster beds has earned it the nickname 'oyster thief'. In its quest for a stable substrate *Codium fragile* ssp. *fragile* will often make its home on the shells of oysters, scallops, and clams. This can cause problems because an attached adult plant can hinder the movement and feeding of the shellfish. In cases where the attached plant is relatively large and wave exposure is high, the shellfish can be swept away with the plant. The species fouls shellfish beds and causes a myriad of impacts on shellfish communities. This species also causes a nuisance to humans when it accumulates on beaches and rots, producing a foul odour.

In Western Australia we have a native species of *Codium fragile*. However, there is an invasive subspecies, *Codium fragile* ssp. *fragile*, that readily colonises new areas. As with oysters, the invasive strain of *C. fragile* ssp. *fragile* cannot reliably be distinguished by an examination of external morphology; genetic analyses are recommended.

Cryptogenic species

The great majority of marine plants and animals have evolved in the area in which they live, and they remain in that particular marine biogeographic region. However, a large number of species have been moved about by human activities over the centuries. Wooden sailing vessels were used for thousands of years. The wooden planks on their hulls provided a ready means of transport for species that could live attached or burrowed into the wood. While organisms cannot burrow into steel, the more recent use of steel ships has still allowed both marine plants and animals to adhere to their hulls, and niche areas or in internal piping. Many species have been found with clearly unnatural distributions, occurring in widely separated ports that are in very different marine biogeographic regions. One example is the nudibranch *Polycera hedgpethi.* The species was described in 1964 from California, and was originally thought to be native to the temperate west coast of North America. However, *P. hedgpethi* was found in Auckland, New Zealand in 1972. It has been recorded from several temperate Australian areas, including Albany in 1980, and also South Australia, Victoria and New South Wales. Overseas it has been found from widespread areas, including South Africa, western Africa, Spain and Japan. Clearly this is not a natural distribution pattern, but where the species originated has not been determined. Species such as these are called cryptogenic (from the Greek *kryptos* = hidden, and *genes* = born) for their uncertain origins.

Bacteria and viruses

The present handbook deals only with relatively large species, and does not include minute forms such as viruses and bacteria. This is not to say such life forms are not important, in fact they can be critically so.

For example, in March 1995 a mass mortality of pilchards occurred and resulted in dead fish washing up on the beaches of South Australia. The mortality event spread rapidly, as much as 30 km/day, and by the end of June stretched across the entire southern coastline of the continent from Carnarvon, Western Australia to Noosa Heads, Queensland. Millions of fish had died during this period. A second mass mortality occurred in 1998 when 60-70% of adult pilchards were killed in Western Australia. This resulted in closure of all of the WA pilchard fisheries. A *Herpes* virus was responsible for the deaths, but the origin of the virus could not be established.

Methods of introduction

Marine species have probably been moved from one location to another ever since humans began to move about in boats, so introduction of species into far-flung areas is nothing new. What differs now is the scale of human activity and the speed of ships and other vessels. Many modern ships can move through the water at speeds of up to 30 knots, or about 55 kilometres per hour. Such a speed means they can travel more than 1000 km in a day. This provides a ready means of moving adhering organisms from one part of the ocean to another in a few days.

Associated with vessels there are two main vectors for introduced marine species, these include ballast water and hull fouling. In the days of wooden ships, heavy rocks and other materials were used as dry ballast to ensure that the vessel floated properly in the water. When the vessel entered a port and was loaded, the ballast was simply thrown overboard or put to use on shore. A stone portico structure intended for the port entry into Jakarta was recovered from the wreck of the *Batavia* in the Houtman Abrolhos Islands. It was being used as ballast on the trip to Jakarta. Several introductions are known to have occurred through such dry ballast.

Since World War II there has been a dramatic change from using rubble and solid material to using seawater as ballast. When a vessel takes on cargo in a port the water is pumped out of the ship. The problem is that the water provides a habitat for the transfer of planktonic larvae of bottom dwelling species and larvae and adults of planktonic species that live in the water itself.

Overall, shipping is considered to have been the source of most of the introductions of marine species into new areas. However, there are many additional sources that are also important in distributing these organisms.

A major concern in northern Western Australia is hull fouling on illegal foreign fishing boats that have been found along our north coast. Many of these vessels are wooden Indonesian prahus. Like the sailing ships of old, the wood provides attachment for many species and others burrow into the wood itself. The boats are slow moving and sometimes poorly cleaned. These vessels often stay in an area for weeks, providing considerable time for any introduced species to move about into nearby areas. Many prahus have been found hidden in mangroves along the shores; the close contact with the bottom and the variety of coastal habitats giving ample opportunity for the transfer of any species that might be on the hulls. Some of the prahus that have been inspected have had the black striped mussel, *Mytilopsis sallei*, attached to their hulls. Often the vessels are deemed to be unseaworthy. If the crew is convicted of illegal fishing the boats are burned to prevent the introduction of diseases, etc into Australia.

Another opportunity for introduction of foreign marine species is presented by ocean going yachts. These vessels are in the water for considerable periods of time, allowing species to become attached to their hulls. As they move into new areas the attached organisms can then be introduced into the new area. Fishing boats are another potential source of introduced species. Like yachts, they are in the water for prolonged periods. Some, such as boats in the Northern Prawn Fishery, move widely about over the coastline. In addition, nets and other fishing gear are in close contact with the bottom. This presents opportunities for species to be caught up in the nets and be taken on board. There is increased opportunity for survival and transmission to new areas if the netting remains damp.

The early settlers to Australia brought with them many items that they found useful in the United Kingdom, including living agricultural plants and animals. The oyster *Crassostrea gigas* was introduced into Tasmania in the late 1940s for aquaculture. The species is farmed commercially in the southeast of Australia. In addition to being beneficial, *C. gigas* is also a pest species that forms feral populations that disrupt local ecosystems. Thus it is both a good and bad introduction. Often, species that have been deliberately introduced into a new area have carried with them other species, including pest species. One famous example is the introduction of the American oyster, *Crassostrea virginica,* into England in the late 1800s. Unfortunately, a predatory snail, the oyster drill *Urosalpinx cinerea*, was among the oysters and became a pest species in southern England. Fortunately, we have learned from such mistakes. Any request for the introduction of new species for aquaculture must undergo rigorous testing before it is allowed into the country.

Maintaining fish and other species such as snails, plants, etc. in freshwater aquaria is a popular hobby that has been going on for years. Unfortunately, people sometimes lose interest in the fish and discard them into nearby rivers and streams where they establish populations. These populations can be used by aquarists to replenish their fish tanks, and the populations can be spread by humans, or through natural means. In 2006 the South American cichlid *Geophagus brasiliensis* was found in the Bennet Brook/Whiteman Park area near Lockridge, WA. The species is carnivorous and can wreak havoc with local populations. The population was thought to be about three years old when it was discovered. So far attempts to eradicate the species from this area have failed.

Photo: Justin McDonald

The South American cichlid *Geophagus brasiliensis* has become established in the Bennet Brook/ Whiteman Park area near Lockridge WA.

Fortunately, saltwater aquaria are much more difficult to maintain than freshwater aquaria, so the problem of no longer wanted fish is reduced because there are fewer owners of marine aquaria. However, there are still many species that could potentially be introduced through this mechanism. That this is a real problem is illustrated by *Caulerpa taxifolia*, a marine alga that was once widely used as decoration in marine aquaria. This species is now regarded as one of the world's most invasive species.

In 1984 a small patch of a vigorous strain of *Caulerpa taxifolia* was found growing near the Monaco aquarium. *Caulerpa taxifolia* spreads by horizontally growing stolons and by 2004 the plant had spread to cover an area of 30,000 hectares – an expansion of 30 million times the original outbreak! It does not reproduce sexually, so all of the transmittal is by movement of fragments of algae that can become established in new areas. As the plants are fragile, boat anchors and fishing nets can easily break off segments. The invasive strain has a higher pollution tolerance than other plants in the area, so it is able to invade polluted environments. The invasive *C. taxifolia* came to dominate the benthic environment. Like many other algae, *C. taxifolia* produces noxious chemicals that repel species that would otherwise feed on it. The fauna of small species living in association with the alga are different, and the entire environment is changed.

The invasive strain, which originally came from southern Queensland, has been transported around the world via the aquarium trade and further escapes have occurred in New South Wales, South Australia and the west coast of the United States. This alga was previously sold in aquarium shops around Perth and was freely traded; it is extremely fortunate that no escapees occurred. It could easily survive in WA's water temperatures. *Caulerpa taxifolia* is now banned from sale, but it is likely that remnant plants are being maintained in home aquaria.

Although the idea would not occur to most people, human food is another potential source of marine species introductions. There is an increasing demand for fresh fish and other marine species that are sold live in markets and restaurants. While these species are usually sourced from within Western Australia, some are imported. Occasionally the animals may be discarded into the Swan River or the local marine environment where they have the potential to survive and establish new populations.

Not all introductions survive

Not all species that are transmitted from one area to another survive. Arriving in a new location is simply the first step to colonising an area. When species arrive they must have the right environment in which to live. Temperature and salinity levels are perhaps the greatest constraint to an introduced species successfully occupying a new area; if the temperatures or salinity levels are too extreme a species will simply not survive. For example, a fish coming from the tropical waters of Indonesia will have a much greater chance of surviving in the warm water areas of the WA north coast than in the cooler waters of the south coast. Similarly an estuarine species adapted to low salinities may not survive in the high salinity environments of the open coast, and a rocky shore species may not adapt to a muddy bottom area. Even if the physical environment is suitable, there are a host of relationships with other species that may prevent the new arrival from surviving, such as predation, competition, parasitism, and many others.

There have been two grand "experiments" in inadvertently changing marine distributions on a large scale, with very different results.

In 1969 the Suez Canal was opened. The 163 km long canal connects the high diversity Red Sea with the low diversity eastern end of the Mediterranean Sea.

The Suez Canal is essentially a channel cut through the sand. It is a sea level canal, meaning there are no locks or other obstructions. Ships are able to move from one end to the other. The canal was dug through a region known as the Bitter Lakes where salinities were much higher than the 35 parts per thousand of normal seawater. In the early decades after the canal was opened, the high salinity in the middle was a barrier to the movement of species from one end to the other. However, salinity became more uniform over time and the barrier disappeared. Over a hundred species have since spread from one end of the canal to the other. Such spread may have occurred by a progressive stepwise extension of populations or by one-off migration or transport by ships. Most of the species have spread from the Red sea to the Mediterranean, presumably because there are move vacant niches in the low diversity Mediterranean. The introductions have resulted in profound changes to the marine biology of the eastern Mediterranean, with as much as 10% of some groups of animals being introduced species.

The Panama Canal, opened in 1914, connects the Atlantic Ocean with the Pacific Ocean at the narrowest part of the Central American isthmus. At 80 km from deep water to deep water, the Panama Canal is only half as long as the Suez Canal. Yet in contrast, there have been fewer than a dozen documented movements of species from one side to another over the last century. The reason is simple – the Panama Canal is a lock canal. To minimise digging through a low lying mountain chain, the Chagres River was dammed, creating what was at the time the third largest man made lake in the world. Vessels entering the canal on one side are raised a total of 29 m through a series of three locks. They then sail through the fresh water of Gatun Lake to the other side and are lowered back to sea level. The average of eight hours spent in freshwater presents an effective barrier that has prevented all but a few species from moving from one ocean to the other.

Where introduced species come from

It is likely that most of the species in the Indo-West Pacific that could colonise the north coast have arrived here over the millennia and survived if the right habitats occurred in the north. However, there are invasive species such as the Asian green mussel, *Perna viridis,* which have the potential to become pest species in the north.

The marine biota of other tropical areas, such as the eastern Pacific, Caribbean Sea or eastern Atlantic, is largely distinct from that which occurs on the north coast of Australia. If species from one of these areas were to reach our tropical shores, there is a significant possibility of it surviving. While such a transfer appears unlikely, it can happen. The black striped mussel, *Mytilopsis sallei,* is thought to have originated in the Caribbean Sea. It has been distributed to many tropical ports, including Fiji, India, Japan, Taiwan, Indonesia, and Hong Kong. Any of these stepping-stones can provide a source population for the species to reach Australia. The species was established in three small marinas in Darwin in the late 1990s. It was thought to have been carried to Darwin on one or more yachts, and rapidly spread in the harbours. Fortunately, this is one of the few marine species to be successfully eradicated.

Temperate southern Australian habitats are considered by many to be at greatest risk from introduced marine species. The south coast of Australia has been separated for geological eons from the flora and fauna of the temperate North Pacific by the extensive temperature barrier of the tropical Indo-West Pacific region. There is little natural exchange of species between the two areas, and they have evolved separately. The advent of modern shipping has provided a means of rapidly transiting through the tropics and transporting species in ballast water or on the hulls. Many species have made the transition, including the destructive Northern Pacific sea star, *Asterias amurensis*, and the mussel *Musculista senhousia.* The Japanese seaweed *Undaria pinnatifida*, also known as 'wakame' in Asian cuisine, has been introduced to Tasmania and Victoria. The issue is not simply with the North Pacific. Species can also be transported from southern hemisphere areas, such as the mussel *Perna perna* from southern Africa. There have also been well-publicised introductions of the crab *Carcinus maenus* and the fanworm *Sabella spallanzanii* from Europe.

Although often not considered, the Eastern Australian overlap zone is also a potential source of introductions into Western Australia. Again, the east coast has species which have evolved independently of the west and which have no natural means of extending their distribution. However, interstate shipping now provides a vector. The scallop *Scaeochlamys lividus* is one such species that has been distributed from eastern Australia into the Fremantle marine area: the lower Swan River, Fremantle Harbour and Cockburn Sound. It has also recently been found in more exposed areas of the adjacent open coast.

It is interesting to note that the flow of introduced species is not all one way, into Australia. Just as species are introduced into Australia, so our marine environment can be a source for introductions into other parts of the world. Genetic testing has shown that the two species of *Caulerpa*, *C. taxifolia* and *C. racemosa* var. *cylindracea*, that are now causing major problems in the Mediterranean and elsewhere, originated from, respectively, southern Queensland and south-western Australia. Other introductions of marine species include the barnacle *Balanus modestus* into the United Kingdom and the snail *Bedeva paivae* into South Africa.

Concentrated in port areas

While we know that introduced species are concentrated in port areas, the reasons for this are not fully understood. Certainly most of the transmittal vectors are concentrated in the marine areas near major towns and cities where ports occur. Most types of vessel movements, from large ships through the fishing boats, recreational boats, and other users are concentrated in protected marine areas. Thus it is natural that species occur in these parts of the coast. However, once they arrive, relatively few species are able to expand their range outside these restricted areas. Dredging, construction of ports, small boat jetties, moorings, roads and breakwaters along the shoreline, buildings, and the myriad of other human activities all disrupt the coastal marine environment and local ecosystems, creating opportunities for introduced species to colonise and survive.

On the one hand, this is good, as it tends to mean that the problem of introduced species is restricted to relatively small areas. On the other hand, those species that expand outside the harbours can create a disproportionate amount of damage and become widespread pests.

Risks posed by different vessel types

Different types of vessels provide very different risks for the introduction of marine species. At the low end of the risk spectrum are ships such as liquefied natural gas (LNG) tankers. They are generally operated by the company producing the LNG and are dedicated for that purpose, operating between a tropical port on the north coast of Australia and a temperate Asian port. There is low biogeographic risk of introductions because temperature shock will kill most species. The vessels are well maintained and are routinely cleaned and anti-fouled. In addition to being good environmental practice, it is in the company's interest to have the vessels as clean as possible, as fouling organisms will slow the vessel and add to fuel costs. When ships are in port it is for a minimum period to load cargo, then they depart. There are many vessels in this category that operate in Western Australia.

The high-risk vessels are generally those that are slow moving, have numerous spaces where marine species can gain purchase, and come in close contact with the sea bottom. Some of these vessels stay in a single area for months, enhancing the opportunities for species to settle at the source and then be introduced to new regions. Vessels in this category include dredges, supply boats and drilling rigs, and some fishing boats. Other high-risk ships include some of the flag of convenience carriers that are low cost operators with poorly maintained vessels.

Minimising risk of introductions

With such a myriad of species that can be introduced, a wide range of potential distribution mechanisms, and a variety of available habitats, management of introduced species is a very complex problem. The key is preventing introductions as a first line of defence; it is by far easier to prevent the arrival of a species than to eradicate it once it has arrived. Successful marine pest eradications are rare worldwide and the costs are substantial. With the massive amount of shipping that is moving around the world, there will always be species that slip through. The goal is to minimise the arrival of new species and to prevent them from becoming established once they are here.

Ballast water

Large vessels use extensive amounts of ballast water to maintain their correct position in the water. Simply put, there are a number of tanks on large ships which can be filled with water when the ship has a light load. These add weight, sometimes thousands of tonnes, to the vessel, allowing it to settle to the waterline at which it should be operated. When a vessel enters a port the ballast water is discharged and the vessel rises in the water. It then takes on a cargo that makes it heavier, returning it to the waterline. This is an efficient system that allows vessels to be operated safely. The unfortunate part is that the thousands of tonnes of water in the ballast tanks provide an ideal habitat for some species of plankton to live inside the ship. Some of these may be species that live permanently in the water column, while others are larval stages that settle and become benthic organisms; either in the ballast tank or after the ballast water is discharged. Seawater taken on as ballast contains sediment, which tends to settle to the bottom of the ballast water tanks, forming a muddy bottom. This can become a habitat for benthic species that live on, or in, soft sediment, or highly resistant resting cysts of some toxic phytoplankton. The walls of the ballast water tank can be a habitat for species that require a hard bottom. Material in the ballast water forms the basis of the food webs within the tank.

Vessels coming into Australia from overseas are required to undertake one of two methods to exchange high-risk ballast water at sea if the water is to be discharged in port. One option is to empty the tank completely (some sea water will still be in the bottom and cannot be drained) and refill the tank with water well away from the coast. The other option is to pump seawater into one part of the tank and out the other side until three times the volume of the tank has been pumped. This substantially reduces the concentration of organisms in the tank. Neither method is perfect. The idea is that the open sea has few nutrients and very low densities of holoplanktonic species, those that live in the water column for their entire life cycle. Meroplanktonic species, the larval stages of species with bottom living adults, are concentrated in coastal areas and are depauperate in the open sea. When the vessel arrives in port it is inspected by the Australian Quarantine and Inspection Service (AQIS) checks the records of the ballast water pumps to check that they have been used if ballast water is to be discharged. Having an empty ballast water tank at sea can be a danger to the vessel and its crew. If the captain determines that it is too dangerous to exchange ballast water, such as in a storm, the requirement is waived.

A major anomaly occurs in handling ballast water – the rules are different for vessels operating entirely within Australian waters. For example, AQIS inspects the ballast water pump records for a ship coming to Western Australia from a foreign port such as Cape Town, South Africa. However, if that same ship went from Cape Town to Melbourne, then to WA, it would not be inspected on the voyage between Australian ports. Yet, there are many introduced species in Melbourne, and there are native species there that do not occur in Western Australia. To overcome this, all Australian States (except New South Wales), the Northern Territory, and the Commonwealth have signed an Intergovernmental Agreement to ensure that ballast water is handled consistently across the country, whether it originates overseas or in a different Australian port. Methods for implementing the agreement are now being developed.

Biofouling

Biofouling or hull fouling as it is more commonly known is the other major source of introductions of species by vessels. In contrast to ballast water, which is an issue only on commercial trading vessels, bio fouling can occur on any vessel, from the smallest boat to the largest ship. Basically on any part of a vessel or its equipment in contact with seawater provides a surface on which marine plants and animals can settle and grow. If the vessel is wooden, many species can burrow into the wood. As it grows, the developing fouling community provides an increasing number of complex habitats for other species to occupy. There are two major mechanisms for combating the spread of species through hull fouling:

regular cleaning and the use of antifoulants. Hull cleaning is relatively simple, and can be done whenever a vessel is in dry dock or removed from the water.

Starting in the late 1960s, tributyltin (TBT) became the most widely used antifoulant chemical. When painted on a vessel the TBT leaches out and inhibits species from adhering to the vessel. TBT is very toxic and effective. Initially it was thought to be environmentally benign. However, adverse consequences soon became apparent in a wide variety of marine organisms. The best known is a phenomenon of imposex, which has now been recorded in over 120 species of marine snails worldwide. Many groups of marine snails are dioecious, having separate males and females. When TBT is present in minute quantities (parts per billion) females start to develop male characteristics, a vas deferens and/or a penis. The rate at which this happens and the degree of change is directly proportional to the TBT concentration; the more TBT there is in the environment the faster imposex will develop and the more severe the effect. In the most severe cases, the female aperture is sealed over. The female is unable to spawn, but eggs continue to develop. Eventually the female dies. Females never become functional males. There are no known effects in males.

The first case of imposex was found in Western Australia at Rottnest Island in 1991. Professor Alan Kohn of the University of Washington, Seattle was working on snails of the genus *Conus* at the first International Marine Biological Workshop at Rottnest. Professor Kohn found 80% of the individuals of six different species had imposex. The striking fact was that most of the animals were collected at the west end of Rottnest, where TBT concentrations were only 1% of their levels in some small boat harbours in Cockburn Sound. Other studies subsequently showed that levels of imposex in Fremantle Harbour and Cockburn Sound were higher than at Rottnest. Following the report of imposex, and a study by the then Department of Environment on TBT levels in sediments, the use of TBT on vessels smaller than 25 m was banned and the rate at which it could leach from the paint on larger vessels was reduced.

The partial bans in Western Australia were part of a worldwide trend to reduce the use of TBT. The half-life of TBT in the water column is a few days, so concentrations fall rapidly. However, TBT can persist for up to 20 years in the soft sediment of harbours. In recent years there have been reports of high TBT levels in predatory species at the peaks of food webs, such as mammals. TBT is now being phased out in favour of other methods of providing antifouling, primarily copper based chemicals.

The ultimate goal of the Intergovernmental Agreement for minimising marine pest introductions is to develop nationwide protocols for both ballast water and hull fouling.

Illegal fishing vessels

For years, the Australian and Western Australian Governments have been concerned about illegal fishing in our northern waters. Not only does illegal fishing damage fish stocks, but the boats also bring disease and pest risks with them. A number of Indonesian prahus have been found hidden in coastal mangroves. The close contact between the wooden vessel and the wood of the trees and the nearby sea bottom provides a real risk of transmitting introduced marine pests. A number of the prahus have been found to be carrying the black-striped mussel, *Mytilopsis sallei,* a potentially high-risk species if it colonises Western Australia. Some of the prahus have been declared unseaworthy, their crews removed from the boats and the boats destroyed at sea. Others have been towed to port and their crews arrested. When convicted, the boats are forfeited and are destroyed by burning.

Construction and Dredging

Large-scale construction projects require assessment under the *Environmental Protection Act 1986.* Often the high-risk vessels involved are dredges. If dredging is approved, the Minister for the Environment, on advice from the Environmental Protection Authority, attaches a series of Ministerial Conditions to ensure the dredging is undertaken in a manner that minimises effects on the environment. Increasingly, if a dredge is being brought into Western Australia for a dredging program, one of the conditions is that it be surveyed for introduced pest species before it is allowed to dredge.

Eradications

As indicated above, the key to managing introduced marine species is to minimise their chances of arriving in Western Australia. There have only been two successful instances in Australia in which a marine introduction was eradicated.

The black-striped mussel, *Mytilopsis sallei,* was found in Darwin in 1999. Only six months previously a survey for introduced marine pests had not found any evidence of the species. The mussel was present by the millions in one small boat marina, and in much smaller numbers in two other marinas. It is believed to have already spawned twice during the six months. Because of the high tidal range in Darwin the marinas are separated from the sea by locks. Water is allowed to enter the lock from the marina until the two levels are equal and the boat can enter or leave the marina. The black-striped mussel was restricted to the marinas and had not colonised the adjacent open ocean. The Northern Territory government made the decision that the artificial marinas were of low environmental value and used chemicals to totally eliminate the mussels. An intensive program was then instituted to locate and inspect all vessels that had been in the marinas. Fortunately, the black-striped mussel had not spread out of the marinas. There is now a continuous monitoring program in place to provide early warning if the black-striped mussel or another species invades the harbour.

In a similar incident, the invasive strain of the marine alga *Caulerpa taxifolia* invaded West Lakes in Adelaide. The entire four kilometre length of West Lakes was sectioned off from the Port River and turned from marine to freshwater by diverting a creek into a stormwater system. Although this appears to have been successful in West Lakes, it is of course impossible to undertake in open areas. In Adelaide additional infestations of *C. taxifolia* have been found and their eradication is an ongoing battle.

However, compared to these two successful eradications, there are many unsuccessful attempts.

What we can do to help

The Biosecurity Group of the Department of Fisheries is the section responsible for undertaking of any emergency activities in response to reports of a marine pest species in Western Australia. Once a report is received, it is investigated to check that the species of concern is in fact a pest species. As indicated above, many potential pest species are closely related to species that occur naturally in Western Australia. If a pest is present, a survey must be conducted to determine the extent of the infestation and an assessment made of whether eradication can be attempted. If eradication is thought possible, it must be undertaken as soon as practical. If not, there may be measures to minimise the impacts of the infestation and to reduce the chances of it spreading. The Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE), which has representation of the Commonwealth and State/Territory governments, must be informed. CCIMPE has access to resources on a national scale that can be used for emergencies.

While the task of minimising introductions of marine species may seem to be daunting there are two things individuals can do to help.

Western Australians have a close affinity for the sea and one of the highest rates of private boat ownership in the world. The Swan River, Cockburn Sound, Rottnest Island, and many other coastal environments near the major towns and cities are all popular with small boat owners. Most people thoroughly wash their boats with fresh water after taking them out of the water to remove salt and any debris. This is good basic maintenance practice. As the boat is cleaned it should be checked to ensure that there are no living organisms, plants or animals, remaining. If there are, they should be removed. Nooks and crannies, wet ropes, nets, and other such gear provides a relatively protected habitat in which species can be transported from one part of the State to another by people going on fishing or camping trips. A few minutes spent checking the boat will ensure that this does not happen. Given that most boats are transported on trailers there is a distinct risk that non-indigenous species can be translocated from one region to another. An example of this occurred in Canada. The invasive water flea was transported from one lake to another by boats on trailers. This flea led to the decline of local invertebrate and fish species.

Many people now dive or snorkel as a hobby, becoming familiar with a wide range of plants and animals that occur in their local area. As with boats, dive equipment should be thoroughly washed in freshwater and dried before using it in another area. If something unusual is seen during the dive it should be reported to the Biosecurity Group at the Department of Fisheries. Early detection of an introduced species is the key to having any chance of preventing it from becoming established, so the earlier an invasion is found, the better the chance of managing it.

Known introduced marine species in Western Australia

Sixty species are known to have been introduced into Western Australia and are established here. Most are cool water, temperate species (37 species) that occur from Geraldton south; only 6 are tropical species that occur from Shark Bay north; 17 introduced species occur in both the southern and northern halves of Western Australia. The preponderance of temperate species is in agreement with most studies in other areas.

Because most of the introduced species are temperate, it follows that southern marine areas have more known introduced marine species than northern areas. The greatest concentration is in the southwest corner of Western Australia: the Fremantle marine area (including Cockburn Sound and the lower Swan River) has 46 introduced species. Fremantle is also the port with the largest number of vessel movements. Albany (25 introduced species), Bunbury (24 introduced species) and Esperance (15 introduced species) are all smaller marine areas with fewer vessel movements and fewer introduced marine species. In addition to the high vessel activity in the Fremantle marine area, there is also considerable habitat diversity (both natural and artificial), which provides a large variety of niches for introduced species to occupy. In this regard, the Albany area also has a wide variety of habitats in close proximity to one another and the port, so the large number of introduced species might be expected. Esperance has lower habitat diversity; so fewer species would be expected in that area. Bunbury stands out in this regard. The marine area is small and habitat diversity is low, so it would be expected to have relatively few introduced species. Instead, at 24, the number of introductions is high.

The fact that most introduced species are temperate does not mean the problem is confined to the southern part of the State. In fact there are invasive species, such as the black-striped mussel, *Mytilopsis sallei,* and the Asian green mussel, *Perna viridis,* which could be easily introduced to our north coast.

In the pages that follow we present information on a selection of species that have been introduced into Western Australia. The introduced species have been chosen to represent a wide range of plant and animal groups.

Dinoflagellates

Dinoflagellates are microscopic, single-celled organisms that are protists, a group that is neither plant nor animal. While some occur in freshwater, 90% of dinoflagellates are marine. The marine group is split fairly evenly between photosynthetic species and those that consume other organisms, including other dinoflagellates. Some species live in the tissues of other organisms, such as sponges, corals and jellyfish. The host does not consume the dinoflagellate, but instead provides shelter and nutrients. In turn the dinoflagellate uses photosynthesis to produce energy used by the host. A single species of dinoflagellate (*Alexandrium minutum*) has been introduced into Western Australia.

Photo: Gustaff Hallegraeff
Material provided by: Was Hosja

Alexandrium minutum

Common name: Toxic dinoflagellate.

Distribution: In Western Australia, *Alexandrium minutum* is known from Bunbury, Geographe Bay, Mandurah, Peel Inlet, Cockburn Sound and the Swan River. Elsewhere it occurs in southeastern Australia, the Mediterranean, New Zealand, the east coast of the USA, and southeast Asia

Habitat: It is a planktonic species that is mostly found in the water column. If it is in bloom it can cause a discolouration of the water. Like other dinoflagellates, *Alexandrium minutum* has a benthic cyst stage that can live on the surface of sediments for years.

Identification features: Accurate identification of most dinoflagellates is a difficult process best left to experts. Like many others, *Alexandrium* forms small spherical cells with an outer casing composed of plates. The arrangement of these plates serves to distinguish the species. Cells have two flagella (tail like structures), one trailing behind and the second encircling the cell and lying in a groove.

Notes: This species is recorded sporadically in Western Australian waters, either as the swimming, flagellated stage or as benthic cysts. In other areas of the world, these species form dense toxic blooms in shallow lagoons and brackish marine embayments that may be accompanied by mortality of fish and shellfish and in outbreaks of paralytic shellfish poisoning. No such blooms have been reported in WA and monitoring is routinely undertaken of commercial mussel and oyster farming areas.

Primary vector: The primary vector for translocating this species is via ballast water.

Marine algae

The Western Australian marine benthic flora includes numerous species that are widely distributed, particularly so in tropical areas where many of the taxa have a broad Indo-West Pacific distribution. These species could be regarded as cryptogenic (i.e., potentially introduced but their origins presently obscure due to their widespread distribution). None have ever shown pest tendencies and are no cause for concern. There are, however, at least three known recent introductions. None of these has reached large densities but all three should be monitored closely. In total five species of marine algae have been introduced into Western Australia:

- *Codium fragile* ssp. *fragile*
- *Elachista orbicularis*
- *Grateloupia imbricata*
- *Pseudocodium devriesii*
- *Stictyosiphon soriferus*


Photo: Rob Hilliard

Codium fragile ssp. *fragile*

Common name: Dead Man's Fingers, Oyster Thief and many others.

Distribution: Originally from Japan, *Codium fragile* ssp. *fragile* has spread throughout Europe, the Mediterranean Sea, western North Atlantic, Pacific Coast of North America, South Africa, New Zealand and southeastern Australia.

Habitat: *Codium fragile* ssp. *fragile* grows on rocks in the mid to lower intertidal down to about 2 m depth.

Identification features: Plants are large, medium to dark green and are dichotomously (in series of two) branched. The branches have a spongy texture. Many native species have a similar appearance and microscopic features are used to confirm identifications. In *Codium fragile* ssp. *fragile*, the surface has what appear to be small spines. These are outgrowths from the plant's utricles (the inflated cell-like structures that make up the surface). Moreover, only plants with utricles of a certain size range are classified as this species. Given this, identification requires significant taxonomic expertise.

Notes: This invasive species was previously know as *C. fragile* subspecies *tomentosoides*, but is now known to be the same as the subspecies *C. fragile* ssp.

fragile. The various subspecies of *C. fragile* are very difficult to distinguish from each other and require an examination of internal structures. DNA sequencing can also be used. Several native species of *Codium* also look similar to *C. fragile*. This alga has recently been collected from Albany, but the extent of the population has not yet been determined.

Primary vector: The primary vector for translocating this species is via hull fouling, although gametes may be transported in ballast water and plant fragments can be transported via vessels and their equipment.

Photo: John Huisman

Grateloupia imbricata

Common name: Forked Grateloup's Weed.

Distribution: In Western Australia *Grateloupia imbricata* is known from a rocky groyne at Cottesloe and from Albany. It is apparently not found elsewhere in Australia. The species was described originally from Japan in 1896 but has since been reported as an introduction to the Canary Islands.

Habitat: *Grateloupia imbricata* grows attached to rock in the lower intertidal.

Identification features: Plants of this red alga are cartilaginous and slightly slippery to touch, with flattened branches that are regularly dichotomously divided. Internally the plants have a loose construction of sparse filaments. This is a feature that serves to distinguish this species from the superficially similar *Rhodymenia sonderi*, which has a structure of densely packed cells.

Notes: Species of *Grateloupia* are well known as introduced and pest species (e.g. *Grateloupia turuturu* in the Mediterranean and recently recorded from Tasmania). *Grateloupia subpectinata* is a cryptogenic species that is common in the Perth region.

Primary vector: The primary vector for translocating this species is via hull fouling.


Photo: John Huisman

Pseudocodium devriesii

Common name: False Codium.

Distribution: In Western Australia, this species is known only from the vicinity of Cottesloe, Rous Head, Fremantle, and Cockburn Sound. It was originally described from South Africa and is common there.

Habitat: *Pseudocodium devriesii* grows on rocks associated with sandy substrata, at depths of around 5-10 m.

Identification features: This species looks like a small *Codium* ('dead man's fingers'). It grows to about 5 cm tall and has forked branching. Plants are generally a bright green colour. When the surface is examined closely, polygon shaped facets can be seen.

Notes: *Pseudocodium devriesii* has only recently been recognized in Western Australia. DNA sequence studies have shown a very close relationship to populations in South Africa. This, along with its local distribution in the Fremantle area, suggests the species is introduced.

Primary vector: The primary vector for translocating this species is believed to be via hull fouling.

Hydroids

While they look like plants, hydroids are actually cnidarian animals, the group that includes jellyfish and corals. Many marine species have a complex life cycle that alternates between an asexual benthic stage that is familiar to divers and a planktonic medusa stage that looks like a jellyfish. The Portuguese man of war, *Physalia physalis,* and the By the Wind Sailor, *Velella velella,* both resemble jellyfish, but are actually hydroids. Hydroids are carnivorous, using stinging cells (nematocysts) to kill their prey. Six species of hydroids have been introduced into Western Australia:

- *Antennella secundaria*
- *Ectopleura crocea*
- *Eudendrum carneum*
- *Gymangium gracilicaule*
- *Halecium delicatulum*
- *Obelia dichotoma*
- *Sarsia eximia*


Photo: Karen Gowlett-Holmes

Gymangium gracilicaule

Common name: Hyroid.

Distribution: *Gymangium gracilicaule* is widely distributed in the tropical and subtropical Indian Ocean and the Indo-West Pacific. It has been recorded in Western Australia from the Houtman Abrolhos Islands and Port Hedland.

Habitat: The species lives on coral rock and rubble.

Identification features: *Gymangium gracilicaule* is up to 70 mm high and lives attached to the substrate. There are several major stolons (low-lying branch like structures), each with branches, and small polyps. The stolons connect the polyps of a colony. Each tiny polyp resembles a sea anemone in that it has a central sac with a mouth at the end surrounded by tentacles.

Notes: Specimens in the Abrolhos Islands were found attached to coral rock and rubble in shallow water and had another hydroid species (*Salacia desmoides*) attached to them. There are literally dozens of marine species of hydroids found in Western Australia. A specialist taxonomist is required to identify the various species.

Primary vector: The primary vector for translocating this species is believed to be via hull fouling.

Polychaetes

Together with earthworms and leeches, the polychaetes are included in the phylum Annelida, the group of segmented worms. Polychaetes are characterised by leg-like parapodia that have bristles (chaete) on their ends. The name polychaete actually means "many bristles". Eight thousand of the 9,000 species of annelids are polychaetes. All polychaetes are marine or estuarine and many can be found in incredible numbers on intertidal sand and mudflats. Sexes are separate, and there is a planktonic larval stage. Some species can reproduce asexually by budding. There are two major groups of polychaetes: tubeworms (Sedentaria) and those that can crawl about on the sea floor (Errantia). Four species of polychaete have been introduced into Western Australia:

- *Alitta succinea*
- *Boccardia proboscidea*
- *Ficopomatus enigmatica*
- *Sabella spallanzanii*


Photo: Karen Gowlett-Holmes


Photo: Justin McDonald

Sabella spallanzanii

Common name: European fan worm.

Distribution: *Sabella spallanzanii* has a native range from the Mediterranean Sea and the Atlantic east coast of Europe to the English Channel. It has been introduced to

Victoria and South Australia, and overseas to North Africa, Brazil and Southeast Asia. The species has been recorded in all Western Australian marine areas associated with ports from Fremantle to Esperance.

Habitat: On debris, rocks, rubble etc. associated with the seafloor and attached to jetty piles.

Identification features: *Sabella spallanzanii* is one of the largest species in the family Sabellidae with a leathery tube and spiral-feeding fan that can reach 10 to 15 cm in diameter. The fan is composed of two lobes, only one of which is spiralled, the other lobe forming a semi-circle.

Notes: The tube of *Sabella* can protrude up to 40 cm above the sediment and bury as deep as 10 cm into the sediment. *Sabella* commonly forms clumps of two or more individuals, creating a canopy of feeding fans that stretches over the sediment. It is not known to be preyed upon by native fish and in any case has a high tolerance to wounding to the extent of being capable of regenerating from fragments.

Primary vector: The primary vector for translocating this species is via hull fouling.

Bryozoans

Bryozoans are colonial filter-feeding animals. Bryozoan colonies can be encrusting, arborescent (branching, and tree-like), or even free living. Individuals within colonies are referred to as zooids. These zooids may have specialised functions, such as brood chambers for young, feeding apparatus or may have spines or pincers to prevent other organisms from settling. Zooids of most species are enclosed in a protective tunic made from either chitin (a tough protein also found in insect exoskeletons) or calcium carbonate. This exoskeleton has an opening, through which the lophophore is extended into the water column for feeding. In some species, the orifice is covered by an operculum (lid or covering which closes over the opening). Fifteen species of bryozoans have been introduced into Western Australia:

- *Amathia distans*
- *Amathia vidovici*
- *Bowerbankia gracilis*
- *Bugula flabellata*
- *Bugula neritina*
- *Bugula stolonifera*
- *Conopeum seurati*
- *Cryptosula pallasiana*
- *Savignyella lafontii*
- *Schizoporella errata*
- *Schizoporella unicornis*
- *Tricellaria occidentalis*
- *Watersipora arcuata*
- *Watersipora subtorquata*
- *Zoobotryon verticillatum*

Photo: Karen Gowlett-Holmes

Amathia distans

Common name: Bryozoan.

Distribution: The native range is uncertain, but *Amathia distans* is thought to be native to the warmer waters of the western Atlantic Ocean. The species also occurs in the eastern Atlantic. It has been introduced to France, the Mediterranean and Red Seas, the Atlantic coast of the Americas, west coast of North America, Indonesia, New Zealand, and eastern Australia, from Queensland to South Australia. In Western Australia, *A. distans* has been reported from Port Hedland and the lower west coast.

Habitat: The species grows on a wide variety of surfaces, including other bryozoans, algae, seagrasses, oyster valves, sandstone boulders, dock, pilings, breakwaters, and man-made debris.

Identification features: *Amathia distans* is a stoloniferous bryozoan found as fragile, erect colonies with many free branches. The colony has dichotomous branching (in series of two), a thin stolon (stalk), and usually grows to about 4 or 5 cm high. Zooids are arranged in paired clusters that run spirally around the stolon. It forms pale-yellow/brown transparent colonies.

Notes: There have been no recorded predators of this species, however nudibranchs commonly feed on bryozoans.

Primary vector: The primary vector for translocating this species is via hull fouling.


Photo: Karen Gowlett-Holmes

Bugula flabellata

Common name: Bryozoan.

Distribution: *Bugula flabellata* is believed to be native to Atlantic and Mediterranean coasts of Europe. It has been widely introduced into tropical and temperate seas. In eastern Australia the species occurs from New South Wales to Victoria, and in Western Australia from Albany to Fremantle.

Habitat: This species lives on a variety of substrata, including stones, shells, and other bryozoans. *Bugula flabellata* is a major fouling bryozoan in ports and harbours, particularly on vessel hulls, pilings and pontoons. It has also been reported from offshore oil platforms. Quite often it is found growing with other erect bryozoan species such as *Bugula neritina* or growing on encrusting bryozoans.

Identification features: *Bugula flabellata* forms an erect broad, branched colony between 2-5 cm in height. Colonies are pale pink in colour. Each branch is broad, flat and wedge shaped with 3-6 rows of zooids. Zooids have spines in the central area that often cover the opening from which the zooid extends its feeding structure (the lophophore). Avicularia (modified beak-like structures with a defensive role) are only found on the marginal zooids, and resemble a bird's head. They are stalked and have a strongly decurved beak.

Notes: Many species of nudibranch have been recorded feeding on this species of bryozoan.

Primary vector: The primary vector for translocating this species is via hull fouling.

Bryozoans


Photo: Karen Gowlett-Holmes

Bugula neritina

Common name: Bryozoan.

Distribution: *Bugula neritina* is widely distributed in most tropical and temperate areas. It also occurs widely in southern Australia from New South Wales to South Australia, including Tasmania. In WA it is found from Esperance to Port Hedland.

Habitat: This is a serious and common fouling organism that grows on a wide variety of natural and artificial substrata. It can even grow heavily in ship's intake pipes and condenser chambers. In Australia, it occurs primarily on artificial substrata, such as jetty pylons.

Identification features: *Bugula neritina* is an erect, arborescent, red-purple-brown bryozoan. Branching is dichotomous (in series of two) and zooids alternate in two rows on the branches. Unlike all other species of *Bugula*, *B. neritina* has no avicularia or spines. Ovicells (reproductive structures) are large, globular and white in colour. Ovicells often appear in such high numbers that they resemble small snails or beads.

Notes: Nudibranchs have been recorded as feeding on *B. neritina*.

Primary vector: The primary vector for translocating this species is via hull fouling.

Photo: Karen Gowlett-Holmes

Schizoporella errata

Common name: Bryozoan.

Distribution: *Schizoporella errata* is widespread in warm temperate to subtropical seas, and occurs in Australia from South Australia to Victoria. In WA it has been recorded from Esperance to Shark Bay.

Habitat: The species is most often found in shallow water in ports and harbours on hard substrates (pilings, hulls, coral rubble, etc.) and reefs.

Identification features: *Schizoporella errata* is typically dark brick red with orange-red growing margins. This species has many forms, from flat encrusting, multi-laminar to erect branching structures, depending on the surface it is colonising. The frontal surface of the exoskeleton housing of individual zooids is porous with a wide semicircular aperture. Avicularia (beak-like structures) occur in varying density on colonies, with one per zooid.

Notes: This is a well-known fouling species and is known to inhibit the growth of adjacent species.

Primary vector: The primary vector for translocating this species is via hull fouling.

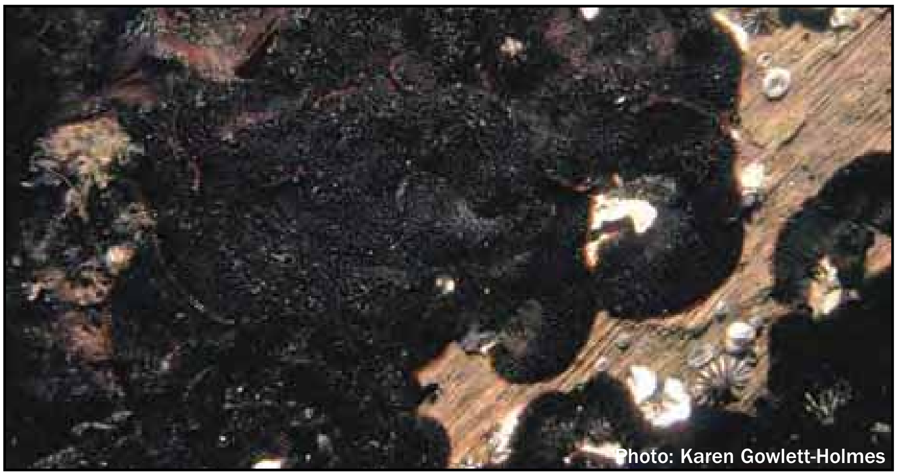


Photo: Karen Gowlett-Holmes

Watersipora arcuata

Common name: Bryozoan.

Distribution: *Watersipora arcuata* is widely distributed in warm seas. In eastern Australia it has been introduced to Queensland and New South Wales. In southwestern Australia it occurs from Esperance to Fremantle.

Habitat: This is an important marine fouling species in ports and harbours where it is found on vessel hulls, pilings, and pontoons. This species can also be found attached to rocks and seaweeds. They form substantial colonies on these surfaces, typically around the low water mark.

Identification features: Colonies range from dark red-brown to black in colour, with a thin bright red margin. Cellular parts of the zooids are orange-red, which explains this colour on the margin. *Watersipora arcuata* has no spines, avicularia or ovicells (reproductive structures). Zooids are elongate, rectangular or subhexagonal in shape, and are typically arranged in rows of about five. The aperture of the zooid is black, with a semicircular distal margin and a concave proximal margin - a key distinguishing feature of this species.

Notes: *Watersipora arcuata* is an abundant fouling organism and is resistant to antifouling paints. It can therefore spread rapidly on vessel hulls and provide an area for other species to settle upon. This in turn has an impact on vessel maintenance and speed, as many more organisms are able to foul the hull. There have been no recorded predators of this species.

Primary vector: The primary vector for translocating this species is via hull fouling.


Photo: Karen Gowlett-Holmes

Watersipora subtorquata

Common name: Bryozoan.

Distribution: *Watersipora subtorquata* has been widely recorded from Brazil, West Indies, Bermuda, Cape Verde Islands, Japan, Mediterranean Sea, and New Zealand. In Australia the species has been recorded from Torres Strait to South Australia, including Tasmania. In WA it is found from Albany to Shark Bay.

Habitat: *Watersipora subtorquata* is most common in lower intertidal and shallow subtidal areas, though it grows to depths of at least tens of meters. This species grows on a wide variety of solid substrata including rocks, shells, docks, vessel hulls, pilings, debris, kelp holdfasts, and other bryozoans.

Identification features: The colony is usually a bright to dull orange or red. The opercula are black or dark brown, and the lines marking the boundaries between zooecia are usually black. The central and older parts of older colonies are often black; in some cases, virtually the entire colony is black, with only the outermost growing edge showing orange or red.

On flat surfaces smaller colonies, up to several centimeters in diameter, are flat and roughly circular. As a colony grows larger it becomes more lobed and may overgrow itself in places. In protected waters where growing conditions are good, colonies may become quite large and grow outward from the substrate (which is often the side of a dock) in lobes and frills, forming a striking, cauliflower-like mass up to 25 cm in height.

Notes: *Watersipora subtorquata* has often been reported from vessel hulls. It is less sensitive to copper than many fouling organisms, and is therefore less affected by copper based anti-fouling paints.

Primary vector: The primary vector for translocating this species is via hull fouling.

The photographs of *Watersipora arcuata* and *W. subtorquata* provide an excellent example of some of the issues encountered in working with introduced marine pests. There are 10 species recognised worldwide in the genus, but only specialists can determine the identity of the various species. The two species shown here are both introduced to Australia, but it is very difficult to tell them apart.


Photo: Karen Gowlett-Holmes

Zoobotryon verticillatum

Common name: Bryozoan.

Distribution: *Zoobotryon verticillatum* is widely distributed in warm waters, including the Mediterranean and Adriatic Seas. In Australia it has been recorded from several locations from New South Wales to South Australia. It is known from Shark Bay and Port Hedland in Western Australia.

Habitat: This is a common fouling species in warmer waters that can grow on virtually any hard subtidal surface. It is common in ports and harbours.

Identification features: Colonies are arborescent, with trifurcately (in threes) branching stolons of approximately 0.5 mm in diameter. Zooids measure approximately 0.4 – 0.6 mm in height and are sac-like, arranged along 2 sides in rows. The lophophore has a diameter of approximately 0.3 mm, and bears 8 tentacles. Young colonies have transparent stolons. The calcium carbonate found in other species is absent in exoskeletons of this species.

Notes: It is highly unlikely that many organisms feed directly on *Z. verticillatum* as colonies produce bromo-alkaloids, a class of chemical compounds related to drugs like nicotine, morphine, and cocaine. These secondary metabolites are likely to protect zooids in the colony by discouraging predation, preventing settlement of other organisms, and preventing bacteria or viruses from invading. Only a few species of nudibranch molluscs are known to feed directly on *Z. verticillatum*.

Primary vector: The primary vector for translocating this species is via hull fouling.

Crustaceans

With over 50,000 species, crustaceans are one of the most diverse groups in the animal world. The group includes such familiar animals as crabs, lobsters, shrimp, and barnacles. Most of the species are marine, but there is a substantial proportion of freshwater species. Some, such as the slaters commonly found under dead wood in the garden, have adapted to living on land. An interesting feature is the chitinous exoskeleton that protects the soft parts of the body of the animal. While it provides important protection, the exoskeleton also prevents growth of the animal. Thirteen species of crustaceans have been introduced into Western Australia:

- *Amphibalanus amphitrite*
- *Amphibalanus reticulatus*
- *Cirolana harfordi*
- *Paracerceis sculpta*
- *Paradella dianae*
- *Sphaeroma serratum*
- *Megabalanus ajax*
- *Megabalanus rosa*
- *Megabalanus tintinnabulum*
- *Monocorophium acherusicum*
- *Monocorophium insidiosum*
- *Monocorophium sextonae*
- *Tesseropora rosea*

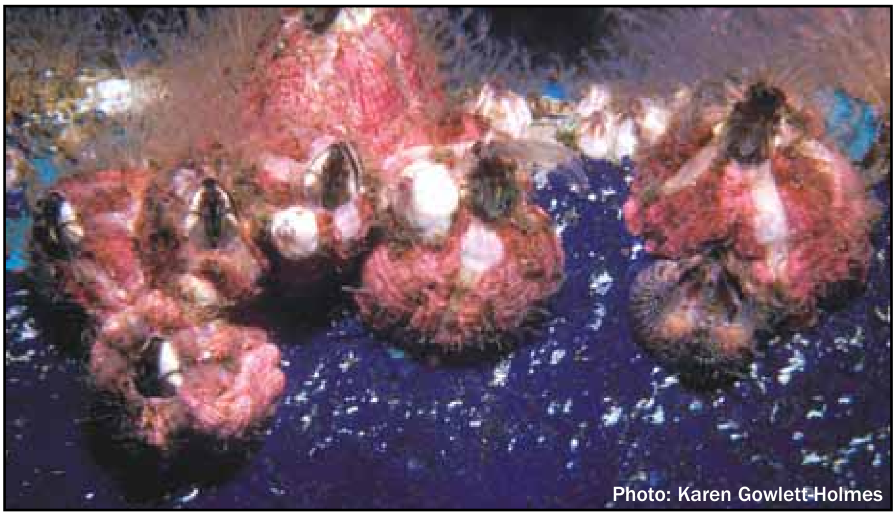


Photo: Karen Gowlett-Holmes

Megabalanus rosa

Common name: Acorn barnacle.

Distribution: Known from Japan, China and Taiwan. In eastern Australia it is found in New South Wales. In WA, the species is widespread from Cockburn Sound to Cockatoo Island in the Kimberley.

Habitat: This is a fouling species that lives on jetty pilings and readily colonises the hulls of ships.

Identification features: *Megabalanus rosa* has six smooth lateral plates that are generally pinkish rose-red to reddish purple (occasionally entirely white) coloured. It grows to no more than 50 mm in height. The orifice is usually greater than half the basal diameter. The detail of the scuta and terga (operculum) of *M. rosa* is used to identify the species. As many of this group display similar characteristics they are regarded as very difficult to identify. This species belongs to a group of 'pink barnacles' that are currently under taxonomic review.

Notes: In its native range *M. rosa* is classified as an open sea species. However it is often found on wharf pylons, vessel hulls and other artificial structures. It is recorded to a depth of 300 m, and from waters ranging in temperature from 15-28 °C.

Primary vector: The primary vector for translocating this species is via hull fouling.

Molluscs

Molluscs are the seashells group. They are the most diverse group in the sea. While the total number of species is not known, it may be in the range of 100,000 species. There are a wide variety of body shapes and sizes, from small animals that reach a maximum of only a few millimetres to the largest of the giant squid. There are a number of classes, or major groups, of molluscs, including cephalopods (squids, octopuses and cuttlefish), chitons (coat of mail shells), gastropods (snails and seaslugs), bivalves (scallops, mussels and oysters), and tusk shells. Most of the species have an external shell composed of calcium carbonate. Some groups, such as seaslugs, have lost the shell in evolution. However, shell-less groups can still be recognised as molluscs through other characters such as the radula (a ribbon of teeth) and the mantle (a unique external tissue). Both of these occur only in molluscs. Nine species of molluscs have been introduced into Western Australia. Most of the invasive marine molluscs are bivalves, though there are also some gastropods and one chiton in this group:

- *Godiva quadricolor*
- *Musculista senhousia*
- *Mytilus edulis planulatus*
- *Okenia pellucida*
- *Ostrea edulis*
- *Polycera hedgpethi*
- *Scaeochlamys lividus*
- *Theora lubrica*
- *Velacumantus australis*


Photo: Clay Bryce

Godiva quadricolor

Common name: Aeolid nudibranch.

Distribution: This is a South African species. Isolated individuals were found in Cockburn Sound and Fremantle in 1980, 1983 and 1997. It has also been recorded in New South Wales.

Habitat: On jetty pilings in protected waters such as harbours.

Identification features: This is a long, narrow species of aeolid that is brownish in colour and reaches 20 mm in length. The body tapers to a long, narrow tail. There is a pair of long tentacles on the front of the head, with a smaller pair at the back. Numerous long, narrow cerata are clumped along the side of the body. The cerata are brown for much of their length, but the tips have blue, orange and yellow colouring.

Notes: This is not an invasive pest species. However it is reported to be a voracious carnivore that feeds on other nudibranchs.

Primary vector: The primary vector for translocating this species is via hull fouling.

Photo: Bill Rudman

Okenia pellucida

Common name: Nudibranch.

Distribution: Uncertain. This is a species that has become widespread through shipping. It has been reported from Hawaii, Japan, Palmyra Atoll, Malaysia, and the United Arab Emirates. In eastern Australia it occurs from New South Wales and Queensland. In WA it has been recorded only from Fremantle.

Habitat: *Okenia pellucida* lives on jetty pilings.

Identification features: The body is up to 20 mm long, and resembles a sea hare in shape. The animal is white with thin brown lines scattered over the surface. The head is separate from the body, with triangular oral tentacles. The body has 10-12 long, narrow elongations (papillae) on each side. The gills are at the back, bipectinate and surround the anus.

Notes: *Okenia pellucida* lives and feeds on the introduced bryozoan *Zoobotryon verticillatum*.

Primary vector: The primary vector for translocating this species is via hull fouling.

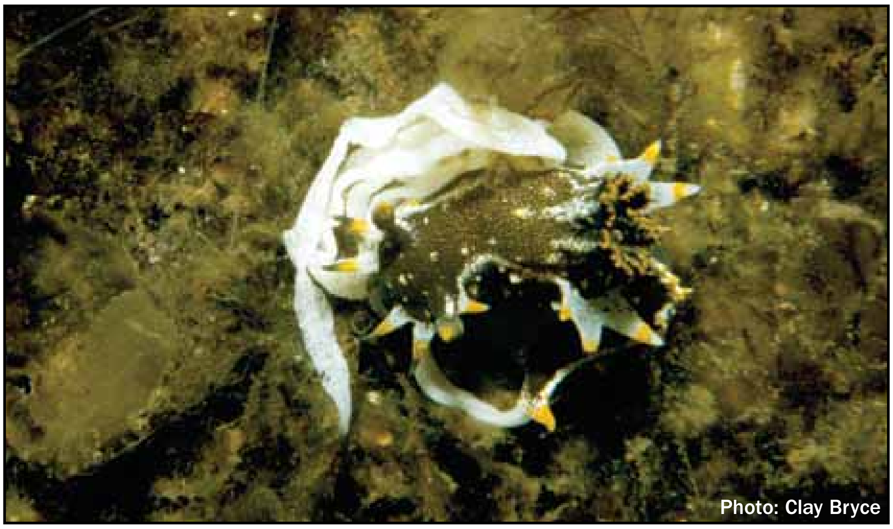


Photo: Clay Bryce

Polycera hedgpethi

Common name: Hedgpeth's dorid.

Distribution: This species was thought to be an introduction from California, where it was originally described. However, the natural distribution of the species is obscure. Specimens were known from New Zealand prior to the original species description and the species was recorded in Australia only nine years later. It has been reported from California, the Caribbean, Mediterranean, South Africa, New Zealand, Japan, and the Iberian Peninsula. In Australia *P. hedgpethi* is known from New South Wales to South Australia. In WA it has been recorded from Albany and Rockingham.

Habitat: The species lives on jetty pilings in harbours in shallow water.

Identification features: This is a small nudibranch that reaches only 15 mm in length. The body is slender, dark brown, with whitish spots. The head has a frontal veil of four to six long narrow extensions that are yellowish on the base, black near the tips, and whitish on the tips themselves. The gills, on the back of the body near the centre, are dark brown, almost black. They are surrounded by appendages with the same colouring as the extensions on the head.

Notes: In Western Australia the species was originally recorded from jetty pilings at Quaranup, Princess Royal Harbour at Albany in February 1980. No further specimens have been recorded from Albany despite several searches at Quaranup.

Primary vector: The primary vector for translocating this species is via hull fouling.


Photo: Helen Cribb, Northern Territory Government

Musculista senhousia

Common name: Asian date mussel.

Distribution: *Musculista senhousia* is native to North Asia. This is an invasive species that has been recorded in a wide variety of areas, including the Mediterranean, United States, India, and New Zealand.The taxonomy of this species is uncertain – there may in fact be more than one species. It has been introduced to Victoria, Tasmania and South Australia. In Western Australia the species is limited to the lower Swan River and Fremantle Harbour.

Habitat: *Musculista senhousia* lives in the intertidal and shallow subtidal region of bays and estuaries. While the species can live on hard or soft bottom, soft sediments are the preferred habitat. Numerous byssal threads that project from the anterior end of the shell are used to construct a cocoon that protects the shell. When there are numerous animals living close together the cocoons form a mat that smothers the underlying surface.

Identification features: The shells of this mussel are small, being from 10 to 25 mm long and up to 12 mm wide. The shell is smooth, thin, and olive green to brown in colour; with dark radial or zigzag markings.

Notes: *Musculista senhousia* was discovered in the Swan River in the early 1980s, and within a few years was one of the most common shells washed up on the beach. Densities of up to 2,600 individuals per square metre were recorded in the lower Swan River in the 1990s. Populations appear to have been decimated by an intense summer rainfall event in 2000. A survey of the Swan River, Fremantle Harbour, Rous Head, and Cockburn Sound in October 2007 failed to find any living individuals of this species.

Primary vector: The species can be translocating via hull fouling or in ballast water.

Photo: Karen Gowlett-Holmes

Photo: Justin McDonald

Mytilus edulis ssp. *planulatus*

Common name: Blue mussel.

Distribution: New South Wales to Western Australia. Common in harbours from Esperance to Fremantle.

Habitat: Abundant on jetty pilings and rocks in shallow water.

Identification features: This is a large (up to 10 cm) mussel, with black or purple shells and a white terminal umbo. Numerous concentric growth lines extend to the rounded end of the shell. The periostracum (horny outer covering) is brown. The inside of the shell is light near the umbos and becomes progressively darker near the opposite margins.

Notes: Blue mussels are widely used for aquaculture in southern Australia, including the Albany harbours, Warnbro Sound and Cockburn Sound, Western Australia under the name *M. edulis*. The taxonomy of this species is confused. Australian specimens were first collected by Francois Péron on the exploratory voyage of the French corvette *Géographe* in 1798. The specimens were later described as described as *Mytilus planulatus* by Lamarck in 1819. *Mytilus planulatus* is now generally considered to be a subspecies of *M. edulis*. In fact they may be descended from mussels brought to Australia by early European exploratory ships. *Mytilus galloprovincialis* is an almost identical species, which can only be separated genetically. The two species can co-occur and be intermingled. Like most species listed in this publication they have not been studied in detail in Western Australia.

Primary vector: The primary vector for translocating this species is via hull fouling.


Photo: David Roberts

Ostrea edulis


Photo: Clay Bryce

The oyster *Ostrea angasi* is on the left and *O. edulis* is on the right.

Common name: European flat oyster.

Distribution: This species is native to Europe. It has been recorded in Western Australia at Oyster Harbour, Albany.

Habitat: *Ostrea edulis* lives on intertidal rocky shores and in shallow water where it is attached to a hard substrate.

Identification features: This is a large (up to 10 cm), oval or pear shaped oyster. It is attached to the bottom by the concave left valve. The smaller right valve is flat and sits inside the left valve. Its upper surface may be scaly with concentric growth lines. The shell is off-white to cream, with the internal shell being a glossy white.

Notes: Vancouver named Oyster Harbour in 1798 because of the abundance of oysters (*Ostrea angasi*) in the area. However, it was recently found that there are actually two species in Oyster Harbour, the native *O. angasi* and the European *O. edulis*. It is not known when or how the European species was introduced, but it could have been quite some time ago.

Primary vector: The primary vector for translocating this species is via hull fouling.

Scaeochlamys livida

Common name: Scallop.

Distribution: This species is native to the east coast of Australia, from New South Wales to southern Queensland. In WA it has been recorded from Fremantle Harbour, Cockburn Sound, and the adjacent open coastline as far south as Mandurah and as far north as Hillarys.

Habitat: *Scaeochlamys livida* lives attached to jetty piles and rocks in shallow water.

Identification features: The shells of *Scaeochlamys livida* are up to 7 cm high, slightly unequal, with the left valve more convex. The auricles (projections where the shells meet) are unequal. There is a pronounced gape in the shell where the byssal threads emerge. The shells are colourful, often brown or purple, or orange, yellow, or white, but in life they are often covered by an encrusting sponge. There are 10 to 12 very strong, low, flattened radial ribs on left side with flat, translucent scales. The scales are much stronger near the shell margin. The right valve has 20 to 25 ribs, but they are lower than those on the left valve.

Notes: This species is unusual as it is an introduction from eastern Australia rather than from overseas. It is widespread in the waters off the Perth metropolitan area. Although it is not classed as a pest species, *Scaeochlamys livida* appears to have largely replaced the local species *Mimachlamys asperrima* locally.

Primary vector: The primary vector for translocating this species is via hull fouling.

Photo: Clay Bryce

Theora lubrica

Common name: Bivalve.

Distribution: The native distribution of this species is the east coast of Asia, from Japan south to Singapore and Indonesia. It has been introduced in Australia from New South Wales to eastern South Australia, including Tasmania. In Western Australia, it is known only from the Swan River, Rockingham and Bunbury.

Habitat: *Theora lubrica* lives in shallow, muddy environments and can be found in depths to 50 m.

Identification features: The shell is small, up to 15 mm long, elongate, almost transparent, with fine concentric growth lines. The shell gapes at both ends.

Notes: The above photo is actually *Theora fragilis*, but the shells are very similar and it would takes significant taxonomic skill to tell them apart. Both species are deposit feeders, using their siphon to suck small particles of detritus off the sediment surface.

Primary vector: The species is believed to be translocated via ballast water and hull fouling.


Photo: Fred Wells

Velacumantus australis

Common name: Mudwhelk.

Distribution: This snail is widespread in eastern Australia, from southern Queensland to South Australia, and also lives in Tasmania. It is thought *V. australis* introduced into the lower Swan River and the Woodman Point area of Cockburn Sound many years ago.

Habitat: *Velacumantus australis* lives in sandy environments, including some with macroalgae and seagrasses, in shallow water.

Identification features: This is a small snail, up to 4 cm long, with a high spire, and a pronounced suture, or indententation, between the whorls. There is a beaded appearance on the body whorl and the upper whorls of the shell are very knobbly. The shell is usually dark brown, with a dark brown opening. Some shells have a distinct white band.

Notes: Thousands of years ago *Velacumantus australis* was widespread across southern Australia, including southern Western Australia, but over time its range became restricted to the east coast. It was recorded from Albany in the 1960s, but the specimen turned out to be a subfossil.

Primary vector: Transport of larvae in ballast water is a possible source of the species in WA. However, it was sufficiently common in the Swan River in the 1960s to be the subject of a series of scientific papers, so it may have already been in WA for a period of time. Ballast water came into widespread use after World War II, and *V. australis* may have been introduced earlier through individuals being brought across in wet ropes or as biofouling.

Tunicates

Tunicates, or sea squirts, are actually chordates because their planktonic larvae have a notochord, dorsal nerve cord, pharyngeal slits, and a post anal tail. The Chordata is the group to which all of the vertebrates, including fish, mammals, birds, amphibians, and reptiles belong. However, tunicates lack a backbone and are thus invertebrates. The body plan of adults is simple: there is essentially a chamber with two openings. Water enters one opening, food is filtered out, and the water leaves through the other opening. Despite this simple body plan there are many variations and numerous species. Planktonic salps resemble jellyfish, but are actually tunicates. Bottom dwelling sea squirts are common as fouling organisms on jetty pilings, ships' hulls and other structures. A number of species have been introduced to Western Australia.

Five species of ascidians have been introduced into Western Australia:

- *Ascidiella aspersa*
- *Botryllus schlosseri*
- *Ciona intestinalis*
- *Styela clava*
- *Styela plicata*

Photo: Karen Gowlett-Holmes

Botrylloides leachi

Common name: Colonial ascidian.

Distribution: *Botrylloides leachi* is widespread in the Northeastern Atlantic, Mediterranean Sea, Adriatic Sea, Black Sea, Indonesia, western Indian Ocean, Red Sea, South Africa, New Zealand, and along all Australian coasts. In Western Australia it occurs from Albany to the Dampier Archipelago and is even found at the offshore Rowley Shoals.

Habitat: *Botrylloides leachi* is an encrusting species, growing on both natural and artificial substrata. It is often seen on seagrasses. It is found in the lower intertidal and shallow subtidal zones.

Identification features: *Botrylloides leachi* is an ascidian composed of many individual zooids growing together to form colonies. Zooids are small, up to 2 mm long but the entire colony can be quite large and greatly variable in colour from grey, red-brown to purple and orange. Colonies are thin, irregular in shape and have a smooth, even surface. Zooids are crowded together in long curving and branching double-row systems with a common exhalent (atrial) siphon between them.

Notes: *Botrylloides leachi* can be a dominant competitor, overgrowing and excluding many other epibiont species. Fouling on aquaculture structures can decrease water flow as well as compete for food with suspension feeding aquaculture species. Various nudibranch, gastropod and flatworms are reported to feed on this colonial ascidian.

Primary vector: The primary vector for translocating this species is via hull fouling.

Photo: Karen Gowlett-Holmes

Ciona intestinalis

Common name: Solitary ascidian.

Distribution: This species is native to the North Atlantic, but has been introduced to North and South America, Hong Kong; China Sea, Indonesia, and New Zealand. In eastern Australia it occurs from southern Queensland to South Australia and Tasmania. In WA, it occurs from Esperance to Fremantle.

Habitat: *Ciona intestinalis* is a solitary ascidian but is commonly found in dense aggregations on rocks, algal holdfasts, seagrass, shells, and artificial structures such as pylons, buoys and ships' hulls. It is found in enclosed and semi-protected marine embayments and estuaries. While it occurs in the low intertidal and shallow subtidal zones, C. intestinalis clearly decreases in abundance with depth.

Identification features: *Ciona intestinalis* usually hangs vertically upside-down in the water column. It is cylindrical, 100-150 mm in length and ends with a cone-shaped branchial (inhalant) siphon. There are 8 lobes on the branchial siphon and 6 on the atrial (exhalent) siphon. The siphon openings may have yellow margins and orange/red spots. The body wall is generally soft and translucent with the internal organs visible, however, the animals may be hard and leathery due to heavy fouling.

Notes: Juveniles are eaten by snails such as *Mitrella*, *Hydrobia* and *Littorina*. Fish such as sticklebacks also consume juvenile ascidians. Jellyfish are known to feed on eggs and larvae in the water column.

Primary vector: The primary vector for translocating this species is via hull fouling.

Photo: Karen Gowlett-Holmes

Styela plicata

Common name: Solitary ascidian.

Distribution: The native range of *Styela plicata* is unknown. It is cryptogenic in widespread locations in the Mediterranean and warmer parts the Pacific, Indian and Atlantic Oceans. It has been introduced to the Atlantic coast of South America and is probably Australia-wide. *Styela plicata* is widespread in WA from Esperance to the Monte Bello Islands.

Habitat: *Styela plicata* is a fouler of ships, boats, docks and aquaculture facilities, attaching to hard substrates. It is usually covered with non-ascidian flora and fauna, which can 'travel' on the tunicate and add more non-indigenous species to aquatic ecosystems.

Styela plicata competes with other organisms, excluding them from the space it occupies. Its larvae are capable of invading occupied space and growing to a large size in a relatively short period of time, attached to other organisms. *Styela plicata* then sloughs off because of its large size, often taking other marine organisms with it. This sloughing destabilises the marine community.

Identification features: *Styela plicata* is an ovular, greyish to tannish white benthic tunicate. This solitary sessile invertebrate is cloaked in an un-stalked tunic that is large, tough, warty and ridged.

Notes: The first WA specimens were collected in Cockburn Sound in 1928. Snails, crustaceans, sea stars and fish have been known to prey on *S. plicata*. Specifically, the species *Linatella caudata* preys upon *S. plicata*.

Primary vector: The primary vector for translocating this species is via hull fouling.

Fish

There are literally thousands of species occurring along the coasts of Western Australia, but only three have been introduced to the State:

- *Acentrogobius pflaumi*
- *Sparidentex hasta*
- *Tridentiger trigonocephalus*

Photo: Mark Maddern

Acentrogobius pflaumi

Common name: Streaked goby.

Distribution: The species is native to the area including Japan, Taiwan, Korea, and the Philippines. It has been introduced to New Zealand, and into Sydney Harbour and Botany Bay, New South Wales, and Port Phillip Bay, Victoria. In Western Australia it is known only from Cockburn Sound and the Swan River in the Fremantle marine area.

Habitat: In WA *Acentrogobius pflaumi* lives in soft sediment, silty areas. In its native area the species lives in protected marine embayments and brackish areas.

Identification features: *Acentrogobius pflaumi* is a small, slender goby, with the eyes very close together. There are two dorsal fins and the anal fin has 10-segmented rays. The body is grey to brown with five dark blotches along each side. The last blotch is at the base of the tail. There are bright electric blue spots on many of the scales.

Notes: *Acentrogobius pflaumi* lives in close association with a small alpheid shrimp, and shares its burrow.

Primary vector: The primary vector for translocating this species is through ballast water.

Photo: Barry Hutchins

Tridentiger trigonocephalus

Common name: Chameleon goby.

Distribution: This species is native to the northwest Pacific (Japan, China and Korea). It has been introduced to California and in New South Wales and Victoria in eastern Australia. In WA it has been introduced into Bunbury and the Fremantle marine area (Fremantle Harbour, Swan River and Cockburn Sound).

Habitat: This species lives on the bottom in estuaries and other protected areas where it occurs near rocks, in holes and crevices, and other places where it can hide.

Identification features: *Tridentiger trigonocephalus* has a typical goby shape. The key feature is two black stripes along the body from behind the eye to the tail. As the common name implies, the fish can change its colour from silvery to brown, sometimes obscuring the stripes. There are two dorsal fins and a pale band at the base of the pectoral fin.

Notes: This species is thought to compete with native species sharing the same habitat and general ecology.

Primary vector: The primary vector for translocating this species is through ballast water.

Potential introductions to Western Australia

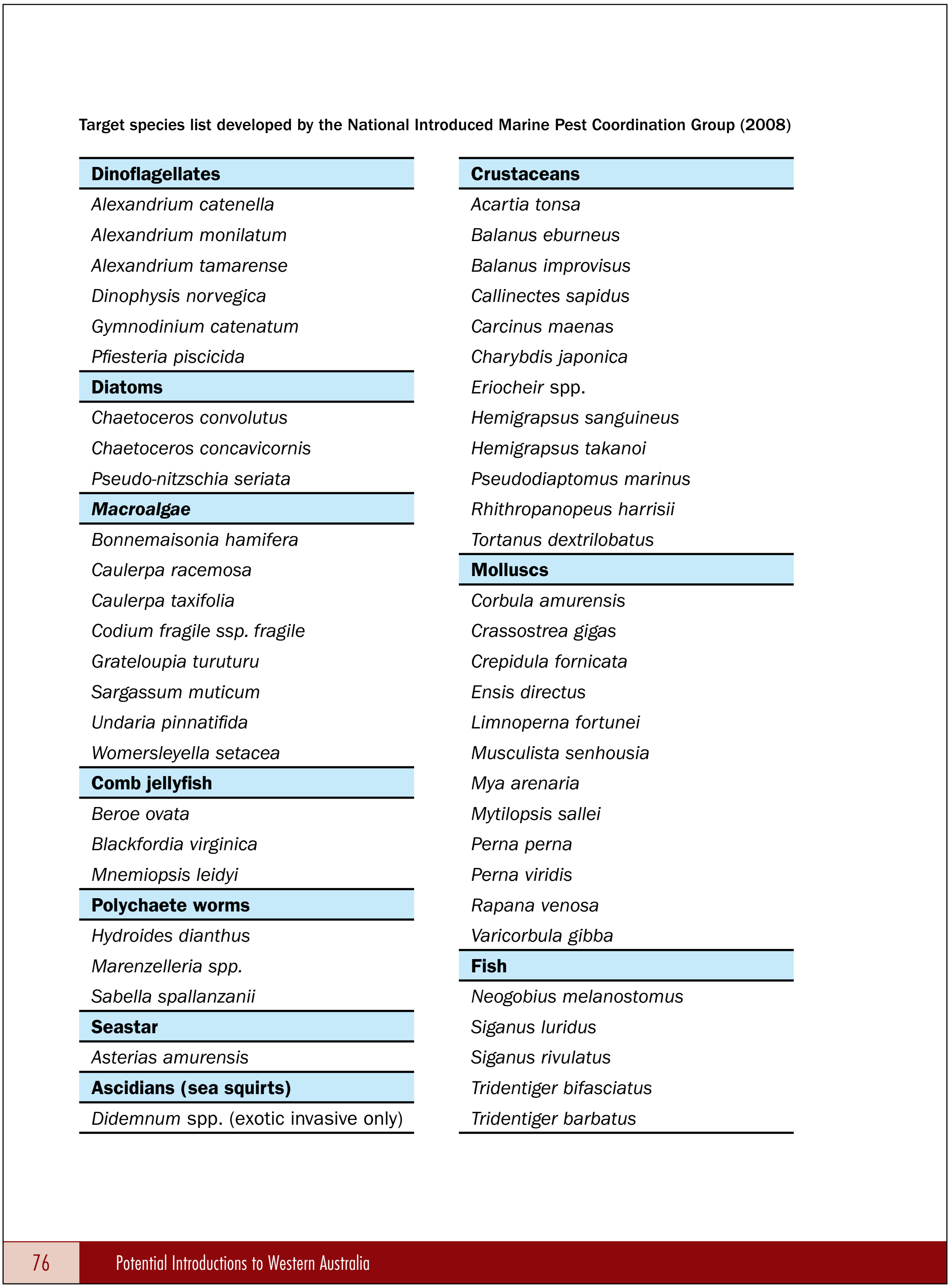
With the wide range of habitats in Western Australia, there are thousands of potential species that could inhabit our shorelines if they were able to arrive in the State. The list of potential introduced species is almost endless, particularly when vessels come from unexpected sources. Any risk assessment of possible species that could be introduced in to Western Australia would seem unlikely to include species from the Caribbean Sea, yet that is exactly where the *Leonardo da Vinci* came from on its way to Geraldton in 2002. While it was on a very unusual route, the dredge *Leonardo da Vinci* arrived in Geraldton virtually directly from the Caribbean. When it arrived in Western Australia an inspection of the vessel revealed a number of Caribbean species, including pest species, on the stern and in tanks near the stern that were open to the sea. Fortunately, steps were immediately undertaken to minimise the chances of Caribbean species becoming introduced into Geraldton. So far, no such introductions have been recorded.


Photo: Justin McDonald

Hull fouling on the bottom of the Leonardo da Vinci.

The National Introduced Marine Pest Coordination Group

The Australian and New Zealand governments have recognised the importance of monitoring for introduced marine pests. Working collaboratively they developed the national introduced marine pest monitoring strategy. This strategy has at its core a set of minimum requirements for marine pest monitoring and the collection of monitoring data from marine environments. The National Introduced Marine Pest Coordination Group (NIMPCG) also compiled a list of introduced species that should be monitored for, consisting of 55 species that are known pests, or are considered to be likely to become marine pests if they are introduced into Australia. A selection of the 55 listed and potential next pest species are detailed in this section.



Target species list developed by the National Introduced Marine Pest Coordination Group (2008)

Dinoflagellates

Alexandrium catenella
Alexandrium monilatum
Alexandrium tamarense
Dinophysis norvegica
Gymnodinium catenatum
Pfiesteria piscicida

Diatoms

Chaetoceros convolutus
Chaetoceros concavicornis
Pseudo-nitzschia seriata

Macroalgae

Bonnemaisonia hamifera
Caulerpa racemosa
Caulerpa taxifolia
Codium fragile ssp. fragile
Grateloupia turuturu
Sargassum muticum
Undaria pinnatifida
Womersleyella setacea

Comb jellyfish

Beroe ovata
Blackfordia virginica
Mnemiopsis leidyi

Polychaete worms

Hydroides dianthus
Marenzelleria spp.
Sabella spallanzanii

Seastar

Asterias amurensis

Ascidians (sea squirts)

Didemnum spp. (exotic invasive only)

Crustaceans

Acartia tonsa
Balanus eburneus
Balanus improvisus
Callinectes sapidus
Carcinus maenas
Charybdis japonica
Eriocheir spp.
Hemigrapsus sanguineus
Hemigrapsus takanoi
Pseudodiaptomus marinus
Rhithropanopeus harrisii
Tortanus dextrilobatus

Molluscs

Corbula amurensis
Crassostrea gigas
Crepidula fornicata
Ensis directus
Limnoperna fortunei
Musculista senhousia
Mya arenaria
Mytilopsis sallei
Perna perna
Perna viridis
Rapana venosa
Varicorbula gibba

Fish

Neogobius melanostomus
Siganus luridus
Siganus rivulatus
Tridentiger bifasciatus
Tridentiger barbatus

Photo: CSIRO Marine and Atmospheric Research

Undaria pinnatifida

Common name: Wakame.

Distribution: *Undaria* currently occurs on the east coast of Tasmania and in several bays in Victoria. Based on its wide temperature tolerance, it could spread to other areas. The species is native to *Japan, China and Korea*.

Habitat: *Undaria* grows on hard surfaces from the intertidal to depths of about 20 m (e.g., reefs, rocks, shells, ropes, wharf piles, and ship hulls). It can form dense stands in sheltered areas. It does not grow well in areas of high wave energy or where native seaweeds are abundant.

Identification features: This species is a kelp that grows to 1-3 m in height. Plants are a golden brown colour and consist of a holdfast, cylindrical stipe (stem) and flattened, branched blade, with the stipe extending as a mid-rib through the blade. Fertile plants produce frilly sporophylls (leaves that produce spores) on the stipe.

Notes: *Undaria* is thought to have spread to, and within, Australia in ballast water and by hull fouling.


Photo: Karen Gowlett-Holmes

Caulerpa taxifolia (invasive strain)

Common name: Aquarium Caulerpa

Distribution: The origin and natural distribution of *Caulerpa taxifolia* (invasive strain) is difficult to assess, as it is morphologically similar to a widespread, non-invasive strain. An algal taxonomist is required to correctly identify the invasive strain of this species, however it is recommended that positive identification be made using molecular techniques. It is likely that the invasive strain originated in Queensland, from where it was distributed worldwide via the aquarium trade. Escapees were first noted in the Mediterranean near Monaco, and outbreaks have also occurred in California. In Australia, the invasive strain is known from Queensland, New South Wales and South Australia.

Habitat: This species grows on a range of substrata, including rocks, sand, mud and seagrasses. Its usual depth range is from 3 to 35 m, but in the Mediterranean it has been recorded from 100 m depth. It can grow successfully in a variety of conditions and water qualities.

Identification features: *Caulerpa taxifolia* is a green seaweed that has creeping stems (stolons) that meander across the sea bottom, from which upright fronds arise. Stems of the upright fronds are unbranched or sparsely branched, compressed, and grow to approximately 20-60 cm in height. They produce small lateral branchlets that are 5-9 mm long and arise in one plane. The branchlets are slightly flattened, unbranched, sickle-shaped, straight or upwardly curved. There is a slight constriction at the base of the branchlets and a small gap between adjacent branchlets.

Notes: Accurate identification of the invasive strain of *C. taxifolia* can be problematic, particularly in tropical areas (including northern Western Australia) where the non-invasive strain occurs naturally. Vigorously growing populations in colder waters, however, will almost certainly be the invasive strain.

Photo: Karen Gowlett-Holmes

Myxicola infundibulum

Common name: Slime feather duster worm.

Distribution: This species is native to northern Europe, where it is widespread from France and the British Isles to Scandinavia. It is also widespread in cold and temperate waters throughout much of the world. CSIRO document the species as being cryptogenic in southern Australia, including southern WA, but there are no records of the species in WA.

Habitat: *Myxicola infundibulum* lives in shallow sandy and muddy environments to a depth of about 30 m.

Identification features: This is a tubeworm. The mucilaginous tube is up to 20 cm long. Except for the opening, the tube is buried in the sediment. The animal has up to 100 segments, and lives in the tube, withdrawing when threatened by a predator. The body is dark yellow-brown. When the animal emerges there is a crown of purple and brown tentacles extending from the tube.

Echinoderms

Echinoderms are one of the most common groups in shallow waters; other species can be found in the deepest depths of the oceans. The 7,000 known species of echinoderms are all marine. There are five groups: seastars, brittle stars, sea urchins, sea cucumbers, and crinoids. Feeding mechanisms vary between the groups, with some of the seastars being voracious carnivores. While most species have bilateral symmetry at some stage in their life, adults have radial symmetry, often with appendages in groupings of five. Sexual reproduction involves external fertilisation and a planktonic larval stage in almost all species. One interesting feature of echinoderms is the ability to replace lost organs. Seastars can even regenerate an entire new individual from only a single arm with a part of the central disc. This regenerative capacity was clearly demonstrated by *Asteria amurensis* in Tasmania. The species was detected in Tasmania in the mid 1980s when a visiting scientist was examining collections in the Tasmanian Museum. *Asterias amurensis* was in the collections but had gone unrecognised. A quick examination of the nearby Hobart waterfront showed the species was already in plague proportions. In an effort to remove this species from local waters a ‘hunt’ was coordinated to collect *A. amurensis*. During this ‘hunt’ over 33,000 animals were collected. Unfortunately many animals were cut in half, believing they would die, and thrown back. These animals regenerated and numbers are believed to be higher than the initial population. To date no echinoderms are known to have been introduced into Western Australia.

Photo: Karen Gowlett-Holmes

Asterias amurensis

Common name: Northern Pacific sea star.

Distribution: *Asterias amurensis* is native to northeast Asia, including Japan. It is present in Alaska and western Canada, but it is not known whether this is part of the natural range or if it has been introduced. The species was introduced into Tasmania, and later spread to Victoria.

Habitat: *Asterias amurensis* occurs in the lower intertidal and subtidal in protected areas on soft bottoms and rocks. It also occurs on jetty piles.

Identification features: A large, up to 40 cm in diameter, five armed seastar with long, tapering arms. There are numerous low spines on the upper surface. The base colour of the upper surface is yellowish with deeper purple and red. The underside is a uniform yellowish. A key identifying feature of this species is the distinct upturned tips to the arms.

Notes: This species is an active carnivore that will feed on a variety of molluscs (including mussels, oysters, and other bivalves and snails) and crabs and barnacles.

Photo: Karen Gowlett-Holmes

Carcinus maenus

Common name: European shore crab.

Distribution: The native distribution of *Carcinus maenas* is widespread along the coast of Western Europe south to the west coast of Africa, and Iceland and southern Greenland. The species has been widely introduced into the east and west coasts of North and Central America, the Caribbean Sea, Brazil, Argentina, the east and west coasts of southern Africa, and Japan. In eastern Australia *C. maenas* has been introduced from New South Wales to South Australia and Tasmania.

Habitat: *Carcinus maenas* lives in a wide range of habitats, including sand, mud and seagrass beds, in protected bays and estuaries.

Identification features: This is a medium sized crab, with a carapace width of up to 8 cm. There are five distinct spines on the carapace to the outside of each eye. Adults are green on the upper carapace but the underside may be reddish-orange.

Notes: A single specimen collected in the Swan River in 1965 is in the Western Australian Museum, but there have been no further records of the species in WA. A detailed survey of the Swan River, Fremantle Harbour, Rous Head, and Cockburn Sound in October 2007 did not find any individuals.

Carcinus maenas is a voracious predator that attacks shellfish beds and disrupts coastal ecosystems.

Photo: Rob Hilliard

Perna perna

Common name: Brown mussel.

Distribution: *Perna perna* occurs from southern Africa from Mozambique to South Africa and also the east coast of South America. It was introduced into the Gulf of Mexico, including Texas.

Habitat: Like other mussels, *Perna perna* attaches to hard substrates in shallow water. The species has a wide range of temperature and salinity tolerances, so it can invade a range of areas.

Identification features: This is a large (up to 12 cm) mussel with a smooth brown shell. It is characterised by the inside of the shell having a distinctive scar made by a divided posterior retractor muscle.

Notes: This is another mussel species that could readily invade Western Australia, but it has not yet been recorded from Australia.

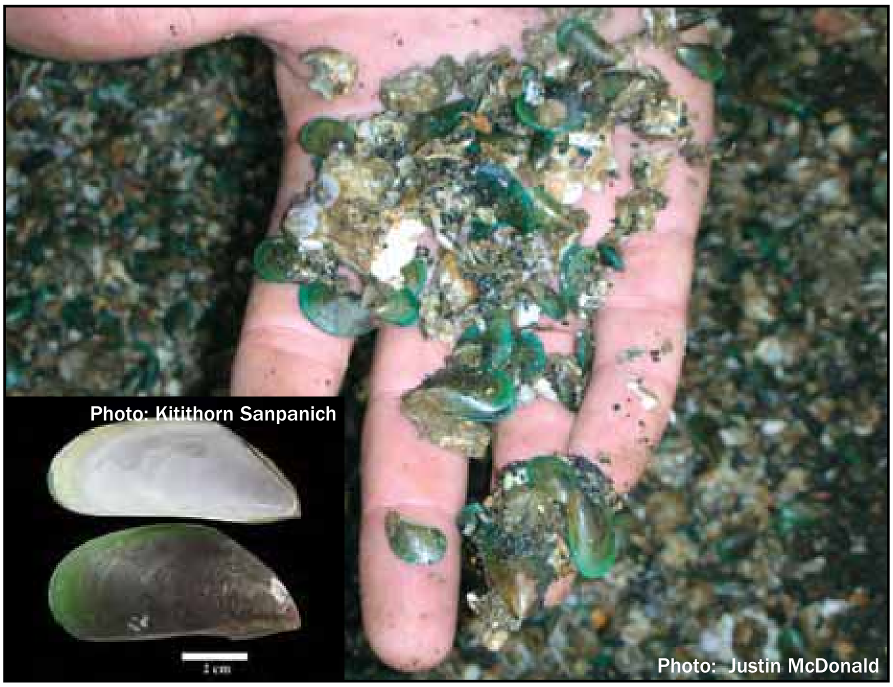


Photo: Kitithorn Sanpanich

Photo: Justin McDonald

Perna viridis

Common name: Asian green mussel.

Distribution: *Perna viridis* is native throughout tropical Asia. It has been introduced to the Caribbean Sea and the east coast of the United States.

Habitat: This mussel lives in the intertidal and shallow subtidal, where it attaches to hard surfaces in coastal areas.

Identification features: There are only two other species in the genus, *P. perna* and *P. canaliculus*. As the common name implies the outer covering of the shell (the periostracum) of the Asian green mussel is greenish in young specimens, though as the animal grows it may become darker. The Asian green mussel most commonly reaches 8-10 cm in shell length, though there are reports of individuals up to 16.5 cm. It has a pronounced downturn at the end of the shell. There are interlocking teeth at the tip of the shell – one on the right valve and two on the left.

If the species were introduced into Western Australia, it would most likely be on the tropical north coast. The closest species in WA would be the blue mussel of the south coast.

Notes: The species has been accidentally introduced into Cairns, where it has been reported to be reproducing. It has been found on ships arriving in Dampier, but to date mechanisms employed to prevent its introduction have been successful.

Like the Pacific oyster, the Asian green mussel is both a pest species and an important aquaculture species. As a pest, it also grows rapidly and out competes other species, including mussels, and alters the ecological balance on coastlines. The species can foul industrial structures, jetties, the hulls of ships and their internal pipes. It has been widely distributed by hull fouling and in ballast water, and in a limited way through aquaculture.

The Asian green mussel is a major food species in Asia. According to the FAO, wild capture peaked at about 160,000 tonnes in 1971. By the late 1990s this had declined to a fairly stable level of just over 20,000 tonnes. The loss of wild stocks has been more than replaced by increasing aquaculture production, which is now near 300,000 tonnes per year.


Photos: Helen Cribb, Northern Territory Government

Mytilopsis sallei

Common name: Black-striped mussel.

Distribution: The origins of *Mytilopsis sallei* are uncertain. Some publications give a range of the tropical Pacific coast of Central America, but others attribute the species to the Caribbean. It has become widespread in the Indo-West Pacific, including India, Singapore, Taiwan, Hong Kong, Japan and Indonesia.

Habitat: *Mytilopsis sallei* can attach to virtually any hard surface. The species is unusual in being able to detach from the bottom and reattach itself with new byssal threads. It lives in estuarine areas and can tolerate a wide range of temperatures and salinities.

Identification features: *Mytilopsis sallei* is in fact not a true mussel (Family Mytilidae); it is in the family Dresseinidae. A key characteristic is that the two shells are not equal; one is slightly larger and overlaps the other. This is a small mussel that reaches a length of only 25 mm. The shell is smooth, dull grey, and may have darker zigzag lines that give it the common name “black-striped mussel”.

Notes: *Mytilopsis sallei* is prolific and fast growing. Individuals mature within a month of spawning, when they have reached a length of only 8-10 mm. They live for about a year, though some individuals live nearly twice that. Their environmental tolerances are high, which allows *M. sallei* to rapidly colonise new areas and rapidly reach plague proportions.

In 1999, *Mytilopsis sallei* was found in three small marinas in Darwin, where it reached incredible densities in a few months. The marinas were artificial habitats with very low 'natural' conservation values. The Northern Territory Government made a rapid decision to use chemicals to essentially poison everything in the marinas to eradicate the mussels. The eradication was successfully undertaken with intensive effort over a short period and is one of very few examples of an introduced marine species being successfully eliminated. Since then *M. sallei* has been detected on a number of illegal foreign fishing vessels in Australian waters. These vessels were inspected before reaching port and were destroyed. So far, to the best of our knowledge the species has not been reintroduced to Australia.

Photo: Karen Gowlett-Holmes

Crassostrea gigas

Common name: Pacific oyster.

Distribution: Asian North Pacific, including Japan.

Habitat: Intertidal rocks and jetty pilings.

Identification features: Oysters are very difficult to identify. They live on rocks and jetty pilings, and other such hard bottoms. The shape of the structure to which they are attached partly determines the shape of the oyster. Individuals are often crowded together, with the shape of adjoining individuals changing that of the ones around them. The key feature of *C. gigas* is its size, often between 15 and 20 cm, but there are unconfirmed reports of animals up to 40 cm long. Another feature is the deeply crenulated shell margins. One valve is deep and cup-shaped while the other is smaller and slightly convex. The outer shell is often off-white to brown.

Notes: Just after World War II an attempt was made to introduce this species into Oyster Harbour, Western Australia and Tasmania. The animals were in poor condition after a month at sea and consequently did not survive once introduced into Australian waters. Two years later the species was successfully introduced into Tasmania by transporting the broodstock by air. It was later introduced into Victoria (1953) and South Australia (1969). The species was not legally introduced into New South Wales, but it is believed there were illegal introductions. Fortunately, there was no second attempt to introduce the species into Western Australia. *Crassostrea gigas* has been extensively introduced into temperate seas worldwide, including the west coasts of North and South America, Europe, west coast of Africa, and Australasia. It is the most widely farmed shellfish species worldwide, with production of 4.4 million tonnes in 2006.

In Australia the species is a commercially exploited introduced species. It is widespread in estuaries in New South Wales, where it is considered noxious, but at the same time there is an important aquaculture industry at Port Stephens worth $ 1.8 million annually. The species contributes tens of millions to the South Australian and Tasmanian economies. The oyster is a concern because it settles in dense numbers, grows rapidly, and crowds out other species, including other oysters.

Glossary

Anti-fouling: the process of removing the accumulation, or preventing the accumulation of microorganisms, plants, algae, and animals on submerged structures, especially ships' hulls.

Arborescent: branching or tree-like.

Avicularia: modified zooids with a defensive role.

Ballast: material taken onto a vessel to allow it to retain the proper level in the water. Most ships use seawater for ballast.

Benthic: relating to the sea bottom

Biomass: the weight of a plant or animal.

Bipectinate: divided into two.

Carapace: a bony or chitinous shield, test, or shell covering some or all of the dorsal part of an animal.

Cerata: outgrowths on the sides and top of the body of aeolid nudibranchs.

Chaeta: bristle or seta, especially of an annelid worm.

Chitin: a hard material found in the shells of crabs, molluscs and other animals.

Cnidaria: a phylum of animals that includes jellyfish and corals.

Cryptogenic: species that have become so widespread over a long period of time that their natural ranges cannot be determined.

Endemic: species that are restricted to a particular area.

Epibionts: an organism that lives on the surface of another organism.

Exoskeleton: an external covering or integument, especially when hard, as the shells of crustaceans.

Lophophore: the ring of ciliated tentacles encircling the mouth.

Mantle: outgrowth of the body wall that lines the inner surface of the valves of the shell.

Moult: a process by which groups such as crabs shed their shell, grow rapidly, and then develop a new shell.

Oligochaetes: a group of worms. Most live in freshwater or terrestrial habitats, but some are marine.

Ovicells: an opening in the body wall of bryozoans in which the eggs sometimes undergo the early stages of development.

Plankton: species that live in the water column and are not strong swimmers. They cannot swim against a sustained current. Holoplanktonic species live in the water column throughout their lives while meroplanktonic species live in the water column as larvae and settle to the bottom for their juvenile and adult stages.

Parapodia: paired lateral extensions from the body.

Perahu: an Indonesian fishing boat.

Periostracum: the horny outer layer found on the shells of many species of molluscs.

Pharyngeal: pertaining to, or situated near the pharynx (throat).

Protists: a group of microscopic, single-celled organisms that are neither plant nor animal.

Puerulus: a larval stage in the western rock lobster and other crustaceans.

Radula: A specialised ribbon of teeth found only in molluscs.

Retractor muscle: the muscle that pulls a snail or bivalve animal back into its shell.

Salinity: the amount of salts in water. The average salinity of seawater is about 35 parts per thousand, or 3.5%.

Stolon: horizontal shoots which grow on the surface or just below the sediment in plants. There are similar structures in animals such as hydroids.

Trifurcate: divided into three.

Tunic: covering or membrane

Umbo: beak of a bivalve shell; the protuberance of each valve above the hinge.

Zoecium: secreted exoskeleton housing of individual zooids.

Zooids: One of the distinct individuals forming the colony of animals such as bryozoans and hydrozoans.

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Invasive Marine Species: A Challenge for Australia's Marine Environment in the 21st Century

A symposium at the annual conference of the Australian Marine Sciences Association University of Melbourne, 9-13 July 2007

Invasive marine species, including pest species, are one of the most challenging issues in the marine environment in the 21st century. Port Philip Bay probably has more introduced marine species than anywhere else in Australia. Having a symposium on IMS at the 2007 AMSA conference is thus very timely.

Many Australians are working on IMS from a wide variety of viewpoints, including: understanding the taxonomy of the species and whether they are in fact introduced; what is a pest?; distribution of invasive marine species; ecological impacts of invasive species; modelling the spread of invasives; minimising the threat of invasions; effects of human disturbance on invasive species; reacting to invasive species; rapid transfer of information among scientists and government agencies; and many other aspects. The symposium is intended to provide a wide coverage of the problem. Talks and posters on all aspects of introduced marine species are welcome, as are people who want to participate without presenting. If you are interested in presenting a talk or poster, simply register with the conference section of the AMSA website, http://www.amsa.asn.au or contact Dr Fred Wells at fred.wells@fish.wa.gov.au.

We would also like to draw your attention to the related symposium on *Shipping and the Environment* being coordinated by John Lewis, **John.Lewis@dsto.defence.gov.au**. Some people may wish to participate in both symposia.

Either way, we look forward to seeing you at AMSA 2007 in Melbourne in July.

Waxes as novel antifouling coatings

Afsar, Anisul, Tim Charlton and Peter Steinberg

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There is an urgent need to develop novel non-toxic, environmentally friendly solutions to marine fouling control to replace current heavy metal based toxic paints. Among several strategies, non-toxic foul-release coatings or surface micro- or nano- structured coatings are promising alternatives. We have been exploring the utility of waxes as non-leaching antifouling technologies and found that different waxes varied greatly in their antifouling efficacy in the field, and in their foul release capacity (the ability to remove fouling which does settle). In particular, little or no hard fouling organisms (barnacles, bivalves) were observed on the best performing waxes and soft fouling (algae, bryozoans) were largely washed off using a low pressure water jet. We suggest that the antifouling and foul release effects of these waxes are due to changes in their surface properties. The surfaces of the most effective waxes changed noticeably after 4 - 8 weeks of immersion in the field or in seawater aquaria. Antibiotic treatments in the laboratory showed that this change in the wax's surface appearance was due to biological (microbial) activity. Bacteria appear to remove the amorphous phase from the surface of the wax, revealing the crystalline phase, which is much less affected by bacterial action. The crystals form a microstructured "bed of nails" in which the crystals vary in their shapes and sizes. We suggest that this "spikiness" inhibits settlement of fouling organisms and reduces the adhesion strength of those organisms which do settle.

A Contaminant in Decline – Long Term Monitoring of TBT in Mussels in a Port Environment

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Antifouling paints based on the biocide tributyltin (TBT) become widely used in all vessel sectors through the 1970s and 1980s because of their high performance and efficacy in biofouling control. However, in the late 1980s detrimental effects of TBT were detected in inshore environments, notably malformations in shellfish including commercially-farmed oysters. Regulations were progressively introduced to restrict the use of TBT paints, culminating in the International Maritime Organisation's Anti-Fouling Systems Convention (AFS 2001) which prescribes a phase-out of TBT use on international shipping by 2008. Measurements of TBT contamination levels in mussel (*Mytilus galloprovincialis planulatus*) populations in and around the Royal Australian Naval Base, Fleet Base West, in Cockburn Sound, W.A. were first undertaken in 1989 and, from 1993, a regular program was established with samples collected and analysed at least annually. Results reflect changing TBT management strategies, RAN fleet usage of Fleet Base West, and the phase-out of TBT antifouling paints across the RAN fleet that commenced in 2002.

Vessel biofouling as a vector for invasive marine species: Biosecurity New Zealand's research programme

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Vessel biofouling has been recognised as a vector in many historical introductions of marine species into New Zealand, such as Pacific oysters (*Crassostrea gigas*), and continues to contribute to both the international and domestic spread of marine species. Biosecurity New Zealand is the lead agency charged with the protection of New Zealand's indigenous fauna and flora from invasive species. In the marine environment, shipping movements provide a vector for both international and domestic translocations of species that would otherwise be impossible. Ballast water has received the most attention with several high-profile introductions, such as the zebra mussel (*Dreisenna polymorpha*) in North America's Laurentian Great Lakes, proving the catalyst for international action. However, ships have other vectors for translocations such as biofouling of sea chests, cooling and ballast plumbing, and hull surfaces. Biosecurity New Zealand has been pursuing a research program into the potential risk posed by marine biofouling, surveying four categories of vessels arriving in New Zealand ports. International yachts, fishing and passenger vessels, commercial vessels, and slow moving barges and oil platforms are all being surveyed over a 2 year period to correlate ship type, geographical movement, fouling level and fouling organisms. Results from this research will help inform risk analysis which will combine known life-history characteristics, probability of (re) introduction, probability of establishment and probability of spread to provide a hierarchical list of high risk invasive species. Such analysis will consequently allow for the development of prevention, mitigation and management measures.

Ships' sea chests: an overlooked mechanism for species transfers

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Since 2000, Cawthron has sampled 53 sea chests from 42 vessels (135 to 13,621 gross weight tonnes) at maintenance facilities around New Zealand. Vessel types included fishing boats, research vessels, bulk carriers, roll-on/roll-off ferries, container vessels, dredges, frigates, cruise ships, tankers and tug boats. Twenty three of the vessels were of domestic origin while the remaining 19 were international. All specimens above 500 µm (dead or alive) within sea chests were identified to the lowest practical taxonomic level.

151 different taxa were identified representing one plant species and 12 animal phyla, namely Porifera (4), Cnidaria (13), Platyhelminthes (1), Nemertea (2), Nematoda (1), Mollusca (30), Bryozoa (11), Annelida (19), Sipuncula (2), Crustacea (43), Echindermata (3) and Chordata (21). Of particular interest was the presence of 85 mobile adult taxa in 45 sea chests (e.g. 10 gastropod species, 19 crabs, 4 fish, a sea urchin, a sea cucumber, and a starfish). Sixty one of the taxa were indigenous to New Zealand, 20 introduced, 15 non-indigenous and 55 were of unknown origin. Most non-indigenous (1 species of isopod, 3 species of amphipods, 6 species of molluscs and 5 species of decapods) were present on vessels operating between the South

Pacific and New Zealand.

A wide variety of organisms are capable of surviving inside sea chests, highlighting the potential for sea chests to introduce non-indigenous and disperse native and introduced organisms around New Zealand. The occurrence of adult mobile stages is particularly significant and indicates that sea chests may be of greater importance than ballast water or hull fouling for dispersing certain marine species. These findings illustrate the importance of managing the ship as a whole rather than different mechanisms (i.e., ballast water, hull fouling, sea chests etc) in isolation.

Treatment methods used to manage an invasive sea squirt, *Didemnum vexillum* in New Zealand

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In October 2001, *Didemnum vexillum* was recorded for the first time in New Zealand, smothering wharf piles and moorings in a northern harbour. A heavily-fouled barge was then responsible for translocating the ascidian to an international shipping port some 500 km south, near the heart of the New Zealand Greenshell™ mussel industry. Its presence was regarded as a significant threat to the mussel industry because of its demonstrated invasiveness and its ability to over-settle and smother mussels.

After consideration of a benefit-cost analysis, an eradication program for *D. vexillum* was instigated in late 2003 by the regional regulatory agency and local port authority. While many of the response methods were completely effective at eliminating *D. vexillum* from different affected substrata, the program overall failed to eradicate the organism from the region. Even though a subsequent benefit-cost analysis suggested further eradication efforts would have net benefits, uncertainty over the timeframe, costs, and the likelihood of success, undermined stakeholder confidence to the extent that they chose to abandon the program. Over the next three years various anthropogenic vectors were responsible for spreading the ascidian throughout the Marlborough Sounds.

By the middle of 2006, *D. vexillum* had successfully affected several mussel farms throughout the Marlborough Sound with alarming consequences. A Didemnum Working Group consisting of various interested stakeholders was formed and a consensus made to attempt a second *D. vexillum* eradication and control program. A variety of novel methods were developed and used to treat both artificial and natural substrates, namely wharf piles, jetties/pontoons, moorings, vessel hulls, mussel lines, salmon cages, seabed, seaweed beds and immersed trees. The various treatment methods used, the success of the program to date, and the valuable lessons learned will be the focus of the presentation.

Commercial and recreational boat harbours offer different opportunities for marine invaders

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Hull fouling has been identified as a primary vector for marine invaders; however few studies have examined the different opportunities for invasion presented by commercial ships versus recreational yachts. One important difference between commercial and recreational vessels relates to the fact that for the past two decades the active biocidal agent in antifouling paints used by most commercial vessels has been tributyltin (TBT), whereas recreational boats have been restricted to copper-based paints. We investigated the development of sessile assemblages on settlement plates deployed in two recreational and two commercial estuaries in NSW, Australia. The plates were painted with copper diuron, copper zinc or TBT antifouling paint around their edges and deployed at multiple sites within each estuary. Sampling after eight months revealed different community composition in commercial and recreational estuaries. Commercial harbours were characterised by barnacles, colonial ascidians and the tubes of tanaeid amphipods. Recreational harbours were characterised by bryozoans and serpulids. Several invasive species responded positively to antifouling treatments and we suggest that antifouling paints may be influencing both the transport and establishment of invaders in different boat harbours. The outcomes of this study will help predict the invasive potential of Australia's native species. Our findings have implications for vector management since recreational and commercial estuaries will act as propagule sources for different invasive species.

Absence of evidence to evidence or absence – drivers, emerging issues and what the future may hold for biosecurity surveillance in NZ

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Biosecurity surveillance is not an isolated activity but one that contributes to many areas within the biosecurity system, including official assurances for trade, risk analysis and import health standards, decision-making during responses and for pest management. There drivers affecting why, how and to what level we undertake surveillance have changed considerably. There are also new issues to contend with; globalisation has resulted in increased opportunities for spread of pests and diseases and environmental changes are resulting in changes to the host ranges and distribution. The Biosecurity Surveillance group are currently developing a surveillance strategy. This strategy includes reviewing the current state of surveillance in NZ and identifying an improved approach and principles to guide future surveillance activities.

Efficacy of three commercially available ballast water biocides against vegetative microalgae, dinoflagellate cysts and bacteria

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One proposed solution to the problem of ballast-mediated aquatic invasions involves chemically treating ballast water to kill key target organisms. Here, we examine the efficacy of three commercially available ballast water biocides using vegetative microalgae, dinoflagellate

resting cysts and bacteria as test organisms. Chemicals tested were the ballast water biocides SeaKleen® and Peraclean® Ocean, and the chlorine dioxide biocide Vibrex®. Results demonstrate that the applicability of each of the three chemical biocides as a routine ballast water treatment is limited by factors such as cost, biological effectiveness and possible residual toxicity of the discharged ballast water. Of the three biocides tested, Peraclean® Ocean holds the most promise. Peraclean® Ocean was biodegradable within 2-6 weeks, could effectively inactivate resting cysts of the dinoflagellates *Gymnodinium catenatum, Alexandrium catenella* and *Protoceratium reticulatum* at 400 ppm, could control bacterial growth at 125-250 ppm, and could eliminate vegetative microalgal cells at a concentration of 100ppm. SeaKleen® did not inactivate resting cysts of *A. catenella* at five times the recommended dose (10 ppm) and was found to degrade at a rate that could result in the discharge of residual toxic water into the marine environment. Together with the poor bactericidal properties of SeaKleen® (100-200 ppm required), this may limit the use of this biocide as a routine treatment option. Vibrex® is not a suitable ballast water treatment option due to the need for hydrochloric acid as an activator, however it was found to be the most effective against bacteria (complete inhibition at 15 ppm) indicating that onboard chlorine dioxide generators may provide an effective bacterial treatment option. The performance of these biocides was adversely influenced by low water temperatures, light versus dark conditions, the presence of humus-rich seawater and ballast water sediments.

The vessel vector; biosecurity challenges large and small

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Vessels ranging from small recreational yachts to large merchant ships are ideal pathways for the transport of organisms, both in ballast water and on their hulls and other external surfaces. The speed of vessels, their construction, voyage route and maintenance history all influence the risk of species being successfully relocated by these means. The cargo that they carry provides another suite of vectors for species' transport. However, ships are an essential and very large component of world trade and, at least in Australia and NZ, recreational vessels an integral part of our outdoor lifestyle. Thus the size and complexity of the 'vessel vector' presents huge challenges to finding effective solutions to the problem of unintentional transport of organisms by these means. Finding effective solutions requires political will, both nationally and internationally, and innovative, targeted research. Above all, it requires dialogue with shipping and port companies at every stage. Approaches being taken in New Zealand to find tools to manage the 'vessel vector' are discussed.

Are there any consistent predictors of invasion success

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This presentation summarises the results of 49 studies that identify correlates of establishment and invasion success across 7 plant and animal groups. The studies reviewed here tested the significance of 74 (84) characteristics against establishment (invasion) success using linear models, chi-squared tests and a variety of other parametric and non-parametric techniques. When comparing failed versus successful introductions, 3 event- and location-level characteristics: climate/habitat match, history of invasive success and number of arriving/released individuals are independently verified as significantly associated with establishment success both within and across plant and animal groups. Only 1 of the species-level characteristics - geographic range size – is consistently and independently verified within (plants) and across (insects and mammals) biological groups. When comparing native species to established introductions, the fertilisation system, leaf surface area and geographic range size of plants are independently verified as significantly associated with establishment success. When comparing failed versus successful introductions, only 1 location-level characteristic – climate/habitat match – is independently verified as significantly associated with invasion success (invaded ranges size) both across plant and animal groups. Within plants, however, a number of event and species-level characteristics are significantly associated with metrics such as abundance, weed status and invaded range size that are variously used by different authors to mean invasion success. These results add weight to the argument that species-level characteristics that are truly predictive of successful invaders are taxa—specific, whereas event- and location-level characteristics are more general. They also impose a tension between the generality and the accuracy of risk assessment schemes that rely on species-level characteristics to prevent introductions.

Ship Biofouling as a Vector for Species Translocation– Observations and Management Strategies

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Modern antifouling paints can prevent the attachment and growth of macroalgal and invertebrate fouling species on the underwater hull of a ship for up to 5 years. However, not all submerged surfaces and equipment on a ship hull are protected in this way. These fouling “niches” can become heavily fouled and provide a refuge for the translocation of exotic species. Examples of niche areas include: seachests, seawater inlet and outlet pipes and grates, internal seawater piping systems, propellers and propeller shafts, bilge keels, anodes and docking block support strips. Several projects have been recently undertaken in Australia to identify these fouling niches, to determine the composition of fouling communities growing within these niches, to assess the risk posed by niche biofouling for the translocation of invasive marine pest species, and to develop management strategies to minimise the risk of such translocation. The Commercial Ship Niche Biofouling Project involved the inspection on an opportunity basis of eight Australian ships when they underwent scheduled dry-dockings for hull maintenance. Some findings from this project will be presented to illustrate the occurrence and composition of niche biofouling communities on ships and possible strategies and recommendations to minimise the risks they pose in regard to invasive marine pest translocation will be discussed.

Reproductive periodicity of the invasive sea squirt *Styela clava* in Auckland, New Zealand

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Although possibly present in New Zealand since 2000, *Styela clava*, the clubbed sea squirt, was first positively identified in Auckland in 2005. As part of its effort to respond adequately to this pest, Biosecurity New Zealand commissioned a study of the reproductive periodicity of this species. A population of *S. clava* has been sampled fortnightly since May 2006, coordinated with the lunar cycle at the time of the first low tide following the new and full moon. Environmental data, including sea surface temperature, salinity, rainfall and surface irradiation was also recorded. Animals were sacrificed in the laboratory and processed for examining changes in relative gonad weight and histology. Plankton samples were collected at regular intervals between spring and autumn and examined for the presence of tunicate larvae in the water column. Settlement plates were also placed at locations adjacent to the sampled population, in an effort to couple gonadosomatic data with recruitment events. Initial observations of fouled aquaculture facilities suggested that spawning and recruitment occurred in the mid (austral) summer. The first year of data collected suggests that the species reproduces over an extended period in the Auckland region, beginning in the early spring and lasting through to late summer. This is broadly consistent with the findings of studies of *S. clava* on aquaculture facilities in eastern Canada. *S. clava* larvae were not detected in the plankton samples, nor were any recruits found on the settlement plates. The consequences of this extended reproductive period for management of this marine pest species are discussed.

The classification of caprellids and isopods in biofouling sampled from RAN Ships

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Biofouling on ships not only impedes ship movement, but also allows species from one location to be transported to a site that it would normally not inhabit. In many cases, these exotic species have had deleterious effects on the native species, sometimes resulting in the extinction of less competitive native species. In an attempt to gain some understanding of the environmental threat posed by biofouling from vessels arriving from overseas, Defence has undertaken a survey of the biofouling present on Royal Australian Navy (RAN) Ships that have returned from overseas duties. The biofouling samples were sorted into taxonomic orders, of which two; Isopoda and Caprellida, were selected for further classification. Within the crustacean order Isopoda, several species are known to have been translocated, as biofouling, on early wooden ships. The two most common species of isopod found in the DSTO/RAN study were *Paracerceis sculpta* and *Sphaeroma walkeri*, both previously reported as introduced species and now having a wide distribution, both in Australia and world wide. Other isopod species that were recorded in the survey were *Neosphaeroma laticaudum* and *Cymodoce gaimardii*. Some of the specimens received were too immature to allow identification to species level; these were identified as belonging to the following genus; *Cymodocella, Ischyromene, Argathona* and *Cirolana.* Caprellid species identified from biofouling samples taken from RAN ships were; *Caprella penantis, C. californica, C. equilibra, C. laevis* and *Paracaprella pusilla*. It seems likely that *C. laevis* was translocated via shipping to Queensland waters, probably from the Sea of Japan.

An overview of Australia's proposed biofouling management requirements

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An estimated 250 exotic marine species have been introduced to Australian waters. For more than two decades, the discharge of ship's ballast water was considered the major vector for the dispersal of marine pests around the world. However, recent research suggests that biofouling on vessel hulls may be responsible for more marine pest introductions around the world than ballast water.

The Australian government has recognised the need to address this issue in a nationally coordinated manner; hence an Inter-governmental Agreement into the Control and Management of Marine Pests was developed and signed by the Australian, State and Northern Territory governments. The Australian Quarantine and Inspection Service (AQIS) is responsible for international border management of the biofouling risk presented by all vessels entering Australian ports and waters. Therefore, AQIS is preparing the legislative and administrative arrangements to implement mandatory biofouling management requirements through a series of vessel class specific protocols. An overview of the proposed biofouling protocols will be revealed in the presentation.

The Use of Urban Stormwater to Control an Introduced Marine Pest in West Lakes, South Australia

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West Lakes is an urban waterfront development located in western Adelaide, South Australia. The lake was artificially created in circa 1970 by the reclamation of swampland to provide waterfront residential properties. The lake is approximately 116 ha in size and holds an average volume of 3.6 GL. The environment of the lake is essentially estuarine, ranging from brackish in the winter months to above ocean salinity in the summer. In March 2002 the introduced marine alga *Caulerpa taxifolia* was discovered in the lake. It is considered a particularly noxious species, which poses a threat to fisheries resources and marine biodiversity. While a particularly hardy plant it is intolerant of extremes in salinity, being susceptible to salinity levels below 10 – 15ppt and above 85ppt. In March 2003 the South Australian government endorsed a plan to reduce the salinity of West Lakes in an attempt to eradicate the introduced seaweed. The plan was based on the harvesting of stormwater from the River Torrens and its diversion through existing stormwater infrastructure to West Lakes. The operation ran from July to November 2003 and delivered a total of 5.2 GL of stormwater into West Lakes. The average salinity of the lake was reduced to 11ppt. At the end of the operation no *Caulerpa taxifolia* could be found in the lake. At March 2004, surveys continue to show no recurrence of the weed. This operation has eradicated the vast majority of *Caulerpa taxifolia* from South Australian waters. Other operations address the remaining outbreaks.

How To Gift-Wrap A Frigate: Hull Encapsulation As A Potential Incursion Response Tool For Large Vessels

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Response to marine pest incursions requires adequate prevention, early detection and effective protocols for the system to work efficiently. Although large vessels are important vectors of introduced species, cost-effective, rapid response tools for these vectors are in need of considerable refinement. A decommissioned frigate of the New Zealand navy was purchased by a charitable trust with the intention to create an artificial reef and diving wreck in a relatively pristine area. The frigate had been docked in Auckland's harbour, a location supporting populations of several invasive species, notably the clubbed tunicate *Styela clava* and the alga *Undaria pinnatifida*. A routine inspection revealed the presence of *S. clava* on the vessel's hull, and given its proximity to known populations of *U. pinnatifida*, it was considered likely that this species was also present. The Trust was required to have the vessel dry-docked for cleaning prior to relocation, thus providing a unique opportunity to trial encapsulation as a potentially cost-effective method for removing fouling organisms. Such encapsulation had been conducted on smaller vessels in the past, but never on a vessel as large (113 m) as the frigate. Biosecurity New Zealand commissioned Cawthron Institute and Golder Associates to undertake the trial in partnership with a commercial diving company. Encapsulation involved sheathing the hull below the deckline in thick plastic in order to create dark, anaerobic, watertight conditions. Water quality within the capsule was monitored over the duration of the trial in order to assess likely efficacy. Problems in implementation of the wrap resulted in a premature loss of integrity and ultimately failure of the encapsulation. Despite these problems a post-experiment inspection revealed the onset of mortality in biofouling species present. Should these difficulties be able to be overcome, large-vessel hull encapsulation can offer a more cost-effective and rapid solution to responding to marine pests than dry-docking.

Battling 'Clingons' and Other Alien Invaders

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The need to control biofouling-mediated incursions of targeted and potential marine pests has been gaining the attention of regulators, not only because of the 1998-1999 Darwin marina infestation by the Caribbean mussel but also a series of subsequent incidents involving hull-infested arrivals including dredges, foreign fishing vessels and cruising yachts. Biofouling assessment and control actions must contend with the fact that every vessel has biofouling of some sort, and every time a vessel sails from one environmentally-similar port or coastal region to another it poses the threat of introducing a new 'clingon' or spreading aliens that have already gained a hold in Australian waters. Before practical and cost-effective management measures can be implemented for any vessel sector, it is essential to gain a clear understanding of its specific operational and route features that its govern propensity to translocate unwanted aliens. When analysing biofouling pathways provided by a particular sector, critical components include the inherent vulnerabilities in hull design, the type and frequency of vessel slipping and maintenance, and the 'promiscuity' of favoured routes and common long-stay nodes. Without a sound knowledge of these features it is impossible to identify the most pertinent, practical and cost-effective risk appraisal, response and communication tools. This paper draws from recent studies that have characterised the biofouling threats posed by six vessel sectors (yachts, apprehended vessels, dredges, petroleum industry vessels, military vessels, commercial trading ships) to highlight where divergent pathway components are leading to different, specifically tailored management approaches. Projects to be described in the paper have directly influenced Government policy direction and 'soon to be released' regulatory requirements, including the revised AQIS biofouling protocol for small international vessels.

Bio-inspired design for fouling control

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Biofouling is an enormous problem affecting all inanimate objects in the marine environment. Although the economic consequences of fouling are well known, of greater concern in the 21st century, is the threat posed by invasive species. The effective control of fouling is therefore crucial to minimise the costs to the shipping industry and to mitigate the spread of invasive species. Previously the control of fouling was predominately based on heavy metals and pesticides. With the imminent banning of these types of harmful coatings by the International Maritime Organisation the search is on for non-toxic alternatives. In this study natural antifouling systems are investigated. The surface of the blue mussel, *Mytilus galloprovincialis*, is used as a model to determine what characterises a fouling resistant surface. Microtextured ripples were discovered on the surface of the blue mussel, which correlated to low fouling cover. The surface features of 36 other species of molluscs were characterised and a variety of microtopographies were discovered. The surface roughness properties of these mollusc surfaces correlated to fouling resistance and removal. When the microtopographies of selected mollusc surfaces were mimicked, those surfaces that provided fewer attachment points reduced the settlement of a wide range of fouling organisms. Biomimics tested in the field were able to resist fouling for three months. It is thought that microfoulers in-fill the microtextures after this time leaving the mimics susceptible to macrofouling. It is believed that some mollusc shells use a combination of surface roughness and chemical repellents to maintain broad-spectrum fouling resistance. With this in mind the periostracum of the blue mussel was investigated. Extracts derived only from the thin periostracal layer inhibited the settlement of a common microfouler (*Amphora coffeaeformis*) and macrofouler (*Bugula neritina*). The implications of bio-inspired design for future antifouling technologies are discussed.

Marine pest invasions - How Biosecurity New Zealand Responds

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The significance of biological invasions into coastal marine waters has become more apparent over recent years. While this is primarily due to ever increasing trade and tourism, it is also a direct result of increased awareness and recognition of the risks posed by marine invaders as well as increased surveillance efforts. Marine invasion biology is a young discipline compared with terrestrial invasion biology and this is echoed by a lack of tools available to react to any new invasions in the marine scene. It is generally accepted that eradication of pests is not currently feasible in the marine environment due to difficulties in detecting invasive species early and the paucity of tools to control and manage marine invasive species. Biosecurity New Zealand is working with a number of research providers and industry groups to develop and test control options and tools for use in the marine environment. Some of the success stories from this research will be outlined and on-going gaps and issues will be highlighted and discussed.

Too Hot to Handle: Evaluation of Steam Sterilization as a Biosecurity Response Tool

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Heat treatments have proven to be an effective tool toward the control and eradication of non-indigenous marine species, such as the Asian kelp, *Undaria pinnatifida* and sabellid polychaete, *Terebrasabella heterouncinata*. To increase Biosecurity New Zealand's capacity to respond to marine incursions, a study was undertaken to evaluate the efficacy of a heat treatment technique developed previously by the New Zealand Department of Conservation to manage founding populations of *Undaria pinnatifida*. The technique generates hot water or steam at the surface, which is then delivered underwater to heat seawater encapsulated inside a silicone cone held against the treated substrate. The study comprised a combination of manipulative experiments and field trials on both artificial and natural substrates, on specific target species (i.e., *U. pinnatifida*) and biofouling organisms. Results indicated that the technique was only partially effective and most unlikely to eradicate an organism with a single treatment. The technique was, however, most effective on uniformly flat substrata, but difficult to apply effectively over complex topography. Application of the heat treatments by this technique was labour intensive and thereby limited to relatively shallow depths due to the risk of decompression illness. Re-colonisation of treated areas by the target organism also occurred. The technique was found to be most suitable as part of an integrated management strategy involving other management techniques, such as manual removal, and could be used to 'mop-up' satellite populations following large-scale management.

Australian introduced marine pest monitoring guidelines: trialling the methodology in Albany, Western Australia

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To address the need for ongoing monitoring of introduced marine species (IMS) the Australian and New Zealand Governments worked collaboratively to develop a targeted monitoring strategy that will form a critical component of Australia's National System for the Prevention and Management of Marine Pest Incursions. A trial of the National Introduced Marine Species Monitoring Manual was recently commenced in Albany as part of a National Heritage Trusted funded program investigating IMS in Western Australia. The monitoring manual was designed as a 'how to guide' for monitoring that can be used by government and regional council representatives, designers of and those carrying out the monitoring programs, stakeholders and funding providers. The manual outlines rationales and procedures aimed at providing scientifically rigorous sampling regimes to ensure data and results meet quality assurance/ quality control (QAQC) principles and allow informed and scientifically sound decision making on IMS management. The manual incorporates a targeted strategy in which 55 IMS have been identified as critical species for monitoring. Albany was the site of the first colony in Western Australia and thus has a long history of potential vectors for IMS transport. The Albany marine area has a wide and well-known variety of marine and estuarine habitats with a diverse native flora and fauna and three interconnected embayments. Albany was selected for

the trial because of its natural features, and human usage patterns including the long European history, which included whaling, an active international port, fisheries, aquaculture and private boat use. The trial will evaluate the rationale and methodology of the manual in order to facilitate changes or additional components that may be necessary for the successful future implementation of the manual.

Developments in managing the introduction and translocation of marine pests in ballast water

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The discharge of ballast water from vessels is recognised as a key factor contributing to the introduction and distribution of marine pests around the world. In 2001 the Australian Government introduced ballast water management requirements for vessels arriving from overseas and further work is now underway to include the movement of domestic ballast water around Australia. An Intergovernmental Agreement sets out that the Australian Government will be responsible for internationally-sourced ballast water while state and Northern Territory governments will be responsible for the management of ballast water sourced from Australian ports. With a focus on ensuring national consistency in what is being asked of the commercial shipping industry, considerable effort has been invested in developing the ballast water elements of the National System for the Prevention and Management of Marine Pest Incursions. Vessels will be required to exchange their port-sourced ballast water en-route to their next port of arrival, at a specified distance from nearest land. However, Masters will be able to claim exemption for low risk ballast water via an automated on-line risk assessment tool. Eventually the requirement for vessels to manage their ballast water via exchange at sea will be phased out as the new requirement for onboard ballast water treatment technology is phased in. Pending the International Maritime Organization's International Convention for the Control and Management of Ships Ballast Water & Sediments coming in to force, starting from 2009 ships will progressively be required to meet new ballast water discharge standards from the Convention that will require onboard treatment of ballast water for all ships coming to and travelling within Australia. This has led to a lot of activity in the areas of research and development as interested parties look to capture a slice of a potentially very lucrative market.

Actions to implement and complement the National System for the Prevention and Management of Introduced Marine Pests in Western Australia

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Numerous introduced marine species (IMS), including pests, are now in Western Australia. A Natural Heritage Trust funded statewide program recently commenced to evaluate the problem and develop strategies to minimise further introductions. The project will undertake a literature review collating existing knowledge on IMS in Western Australia, including: evaluation and determination of the risk of the different vessel types; review and collation of existing data from WA port surveys; other records of IMS; current risks to WA ports and marinas based on assessment of shipping patterns; and the marine species likely to be introduced. The project will trial the National Introduced Marine Species Monitoring Manual in Albany. We will also establish a centralised Introduced Marine Species Monitoring framework that uses the national monitoring approach; determines locations where monitoring should occur (in addition to the required locations of Fremantle, Dampier and Port Hedland), recognising both ports and high value areas (i.e. Shark Bay World Heritage Area); and provides information for the developing national database. The project will analyse potential future changes to threats due to increased shipping movements and changes in vessel origins. It will also roll out some of the National Biofouling Protocols and implementation of the National System, including: some of the Western Australian activities to implement the national communication strategy, i.e. regional communications; assistance in the delivery of the national monitoring program; and implementation of the national communications strategy. The project will be integrated with existing programs on both a state and national level.

Charting new waters controlling marine pests in New Zealand

Willmer, John

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Marlborough mussel farmers have been the driving force behind a marine pest management programme underway across the Nelson / Marlborough regions of New Zealand. The mussel farmers have taken a leadership role working with a range of local and central government agencies and stakeholders to develop and implement a pest management programme. In doing so, they have achieved some notable results.

In the best traditions of kiwi ingenuity the mussel farmers and service providers applied their resources, capability and experience of operating in the marine environment to undertake extensive pest control activities throughout the region. In doing so, they trialled and refined a number of pest control techniques that involved wrapping various structures in plastic and covering the seafloor to kill off *Didemnum vexillum*, an invasive fouling sea squirt.

The local councils played key supporting and coordination roles within their respective communities. Councils engaged with stakeholders to deliver a wide range of activities from public awareness, to liaising with vessel operators to reduce the risk of the pest being spread, through to providing a containment area within the port where vessels or marine equipment could be safely decontaminated.

The programme continues to demonstrate the value of working in partnership to deliver marine biosecurity outcomes, and provides a useful model for future initiatives. It has resulted in an increasing willingness of agencies, industry and other stakeholders to engage and invest resources in the programme, in turn, building regional marine biosecurity capability.

The programme has paved the way for biosecurity agencies and stakeholders to work in partnership to develop an integrated regional marine biosecurity programme across the top of the South Island. The regional programme will take a generic approach dealing with the full range of biosecurity risks. First steps for the partnership is to develop a regional biosecurity plan that will provide a framework for agencies and stakeholders to identify, and provide for their broader biosecurity interests in a coordinated manner.

Inhibition of fouling by *Pseudoalteromonas tunicata* immobilised in k - carrageenan beads

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Antifouling solutions that leave little or no impact in the world's oceans are constantly being sought. This study employed the immobilisation of the antifouling bacterium *Pseudoalteromonas tunicata* in κ-carrageenan to demonstrate how a surface may be protected from fouling by bacteria, i.e. a "living paint". Attempts so far to produce a "living paint" have been limited in both longevity of effectiveness and demonstration of applicability, most noticeably regarding the lack of any field data. Here we demonstrate long term survival of bacteria immobilised in κ-carrageenan for 12 months in the laboratory and evidence for inhibition of fouling for up to 7 weeks in the field, Sydney Harbour, NSW, Australia.

This is the abstract of a preprint of an article accepted by Biofouling [2007] [copyright Taylor & Francis]; Biofouling is available online at: http://journalsonline.tandf.co.uk/

SCIENCE FOR SUSTAINABILITY

New project to combat marine pests

According to the United Nations and other governing bodies, invasive marine species are one of the four greatest threats to the world's oceans caused by humans.

Considering Western Australia's unique marine environment and extensive ecosystems, it is vital that we develop a comprehensive program to understand the threat that marine pests pose to the WA marine environment, how we can minimise the chances of foreign species being introduced, and what can be done if a species does arrive on our shores.

The problem of marine pests is particularly difficult in Western Australia because our 12,500 kilometres of coastline feature a wide variety of different habitats and temperature regimes. Hence the problem is not uniform, but differs in the various parts of the State.

There is little wonder why invasive marine species are seen as a major threat to the world's oceans – they can cause severe ecological and economic damage.

"Marine pests can take over natural habitats, causing severe health consequences for native marine species and ecosystems" Dr Fred Wells of the Department of Fisheries said.

"Not only that, they can affect industries such as fishing and boating, and can damage tourism and shipping. Some marine pests can even threaten public health."

Musculista senhousia.
Introduced mollusc. Swan River.
Photo: Clay Bryce

Western Australia is a signatory to a national program aimed at combating the threat from marine pests. The idea is to have a nationally coordinated program with uniform standards that apply throughout Australia. The Department of Fisheries is the lead agency in the WA government for this issue.

In cooperation with several other agencies, Fisheries recently started a project *‚Actions to implement and complement the national system for the prevention and management of introduced marine pests in Western Australia,* headed by Dr Wells. The project is funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State government. The project, which started in October 2006 and is set for completion in June 2008, will be integrated into existing state and national marine pests programs.

Botrylloides leachi.
Introduced ascidian.
Photo: Clay Bryce

Dr Wells, who heads the project, said, "The project looks at developing new information and trialling new strategies to minimise the introduction of more pest species into our waterways."

The first component of the project is to bring together existing information on the approximately 90 species of marine plants and animals known to have been introduced into Western Australia. Many of these species cause no apparent harm, but some can become serious pest species.

This aspect of the work is being done in cooperation with Diana Jones of the WA Museum and Dr John Huisman of the WA Herbarium. It will feed into information assessing the threats posed by a variety of potential sources, including shipping, private yachts, illegal fishing vessels, fishing boats, aquaculture, and marine aquaria. Changes in usage of the marine environment may mean new threats will emerge in the future.

In November last year, a stakeholder workshop was held in Perth to discuss the project and its implementation. "The workshop helped us to clarify the aims and objectives of the project and to think of ways to continue the work after the project ends in June 2008. Comments were also made about how to ensure the project fits closely within the national system.

"We will continue to hold stakeholder workshops throughout the project to ensure people know how the project is developing and that it meets their needs." Dr Wells said ■

The Watermans site on a rough day.

The inshore platform zone.

The *Ecklonia* zone.

The south-west side of Garden Island is difficult to access, and had been fished almost exclusively by professional fishers. Cottesloe had a few abalone, which were targeted by recreational fishers. Trigg had initially been fished commercially, but within a few years had become a recreational area. Watermans had become a marine reserve about the same time as the abalone fishery commenced in the late 1960s and was free of legal fishing.

An analysis of the platforms showed that they could be divided into different areas based on the marine algae present. Near the shore the 'inshore platform' was a diverse mixture of seasonal algae during summer that tended to be dislodged by winter storms. The '*Sargassum* zone' of the middle of the platforms had a mixture of larger algae dominated by *Sargassum.* These algae also suffered losses during winter, but there was always a remnant algal presence. In many areas, the seaward margin of the platforms was a 'bare zone' which was largely devoid of macroalgae, though isolated plants were found in many of the holes in the rock. In addition, a slightly deeper area of the Cottesloe platform had a large stand of the kelp *Ecklonia radiata.*

Quantitative transects with eight stations each were run through each of the habitats on each of the reefs during the summers of 1983, 1984 and 1985 as part of the Fisheries project. At each station, the total number of species, and the density and biomass of each species were calculated. In 1986 the study was repeated as part of the background work for the establishment of the Marmion Marine Park. Echinoderms were also measured during the last two years of the study.

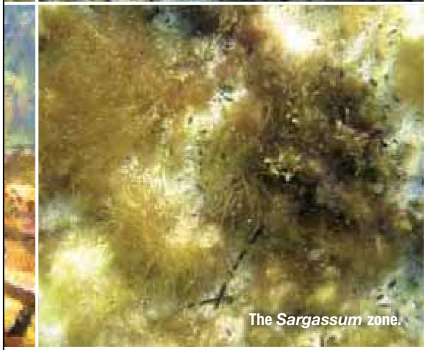
As a separate exercise, abalone were measured at six stations on the Cottesloe (one station), Trigg (three) and Watermans (two) reefs. At each station all abalone in 20 square quadrats 0.5 metres on a side were counted and measured. Additional abalone were randomly measured until a total of 200 had been measured at each station. Together the work provides a substantial source of quantitative information for molluscs and echinoderms dating from 1982 to 1986.

The project formed much of the basic research behind the management of the abalone *Haliotis roei* in the metropolitan area. A substantial portion of the project was devoted to understanding the fisheries biology of this important species. Over the years the recreational fishery has been progressively more tightly managed so that now the season is open only for one hour (7am to 8am) on six successive Sunday mornings starting with the first Sunday in November. Daily individual bag limits of 20 abalone and a minimum size of 6 cm apply.

During the intervening quarter of a century since the original platform mollusc study commenced, there has been a huge increase in environmental awareness in the Western Australian community. All of the platforms now have enhanced protection of the plants and animals that live on them.

Trigg and Watermans are part of the Marmion Marine Park, which was established in 1987. The Cottesloe Fish Habitat Protection Area was established in 2001. Collecting abalone was banned in the Cottesloe FHPA during the 2006 season because of concern over the low stocks. Rottnest Island has had a

The bare zone with abalone.



The *Sargassum* zone.

progressive tightening of regulations by the Rottnest Island Authority.

It is unusual to have such a good quantitative dataset from 25 years ago anywhere, much less where management arrangements have changed so significantly. In recognition of this, the Department of Fisheries, CSIRO and the Swan Catchment Council have partnered to resurvey the platforms in 2007 and 2008. The project is funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State Government. The Swan Catchment Council is the regional Natural Resource Management group in the region.

Molluscs and echinoderms at Trigg, Cottesloe and Watermans were surveyed during the recent summer using the same methods as in the 1980s, so the data are directly comparable. The west end of Rottnest Island (Cape Vlamingh and Radar Reef) will be surveyed in the summer of 2008. The surveys will provide an invaluable insight into how management practices on these biodiverse habitats are working and if we need to do more to protect them. ■

Research news

From the Department of Fisheries Research Division

ARTIFICIAL MARRON HABITATS

Dr Martin de Graaf, with Recfishwest and the Water Corporation, has secured funding through the Recreational Fishing Community Grants Program to build artificial habitats for marron when Drakesbrook Dam is drained for refurbishment in the summer of 2008-2009. Researchers have already begun surveys of the dam area using underwater visual surveys and traps to estimate the distribution and abundance of juvenile and adult marron. When the dam is drained, marron will be transported to the Pemberton Freshwater Research Centre for safekeeping while rock piles are built in suitable areas.

All marron re-stocked into the dam will be micro-tagged and follow-up surveys will show whether re-stocking marron rebuilds the population to similar levels as before the draining and whether the rock refuges provide enough shelter to increase marron survival and enhance the recreational marron fishery in the dam.

DEEP-SEA CRABS

For the last five years, the Fisheries Research and Development Corporation has funded a project to collect 'Biological and Fisheries Data for Managing Deep-Sea Crabs in WA'. The project, run by Prof. Ian Potter and Dr Roy Melville-Smith, is now complete, but monitoring and tagging of the crystal crabs that are the basis of the fishery will continue. For several years, about 200 tonnes of the crabs have been caught by three fishers off the west coast at depths of 500-800 metres and exported mainly to China and the United States. A few reach the local market and can be found in some Northbridge restaurants.

LOBSTER COMPUTER MODEL

Over the last couple of years, Fisheries staff have been developing a new computer model for assessing the state of the lobster fishery and a panel of experts will visit in July to help review it. Several research staff will then go to the 8th International Conference and Workshop on Lobster Biology and Management in Canada in September. Held every three or four years in lobster-producing countries such as Canada, Japan, Cuba and New Zealand, this conference series began in Perth in 1977. Lobsters are one of the most studied, and commercially valuable, animals on Earth and WA's rock lobster fishery was the first commercial fishery to be certified sustainable by the Marine Stewardship Council (MSC).

Deep water rock lobster studies identified by the MSC are also being completed. Dr Lynda Bellchambers will present results of her studies into the behaviour of rock lobsters once they move into deep waters as part of their annual migration at a workshop in August. Valuable data about what the lobsters eat and how they use various habitats have been gathered. The workshop will also develop guidelines for the next lobster ecology project.

Protecting species on intertidal platforms

Fred Wells, John Keesing and Tennille Irvine

Fishing for Roe's abalone in the Perth Metropolitan area is only permitted for one hour over six consecutive Sundays in November and December.

In a study funded by the Natural Heritage Trust, Dr Fred Wells, Department of Fisheries and Dr John Keesing, CSIRO Marine and Atmospheric Research, Floreat, are returning to intertidal platforms off metropolitan beaches that they first studied a quarter of a century ago. Tennille Irvine of CSIRO joined the study last year.

The coastline of the Perth metropolitan area is essentially a single sandy beach broken up by occasional small intertidal limestone platforms. The shifting sands of beaches are essentially biological deserts. Marine species living in the sands are alternately covered up when sand accumulates or are exposed when it is removed. As much as a metre of sand can move at a single place during a 24 hour period. Only species capable of digging into the sand when they are exposed, or out of it when they are buried, can live in this area.

In contrast, the limestone platforms are very different environments. The rock surface provides plants with somewhere to establish a foothold. The marine algae, and even limited seagrasses, on the platforms in turn provide purchase and food for a wide variety of marine animals. Other animals such as limpets, abalone and barnacles are able to adhere directly to the rocks. Over thousands of years, rasping of the bottom by some species, such as sea urchins, has left shallow depressions in the limestone that are colonised by other organisms. The net result is that there is a diverse and abundant community of plants and animals on platforms such as those at Trigg, Cottesloe and Watermans.

Just as there are incredible differences in the plants and animals living on sandy beaches and limestone platforms, the people of Perth react differently to the two habitats. The extensive sandy beaches of Scarborough, south of Trigg, Cottesloe and the smaller beaches near Watermans are all favourite places for beachgoers on a hot summer day. Throughout the year recreational fishers can be seen day or night quietly fishing for the big one. Surfing is popular whenever there is a wave. In contrast, hardly anyone ventures onto the platforms.

That all changes every year at 7am on the first Sunday morning in November. Suddenly thousands of people descend on the platforms in a frenzy to each collect their daily bag limit of 20 Roe's abalone. An hour later they all depart and the platforms return to their normal tranquil state. The process is repeated on six successive Sundays in November and December – then the platforms return to obscurity.

The Department of Fisheries has developed one of the most tightly managed recreational fisheries in the world to protect the stocks of Roe's abalone and share the catch between the thousands of recreational fishers. But what of the other plants and animals on the platforms? How are they being protected?

In 1982 we were asked by the Department of Fisheries to survey the molluscs of the intertidal platforms at Trigg, Cottesloe and Watermans. At the time, collecting gastropod molluscs and sea urchins on metropolitan platforms had been banned because the Department was concerned about the large numbers of abalone and other molluscs being removed.

Over four summers from 1983 to 1986 we examined mollusc populations in considerable detail. The work formed the initial research basis for managing Roe's abalone. It also provides a benchmark for determining how management measures developed in the last quarter of a century have been working in protecting species other than abalone on the platforms. We can use the mollusc data as a basis for drawing conclusions about broader management.

In recognition of this, the Department of Fisheries, CSIRO and the Swan Catchment Council have formed a partnership to re-survey the platforms (see *Western Fisheries* July 2007). The project is funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State government. The Swan Catchment Council is the regional Natural Resource Management group in the Perth metropolitan area.

Since the studies in the 1980s there have been two major developments in managing the platforms. Trigg and Watermans are now part of the Marmion Marine Park, which was established in 1987. The Cottesloe Fish Habitat Protection Area was established in 2001. How are these management areas working?

In 2007 we resurveyed the molluscs of the same platforms as in the 1980s, using the same techniques. Day after day we would visit one of the platforms. The weather was reasonably good, though on some days swells were too high to work. There was even a strong summer storm when no

work could be done for several days. The hand drawn maps we made a quarter of a century ago were used to find the locations of the original sites. It was amazing that with these maps we could get within a few metres of where we worked 25 years ago.

The original surveys showed that mollusc populations were quite variable. For example, the inshore platform at Watermans had a thriving population of plants and animals when we first surveyed it in 1983. The following year the same area was covered in sand except for the tops of small ridges; the animals were essentially gone. Mussel populations on the platforms differed considerably. One year there might have been a good settlement and survival, with plenty of small mussels in an area. The following year might not have been so good, with the mussels not nearly as abundant.

But within this range of natural variation, we were pleased to see that the molluscs of the platforms are very similar to those we found a quarter of a century ago – the same suite of species on the same parts of the platforms in approximately the same densities. So, it is reassuring that for these species, management measures are in fact working.

In 1982 we conducted similar studies at Cape Vlamingh and Radar Reef at the west end of Rottnest Island. It will be interesting to make a similar comparison during the coming summer. ■

New knowledge shared at Leeuwin Current symposium

By Eloise Dortch

Two hundred years ago, British explorer Matthew Flinders noted '*Curr. 1½ per hour*' on a navigational chart as he sailed along the south coast of Australia. With hindsight, we know he was recording the speed of the Leeuwin Current.

Named after a Dutch merchant ship that explored WA's south-west coast in 1622, the Leeuwin Current is unlike the cool currents that flow in a northerly direction along the west coasts of South Africa and South America. Unusually, the Leeuwin Current carries warm, tropical water in a southerly direction along WA's west coast. It then turns east and flows along the bottom of Australia as far as Tasmania.

The 5,500 kilometre-long phenomenon is the dominant and for many, most fascinating feature of WA's marine environment. Following Flinders, various navigators, biologists and oceanographers observed and pondered evidence of a south-flowing, warm current. But it was not until 1980 that the Leeuwin Current was clearly identified and named, following landmark research by CSIRO oceanographer George Cresswell.

In March 1991, the Royal Society of Western Australia held a symposium for scientists studying aspects of the Leeuwin Current. The event, attended by 100 people at CSIRO's Floreat theatrette, saw speakers address, among other items, the Leeuwin Current's relationship with other currents, climate change and sea temperature; its yearly variations and ways to model it; and its effect on tropical fish, marine flora, coral reefs, rock lobsters and seabirds. A second, similar symposium was held in September 2007 at the University Club, University of Western Australia.

Both the 1991 and 2007 events were organised by former CSIRO oceanographer Alan Pearce. Although semi-retired, Mr Pearce is working on a PhD that examines the influence of ocean processes, including the Leeuwin Current, on the recruitment of tropical fish and rock lobsters off WA.

He said the recent symposium – attracting 105 people from academia, State and Federal government agencies and the general public – showed that there had been considerable advances in oceanographic and biological knowledge about the current in the past 16 years.

"Since 1991, so much useful work has been done around our coasts," Mr Pearce said. "We have an immense coastline, including such a wide range of water properties and ecosystems, that there is plenty to keep everyone busy. Trying to pinpoint any major gaps in our knowledge is difficult, but one particular issue is how the Leeuwin Current is changing over time and the effect that this will have on our ecosystems."

Dr Cresswell, who is now a research fellow for CSIRO in Hobart, was a key speaker at both the 1991 and September symposiums. He said there had been a big increase in the number of scientists, students and inter-disciplinary teams studying the Leeuwin Current.

Important developments since 1991 included a remarkable increase in satellite data – including surface temperature, topography, colour and roughness – as well as temperature, salinity, and biological and chemical data gathered using a range of innovative devices, oceanographic stations, ships, moorings and floats. This research had enabled good data sets, some of which dated from the early 1990s, to be established and had been accompanied by improvements in numerical modelling systems.

Other significant developments included: mapping of the behaviour of the current's eddies and their biological significance; recognition that the current flows all the way to Tasmania and that waters along the length of the North West Shelf probably contribute to the Leeuwin Current; and a greater understanding of the current's paleoceanography, including nutrient-rich upwellings when the sea level was 130 metres lower than at present.

Mr Pearce said all papers submitted as the proceedings from the second symposium would be peer-reviewed and published this year in a special edition of the Journal of the Royal Society of Western Australia. ■

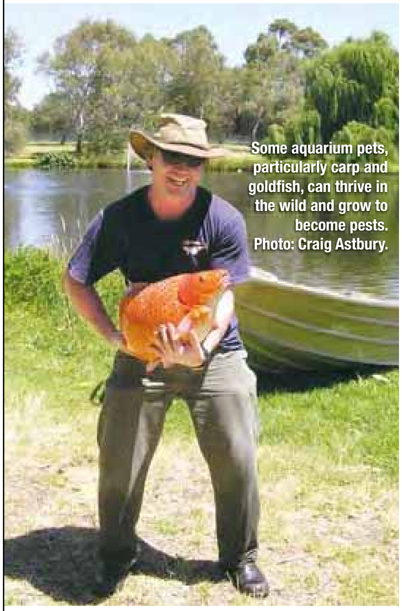
UNWELCOME GUESTS

By Cathy Anderson

Imagine somebody's dream holiday, slowly sailing a small yacht through the Indonesian archipelago, taking time to anchor, swim and fish in remote bays. The yacht crosses to the north of Australia and gradually works its way down the Kimberley coast as the sailors enjoy the stunning scenery and pristine beaches.

Eventually it reaches the beautiful coral reefs at Ningaloo, where some of the little hitchhikers on the boat's hull drop off or shed some offspring. Ningaloo, meet the black-striped mussel, which could eventually smother the whole reef ecosystem. There, another species has been introduced…

So far, this is only an imaginary scenario but without care it could easily happen. There are an estimated 250 introduced marine species currently recorded in Australia, with 55 of those species having been recorded in Western Australia. But we have none of the really nasty ones – yet.



Some aquarium pets, particularly carp and goldfish, can thrive in the wild and grow to become pests. Photo: Craig Astbury.

"Biosecurity is increasingly an issue of State and national concern", says Dr Stephanie Turner, the Principal Management Officer, Biosecurity, at the Department of Fisheries. Dr Turner leads a small team within the Fish and Fish Habitat Protection Program that has the challenging task of managing aquatic biosecurity within Western Australia.

What is biosecurity?

'Biosecurity' is about reducing the risk of the introduction or spread of organisms into an environment where they do not naturally occur. The introduction is usually through direct or indirect human activity and can have significant effects on the organism's new environment.

Not all introduced species give cause for alarm, though. Most of us have gardens containing exotic plants that provide food, colour and scent. The crucial difference is whether the species is harmful or not and the kind of effect they have on their new environment.

'Introduced', 'non-indigenous', 'invasive', 'exotic' or 'pest' organisms can displace native species by competing for habitat or food, modifying the environment or carrying diseases that are harmful to our native plants and animals. Everyone knows about the disasters of both deliberate and accidental releases of rabbits, foxes, rats, cats and cane toads in Australia. Once established, introduced pest organisms often have long-lasting, irreversible effects and can be impossible to eradicate.

Introduced marine species and diseases are now recognised as one of the greatest threats to the world's oceans. Aquatic biosecurity means reducing the risk of introducing and spreading organisms in our local aquatic ecosystems. Such organisms can also cause great economic and social damage by affecting fisheries and aquaculture operations, shipping and ports, marine industries, recreation and tourism, and even human health and cultural values.

Non-indigenous aquatic organisms can be introduced or moved (the technical term is 'translocated') to a new environment in a variety of ways; for example, escaping

The Northern Pacific sea star can reach plague numbers rapidly and devastate its surroundings. Photo: Rod Knights.

Aquatic plants, both marine and freshwater, can become pests if not confined. Photo: Craig Astbury.

or being released from an aquarium or aquaculture facility, released as live bait, attached to vessels and structures such as oil rigs, or discharged in ballast water from a vessel.

Aquatic biosecurity management

In Western Australia, the Department of Fisheries has been appointed the lead agency responsible for aquatic biosecurity, which covers both freshwater and marine ecosystems.

A new Act of Parliament will give the Department the powers needed for effective aquatic biosecurity management. The *Biosecurity and Agriculture Management Act 2007* was passed by the WA Parliament in September 2007 and combines powers scattered throughout 17 existing Acts over various government agencies. The purpose of this new Act is to prevent plant and animal pests and diseases from entering Western Australia and control those that are already found here, to minimise their spread and impact.

"The new Act is a significant development and will provide the Department with the necessary regulatory tools for managing aquatic biosecurity and consolidating guidelines in Western Australia", Dr Turner said.

"The Department's new responsibilities will also require building relationships with new stakeholders and strengthening relationships with existing stakeholders.

"We are also involved in national biosecurity initiatives, such as contributing to the development and implementation of the National System for the Prevention and Management of Marine Pest Incursions."

The National System concentrates on developing prevention systems to reduce the risk of introducing and translocating marine pests, and includes management arrangements for ballast water and biofouling, providing a coordinated emergency response to new incursions and translocation, and the ongoing control and management of marine pests already established in Australia.

A committee formed as part of the National System (The Consultative Committee on Introduced Marine Pest Emergencies) has compiled a list of 20 species that, if identified within Australia, would trigger an emergency response by the relevant authorities.

Certain species, such as the Chinese mitten crab (*Eriocheir sinensis*) that burrows and undermines riverbanks, the American slipper limpet (*Crepidula fornicata*) which has become a pest in mussel and oyster farms, and the black-striped mussel (*Mytilopsis sallei*), have been identified as high-risk species for Australia, based on their demonstrated invasive history and behaviour overseas. The rapidly growing black-striped mussel can colonise marine structures, choking out local species as it competes for space and food.

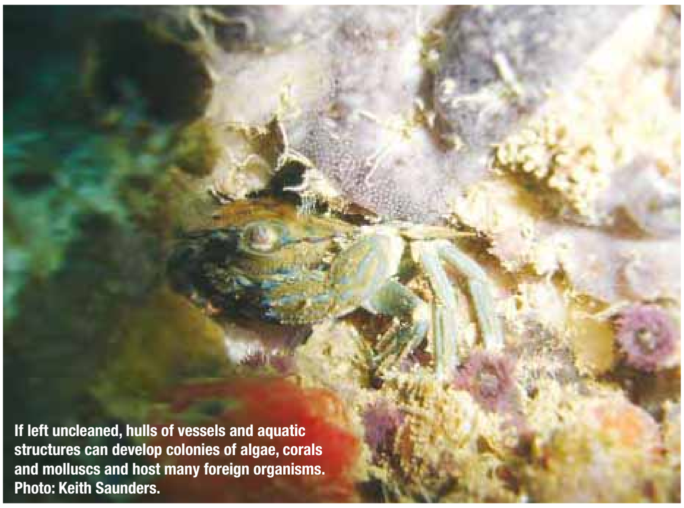
Plants like the Japanese kelp (*Undaria pinnatifida*) can also become a problem for various reasons – they may out-compete local species or reduce the light reaching other underwater communities such as coral reefs.

The globalisation highway

Worldwide trade has boomed in recent decades and shipping is the main transport option for heavy goods, large volumes and raw resources such as grain and iron ore. This has ramifications for nations such as Australia, which ship huge quantities of these commodities. Offshore mining and exploration also requires infrastructure. But shipping can carry unwanted hitchhikers.

Most marine species introduced into WA arrive in or attached to vessels and marine structures, such as oil rigs. Western Australia's resources boom has seen a great increase in traffic of marine vessels and equipment into the State and thus an increased potential opportunity for exotic organisms to arrive and establish themselves.

Western Australia has some of the busiest ports in the country, handling more than half of the nation's export tonnage. We have three of the top five tonnage ports – Dampier, Port Hedland and Fremantle – and the first two are the only ports in Australia handling more than 100 million tonnes per year. This means a lot of



If left uncleaned, hulls of vessels and aquatic structures can develop colonies of algae, corals and molluscs and host many foreign organisms. Photo: Keith Saunders.

ships to monitor for possible introduced organisms. In 2006, there were 7,683 port visits in Western Australia, with Dampier hosting 3,301 and Fremantle 1,717.

"Ships present two main potential risks of introducing marine organisms," said Dr Turner. "Ballast water, which is the water carried by ships to ensure stability, trim and structural integrity; and biofouling – organisms attached to the hull, ropes or other structures in the water."

Ballast Water

Since July 2001, Australia has had requirements for the management of internationally-sourced ballast water that apply to all ships arriving from overseas. To reduce the risk of releasing exotic marine organisms picked up in ballast water at an overseas port, ships must not release foreign ballast water into Australian waters unless it has been properly exchanged at sea.

"Under the new *Biosecurity and Agriculture Management Act 2007*, the Department of Fisheries will introduce similar management arrangements for vessels moving into and within Australian waters, to reduce the risk of spreading pest organisms already established within other areas of Australia into Western Australia," Dr Turner said.

Biofouling

Biofouling is of even greater concern because researchers believe that around 70 per cent of introduced marine species are arriving through this source. Once, toxic paint applied to the exposed surfaces of marine structures deterred the settlement and growth of marine organisms, but since it was banned because of its harmful effects on the marine environment, an effective substitute has not yet been found. The best current control method is frequent cleaning of boats in a properly maintained facility, being careful not to spread any potential pest organisms by allowing any removed biofouling material to enter waterways.

"We propose to manage biofouling by encouraging all sectors to adopt best-practice guidelines to minimise the risk of translocating marine organisms," Dr Turner said. "The guidelines will provide advice on such things as cleaning vessel hulls and equipment, and treating internal seawater systems."

Recreational Vessels

Recreational marine and freshwater craft pose a significant risk of introducing and spreading aquatic pest organisms. There were a whopping 86,000 recreational boating licences issued in WA in 2006, a 50 per cent increase since 1996, reflecting WA's booming economy.

"One of the Biosecurity group's priorities is to get the message across to boat owners that any boat could be a possible carrier for unwanted aquatic species," Dr Turner warned.

"The sheer number of vessels, their ability to move to various locations, the frequency of movements and the potential length of time spent in the water, are all factors that make recreational vessels difficult to manage, especially in remote locations like the Pilbara and Kimberley. "

Safe harbours

At the WA Fisheries and Marine Research Laboratories at Hillarys, Dr Fred Wells and a small team are using a National Heritage Trust grant to link up with national systems to prevent and manage introduced marine pests.

"We're providing the background scientific information that Dr Stephanie Turner, the Department of Fisheries' Principal Management Officer, Biosecurity, can use to make management decisions," Dr Wells said.

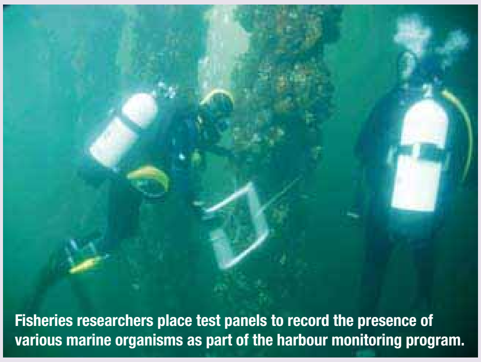
"Through her, our material flows through to national groups; so while we are working on our own in WA, we are still integrated into the national scene and using similar methodology."

A list has been compiled of Australia's 18 major ports that are considered to be areas of greatest concern where marine pests may appear. WA has three of them – Dampier, Port Hedland and Fremantle.

Researchers around the country are testing ways of monitoring these ports, working towards a National Introduced Marine Species Monitoring Manual.

The WA project has several main components – and the first step is assembling existing knowledge.

"Our starting point is that there have been surveys done by the CSIRO and other people in different areas of the State," Dr Wells explained.



Fisheries researchers place test panels to record the presence of various marine organisms as part of the harbour monitoring program.

"I was at the WA Museum for some time – and they have identified a lot of the introduced material but not all of it – so before I got here I knew quite a lot about marine pests and what had been introduced, but still nobody's got the full picture.

"The first thing we have to do is to pull everything together and make all that information available in a more readable fashion."

Out in the field, the team is also testing various monitoring methods, such as putting test panels into Albany Harbour at various times of the year to see what organisms may settle on them.

"Except for Dampier, all the major ports in WA have been surveyed, so we know what's already there. Now we've got that information, we can target the 55 species that have already been introduced or might be introduced and become a problem," explained Dr Wells.

"We already know some methods are working and some aren't. It's quite labour- intensive and not easy when you're out on the water with high waves and the temperature is only 12 degrees Celsius – but we need to test methods that look good on paper and find their strengths and weaknesses."

Once the most efficient methods have been determined, the same monitoring will be applied in ports nation-wide so results will be consistent.

But it's not quite that simple…the biosecurity team must co-operate with a wide range of owners and authorities.

"One of the critical things brought home to us at stakeholder meetings is that we shouldn't really use the term 'ports' – we're trying to use 'marine areas' now because the program captures other affected areas," Dr Wells said.

What to do with goldie?

There's another source of introduced pests much closer to home – animals and plants kept as pets in aquaria can also pose a significant biosecurity threat to our native species and local aquatic environments. Some aquarium owners, in an act of misplaced kindness, release unwanted fish or plants from their aquarium into local waterways, drains and lakes without realising the serious effects they can have.

"More and more feral populations of fish are being reported to the Department in our local waterways," Dr Turner said.

Recreational fishers have also reported unusual symptoms of diseases and parasites on their catches, and scientists think these have come from aquarium organisms that have escaped or been released.

The Department of Fisheries will be carrying out a public education campaign to encourage aquarium owners to not release their pet fish or plants into waterways and dispose of them by either returning them to their local pet store or destroying them humanely.

The Department of Fisheries biosecurity team was called in to help eradicate an outbreak of cichlids (popular aquarium species) in Bennett Brook and used electrofishing to stun and remove the fish. Photo: Craig Astbury.

The home guard

Public alertness has been, and remains, one of the best weapons in preventing populations of introduced pest organisms becoming established.

Beachcombers in Inverloch, Victoria, noticed a number of unusual sea stars at their beach and were the first to alert authorities to an outbreak of what turned out to be the Northern Pacific sea star (*Asterias amurensis*). Thanks to early reporting, and after hours of intensive effort by the local community and authorities, the sea stars were eradicated and not given a chance to become established. Northern Pacific sea stars are voracious predators that breed rapidly and can quickly reduce a flourishing marine ecosystem to a desert.

Divers, fishers, walkers, kayakers, beachcombers – anyone familiar with their aquatic surroundings – can become sentinels in reporting anything unusual to the Department for further investigation. If you see anything unusual in your local waterways, please call the Department's Biosecurity group on 9482 7333.

"The sooner we can identify an organism as a potential pest, the sooner we can determine an appropriate management response.," Dr Turner said. "The sooner a response can begin, the more likely it is to succeed."

The cost of eradicating introduced species once they become established can be enormous. For example, removing black-striped mussels from three small marinas in Darwin in 1999 cost an estimated $3 million. Prevention is far better, and much more effective and economical, than eradication.

"It's important that we encourage all water users to be careful and responsible to help prevent the introduction or spread of introduced organisms," Dr Turner said. "All water users need to be aware that they could be potential vectors for introducing or spreading pest organisms."

The message from the Biosecurity group is to remember to clean your equipment before leaving an area; think twice before discarding any old bait, unwanted aquarium pets or contaminated water into waterways; and report any unusual sightings of species within your waterways. ■

"If we look at Fremantle – introduced species is a Fremantle Port issue, but it's a wider concern than just the official port area.

"The port goes halfway to Rottnest because of Gage Roads, and down to Cockburn Sound.

"But the Navy is not part of the Port of Fremantle, there are commercial leases of mussel industry and some of the major shipping jetties are private.

"Then there are yacht clubs, fishing harbours, facilities owned by the Department for Planning and Infrastructure and the Marine Operations Centre, so it's not just a port authority issue."

In spite of the complexity and sheer scale of trying to keep marine pests out, Dr Wells is optimistic that given enough time and resources, effective protocols will be developed and installed.

"It's a minimisation exercise; you can't ever get rid of the risk, but we actually have very few pests and very few introduced species here, compared to other places in the world and other parts of Australia."

He sees the immediate threat as pests such as the Northern Pacific sea star coming from other parts of Australia, because laws and management plans covering inspection of domestic vessels have not been completed and we rely on diligent vessel owners to change ballast water.

"Biofouling brings in more stuff than the ballast water and while water exchange at sea isn't 100 per cent effective, it does cut it down," Dr Wells said.

"With biofouling you are talking about boats of all sizes, and organisms can lodge in boats and gear and survive in damp conditions – we need to think about that.

"Rigs and barges are an issue. Structures linked to the sea bottom, or which are stable or slow-moving, tend to accumulate organisms."

The next stages of the three-year project are building a monitoring framework (determining where and when monitoring should happen), feeding information back into the national database, and attempting to analyse and adapt to future threats as shipping patterns change in volume and origin.

Globalisation will require eternal vigilance for biosecurity, but so will nature.

"Nature always surprises us," said Dr Wells. "Just when we think we've spotted the threat, something else we haven't anticipated will happen."

The broken up platform in this area provides a wealth of niches, but is very hard to sample.

Rottnest intertidal platforms – then and now

By Fred Wells, Department of Fisheries, and John Keesing and Tennille Irvine, CSIRO Marine and Atmospheric Research

In 1980, two CSIRO scientists, George Cresswell and Stuart Golding, formally described the Leeuwin Current. As many people now know, this is a southward-flowing current that brings warm tropical water down the west coast of Western Australia, particularly during winter when sea surface temperatures are lowest. It provides a mechanism for tropical species to occur much further south than otherwise would happen.

In the 28 years since the current was formally described, scientists have discovered what a profound influence the current has on many aspects of the Western Australian marine and aerial climates.

Much of this was unknown in 1980 when the current was freshly described. Fred Wells and John Keesing decided in 1982 to compare the molluscs living on the intertidal platforms at the western end of Rottnest Island, where the Leeuwin Current increases winter sea surface temperatures, with similar platforms on the mainland at Trigg and Cottesloe that are unaffected by the current. The idea was that there would be more tropical species at Rottnest.

The first step was to examine the collections of the WA Museum for records of tropical, temperate and west coast endemic species of molluscs at the western end of Rottnest and along the inshore metropolitan coastline. As predicted, we found nearly twice as many species of tropical marine molluscs at the western end of Rottnest Island (33 per cent tropical) than along the metropolitan coastline (19 per cent) – clear evidence that the Leeuwin Current was having an impact.

Then to investigate mollusc populations in detail, we sampled quantitative transects at Rottnest (Cape Vlamingh and Radar Reef), and then sampled at Trigg and Cottesloe. In each quadrat we identified all of the molluscs present, and measured their density and biomass. The results showed that not only was there a greater percentage of tropical species at Rottnest, but they were also much more abundant on the platforms.

Chemical effects on snails

Eight years later there was another major finding on the biology of molluscs on the Rottnest platforms. In January 1991, Professor Alan Kohn of the University of Washington was working on the biology of snails of the genus *Conus*, when he found that they were affected by 'imposex'.

Imposex is a reproductive abnormality where female snails begin to develop male reproductive structures. The females never become functional as males, but in the most severe cases the females are unable to spawn. Deprived of young animals entering the population, the populations can collapse. Males are apparently unaffected.

Eighty six per cent of individuals of six species of *Conus* were affected by imposex. There is a scale that ranges from zero (no effect) to six (death) used in measuring the severity of imposex. Most of the snails were at levels three and four.

Imposex is caused by incredibly minute concentrations of tributyltin (TBT), a

Sampling is best done on very good low tides, but unfortunately the weather is not always like this.

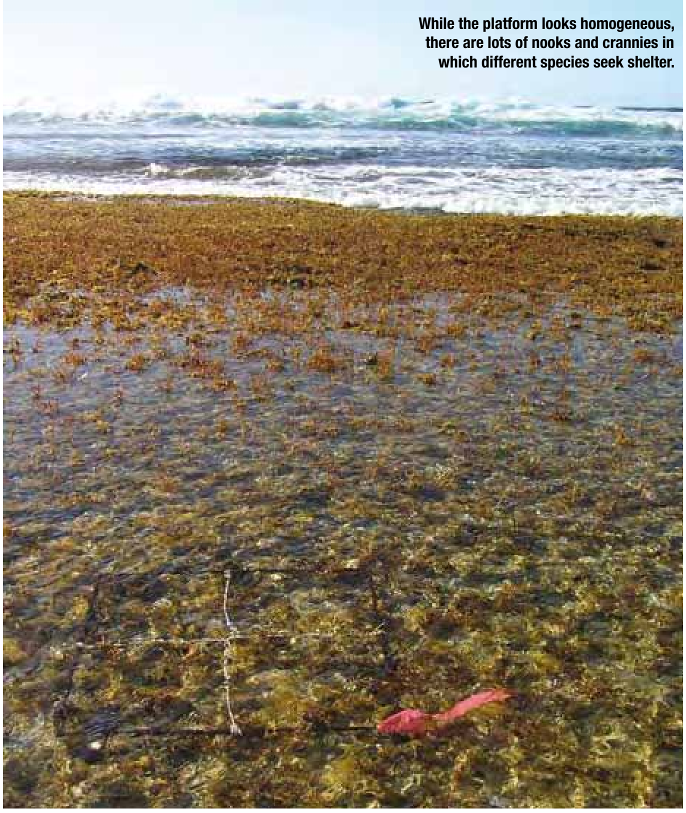
chemical added to boat paints during manufacture to act as an antifoulant. Concentrations as low as one part per *trillion* begin to affect the snails.

By coincidence, what is now the Department of Environment and Conservation measured TBT levels in sediments in the metropolitan area in 1991, finding the chemical everywhere. Concentrations at the west end of Rottnest were less than one per cent of those in some areas of Cockburn Sound.

This led to the total ban on the use of TBT in vessels smaller than 25 metres and a reduction in the rate at which TBT is allowed to leach out of the paint in larger vessels. Following the bans in late 1991, a further study was conducted at Rottnest in 1996 that showed some improvement in the imposex rate in *Conus*.

It is unusual to have such a good quantitative dataset from 25 years ago in the case of the platform molluscs and 17 years ago for imposex. In recognition of this, the Department of Fisheries, CSIRO and the Swan Catchment Council partnered to resurvey the Rottnest platforms in November 2007.

The project is funded by the Australian Government's Natural Heritage Trust, delivered in Western Australia in partnership with the State government. The Swan Catchment Council is the regional Natural Resource Management group in the region. The Rottnest Island Authority provided a permit for the research.


While the platform looks homogeneous, there are lots of nooks and crannies in which different species seek shelter.

Since 1982, there have been progressively tighter regulations on collecting molluscs and other organisms on the intertidal platforms at Rottnest. The late 2007 survey demonstrated that within the range of natural variation, the mollusc populations are essentially the same as they were 25 years ago. The management measures in place are working effectively.

The story for imposex is quite clear. In 1991, 88 per cent of the *Conus* were affected, with 71 per cent being stages three and four. Five years later it was down to 69 per cent with imposex, with 49 per cent at stages three and four. By the end of 2007 this had declined to 35 per cent, with only 16 per cent at level three and no animals at level four – truly a success story! ■


The tropical *Septifer bilocularis* forms dense aggregations on some parts of Radar Reef.

INVASION OF THE WATER SNATCHERS

In the final of two articles on how marine species from other places made their homes in Western Australia, ***Steve Ireland*** looks at how marine invaders have turned up uninvited on our shores. Some have prospered, while others have disappeared as silently as they arrived.

When the first European ship anchored off the Western Australian coast, it is a good chance that it was carrying on its hull a marine organism of some kind, which eventually made a new home here.

Ever since ships started to navigate the seas and oceans of the world, carrying passengers, cargo and crew, they have also unintentionally transported marine species. Every ship that turned up in Australia in the 19th century with a cargo of transported convicts or hopeful settlers brought another uninvited cargo of shellfish, such as barnacles, limpets and mussels, which hitched a ride from Mother England or one of the various ports that were called into *en route*.

This great tradition of hitchhiking by marine organisms still happens to this day. It has become complicated by the variety of ways they can make the trip – from attaching themselves to the hull or a handy water inlet, or taking a pleasant swim in a ship's ballast water tanks.

Of course, when the convicts and settlers arrived on Australian shores, they deliberately brought with them a whole heap of terrestrial invaders as food sources, in the form of plants and animals.

"People brought out everything from rabbits to sheep – and the former have caused us terrible problems," said Dr Fred Wells, principal management officer with the Department of Fisheries' Environment Program.

"Australia ended up building an entire economy that was based on sheep and wheat – both of which were invaders."

Dr Wells said that as awareness of the environmental damage of introduced species has grown, the rules about bringing terrestrial organisms into the country have tightened progressively.

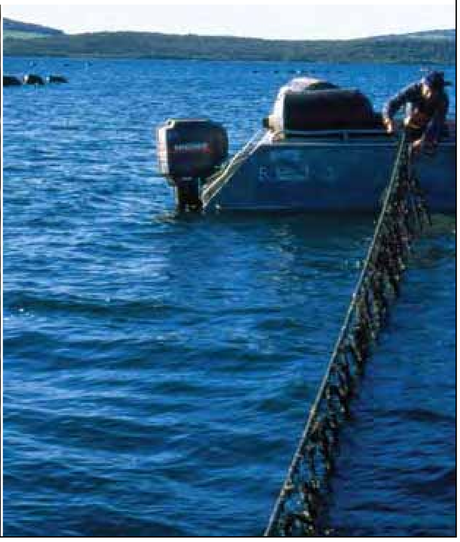
But he added that when it comes to an awareness of invading marine organisms and the ocean, in comparison to the terrestrial world we are a little behind.

"Pests are much more obvious in the terrestrial environment – feral goats and pigs are easy for everyone to see. When it comes to flora, if you are a biologist, introduced grasses are easy to recognise and relatively easy to remove.

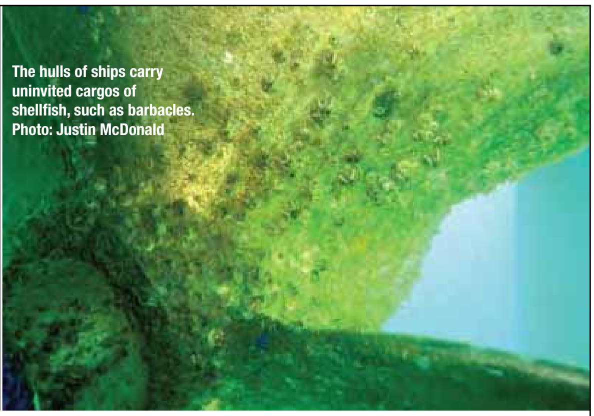
"When it comes to water, everything is difficult to see, let alone remove. For example, for a scuba diver, being able to see as far as 20 metres is regarded as good visibility."

However, Dr Wells said the good news is that there is an increasing awareness amongst scientists and the Western Australian population in general about

The feared Asian green mussel (*Perna viridius*). Photo: Justin McDonald



Shell of a Pacific rock oyster.
Photo: Clay Bryce



The hulls of ships carry uninvited cargos of shellfish, such as barbacles.
Photo: Justin McDonald

the dangers of pest aquatic species. This awareness has been matched by an increase in public regulation about releasing exotic species into the wild.

"In fresh water, we have big issues, which still involve things as simple as people flushing their unwanted guppies down the toilet. A lot of the work needed is further education as well as more regulation. At least the aquatic environment hasn't been affected as much as the terrestrial one."

While terrestrial pests such as rats and mice – which have pretty much been here since the arrival of the first European ship – have prospered, the good news is that some of the unwanted marine migrants that have rocked up here appear to have disappeared as silently and suddenly as they arrived.

In 1983 the Asian date mussel (*Musculista senhousia*) was found at Chidley Point in the Swan River estuary. This was not good news, as the Asian date mussel was a very successful invader of many parts of the world and had a well-earned reputation for forming large mats over shallow, sheltered tidal flats and out-competing everything that lived in them for food. The density of these mats was downright scary, with as many as 3,300 individuals being found in a single square metre.

"When sampling was carried out in 1984, the Asian date mussel was found as far upstream as Canning Bridge and was also reported in Fremantle. Over the next few years, the mussel became the most common object washed up at the University of Western Australia campus on the Swan," Dr Wells recalls.

The Asian date mussels were monitored and fortunately, despite their prevalence, did not form into large mats. "The arrival of *Musculista senhousia* was definitely human-assisted. It could have been in ballast water that was jettisoned or on the hull of a vessel," said Dr Wells.

Last year, the Department of Fisheries undertook some further sampling for the Asian date mussel in the Swan River. After being common for over 20 years, the date mussel seems to have disappeared.

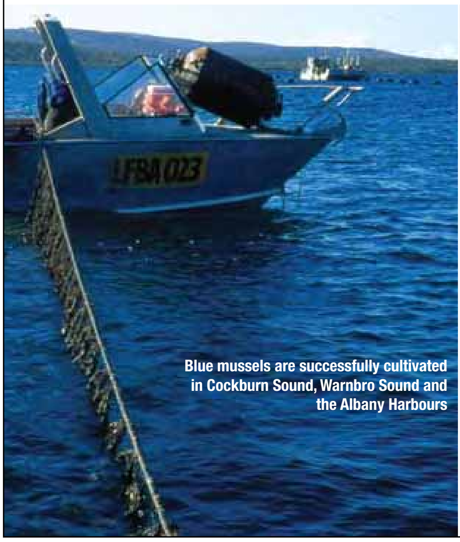
Dr Wells said there are a number of examples in Western Australia of invaders that have suddenly appeared and then later almost disappeared just as quietly. In the 1970s, the cockle *Spisula trigonella* was identified in the Peel-Harvey Estuary and reached a huge population density over the next decade.

However, by 2000, the numbers of the off-white cockle (which grows to an average length of two to two-and-a-half centimetres) had dropped sharply, falling to around 344 per square metre in summer but dropping to around four in early autumn. Since then, the population appears to have dropped further.

"There may be some populations we haven't found, but certainly its numbers have crashed. This was probably a natural occurrence," adds Dr Wells.

The Pacific oyster (*Crassostrea gigas*) occupies a strange niche amongst shellfish. It is considered in some quarters as a pest and in others as being a great species for aquaculture. These days it is classified as a pest species in WA, but in 1947 efforts were made to actually introduce this species into Albany's Oyster Harbour.

Once introduced into an area, the Pacific oyster – also known as the Pacific rock or Pacific king oyster – is generally impossible to contain if the environmental conditions are suitable; it will out-compete native oysters.



Blue mussels are successfully cultivated in Cockburn Sound, Warnbro Sound and the Albany Harbours

Blue mussels are grown on long lines, which are suspended vertically above the sea bed.

Specimens were shipped from Japan to Oyster Harbour by boat, in the hope of producing commercial oyster farms. The trip took too long and the oysters died. In 1980, Dr Wells was involved in a study of molluscs in the Albany area and he and a fellow research scientist found no Pacific oysters at all. A similar study carried out in Esperance also yielded no trace of the Pacific oyster.

In the past, the Pacific oyster has also been deliberately introduced into Tasmania. It has since spread into Victoria, South Australia and New South Wales. The oyster has colonised a number of NSW estuaries and offshore locations, owing to its abilities to tolerate a large range of salinity and water quality.

While the Pacific oyster is regarded as a definite pest in WA waters, we have another equally famous interloper that has come to be a staple of aquaculture in Western Australia – as the Pacific oyster has become in NSW. Its origins are as old as the history of European visits to Western Australia.

“I guess you could say that the blue mussel is a friendly pest. My suspicion is that it probably came here on the hulls of old wooden sailing boats – maybe as early as the 1600s,” Dr Wells said wryly.


This looks like a reef but is actually organisms living on the bottom of a ship. Photo: Justin McDonald

The blue mussel (*Mytilus edulis planulatus*) is highly successfully cultured in the Albany harbours, Warnbro Sound and Cockburn Sound. Western Australians, through their addiction to chilli mussels, are the largest consumers of blue mussels in the country.

Blue mussels were actually collected in 1798 in King George Sound by the explorer Francois Péron on his voyage on the French corvette *Géographe*. They are now found in sheltered bays and estuaries as far north as Cockburn Sound.

Blue mussels are farmed by collecting ‘spat’ – juvenile mussels from the wild. The spat are then attached to vertical ropes called ‘long lines’, at least two metres above the seabed, where they grow until reaching market size. As mussels are filter feeders, the farms rely upon natural feed that occurs in the water (such as algae, detritus and bacteria) rather than artificial diets or pellets. In 2005/06, WA producers grew 765 tonnes of blue mussels.

Licences for farms are required and regular site inspections are carried out by the Department of Fisheries to ensure farmers are operating within their site coordinates and that their sites are clearly marked for marine safety compliance.

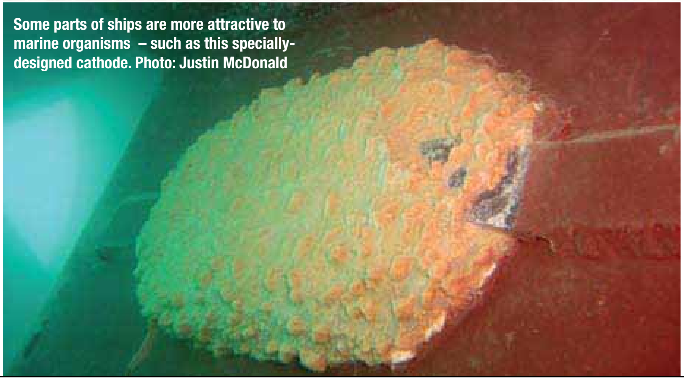
The mussel industry must also meet the requirements of the WA Shellfish Quality Assurance Program, which makes a significant contribution to the overall water quality of the farming areas, such as Cockburn Sound. It also provides the industry with a mechanism whereby harvesting and processing of mussels can be stopped if the water quality declines.

Mussel farms present a low risk to the environment because there is no addition of feeds and, in general, can be considered as significant removers of excess nutrients from waterways – the algae that use these nutrients for food are in turn consumed by the mussels.

While faecal-type wastes from the farms may occur, these are far less likely to cause high organic loadings on the seabed in WA than in mussel farms elsewhere in the world because the long lines of mussels here are more widely spaced in response to the relatively low local food (plankton) levels.

In Cockburn Sound, large pink snapper that gather in the area to spawn seem to be attracted to the mussel farms in some years and are thought to consume significant amounts of mussels.


Asian date mussel. Photo: Clay Bryce


Some parts of ships are more attractive to marine organisms – such as this specially-designed cathode. Photo: Justin McDonald

The cultivation of this tasty invader provides employment for around 40 to 50 people and adds diversity to the menu in WA's cafes, restaurants and pubs.

WA came close to an invasion by a very dangerous type of mussel – the black striped mussel (*Mytilopsis sallei*). During a routine inspection of Darwin Harbour by the CSIRO's Centre for Research on Introduced Marine Pests in 1999, this pest was found in frighteningly large numbers in the Cullen Bay Marina, covering practically everything that was below water level – from boat hulls and jetties to rubbish.

What was particularly scary was that a similar survey five months earlier had found no trace of the black striped mussel, so it looked as though the incursion had gone from nothing to enormous in a very short time.

The black striped mussel is recognised as one of the world's most damaging pests and is well-known in countries such as Taiwan, China (Hong Kong), Japan and India. The mussel is capable of growing to a length of 8-10 mm within a month of spat settling into an area. It quickly out-competes native shellfish species, growing on their shells and literally smothering them. It appears to have been introduced into Darwin on the hull of a vessel – and the outbreak quickly spread to two other parts of Darwin Harbour.

Agencies with expertise in marine pest control, including the Department of Fisheries WA, were called in from all parts of Australia. In order to eradicate the black striped mussel, the gates on the three marinas where they had been found were closed. The water, vessels and all submerged surfaces in the marinas were exposed to copper sulphate and chlorine, which were poured into the water, killing the mussels.

"In general, eradicating an invader can be just about impossible. In Australia, this has only been done with the black striped mussel and a marine alga in some parts of South Australia to my knowledge," Dr Wells remarked.

"The stark fact is that everything in the marinas' water in Darwin had to be killed in order to get rid of them."

Dr Wells says that the black striped mussel outbreak served to crystallise the thinking of those who worked in and were responsible for managing the marine environment about the issue of marine invaders. Whilst government agencies involved in this work do not have a perfect knowledge about these issues, he thinks there is now an increased focus on policing for pest outbreaks.

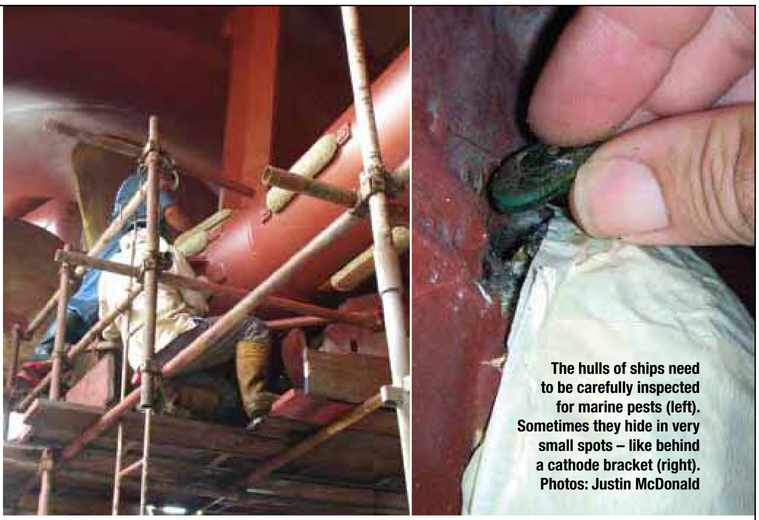
"Where we are at is to stop other things from getting in – it will be our job to police for them," he added.

With the increased speeds of modern ships, Dr Wells says it is more difficult for some invaders to literally 'hang on' to their hulls. Many vessels are now staying in a harbour for only around 18 hours. This time frame does not give marine pests much opportunity to attach or detach. He sees dredgers as being much more of a potential problem – "they are in close contact with the sea floor, move at a slow speed and sit in one place for a long time."

In the first part of this article on William Saville-Kent and deliberate introductions of fish into WA waters (see *Western Fisheries June 2008)*, the factor as to whether a species survived or not came down to the right environmental conditions. Basically, the temperature and salinity levels had to be suitable to the species, along with suitable water quality and a plentiful source of food. The same things are, of course, true for invasions of pest species.

In the case of the Asian date mussel and the Swan River, it appears in the end there was something about the environment that didn't suit the mussel and the species seems to be dying out. In the case of the black striped mussel and Darwin Harbour, the species found itself right at home and, without a chemical holocaust in a very small area, would have spread very quickly and killed off the native species.

The message is 'watch out for alien invaders' – see 'Join the Anti-Pest Program' nearby – so that the clear, lively waters of WA end up staying that way. ■


The hulls of ships need to be carefully inspected for marine pests (left). Sometimes they hide in very small spots – like behind a cathode bracket (right). Photos: Justin McDonald

Join the Anti-Pest Program

WA's waters are full of a diverse range of marine plants and animals. This 'biodiversity' has evolved over time and its members have established complex relationships with one another and adapted to the available habitat. The introduction of exotic species from other countries (and from elsewhere in Australia) has the potential to disrupt these long-established marine ecosystems.

There are around 250 introduced marine species in Australia and 60 of them are now found in WA. The Department of Fisheries would like you to help by monitoring our coastline for introduced marine species to prevent any more from being established.

Among the species that need to be particularly watched out for are the northern Pacific seastar, green crab, Pacific oyster, New Zealand screw shell, Asian date mussel, black striped mussel, Chinese clam, European fan worm, Japanese goby, Japanese seaweed, and the bryozoan *Watersipora arcuata*.

If you think you have seen a pest species, please contact the Department of Fisheries' FISHWATCH service on 1800-815-507 to report your sighting. Your contribution in monitoring WA's coastline is invaluable.

Actions to implement and complement the National System for the Prevention and Management of Introduced Marine Pests in Western Australia

Report to Stakeholders

June 2007

Stakeholders workshop

The most recent major event in the project was the stakeholders workshop held at the WA Fisheries and Marine Research Laboratories on Friday afternoon, 22 June 2007. There was a steering committee meeting in the morning followed by the stakeholders' workshop in the afternoon. There were 25 stakeholders present, from a variety of backgrounds. The meeting went very well, and was followed by an informal networking session.

One key feature of both the steering committee meeting and the workshop was the presence of Dr Stephanie Turner. Steph was recently appointed to manage the biosecurity section of the Fish and Fish Habitat Program at WA Fisheries. She comes to the job with a broad experience in marine biology, having worked in government departments and private industry in both Australia and New Zealand. Steph also undertook a one-year course in environmental law at the University of Auckland.

The issue of biosecurity, particularly marine biosecurity, is rapidly advancing in Western Australia. The *Biosecurity and Agricultural Management* bill is progressing through Parliament and will fundamentally improve the ability of the Department of Fisheries to manage the issues of invasive marine pests. Steph is working closely with the national bodies such as the National Introduced Marine Pests Coordinating Committee (NIMCPG) to ensure that arrangements within WA are fully integrated on the national scheme. The NHT funded marine pests project is working closely with Steph to ensure our local activities are complementary.

Studies Already Initiated in the Project

The following components of the project are well underway:

Existing information. A key early commitment was the development of an initial literature review to collate existing national knowledge on introduced marine species as relevant to Western Australia. The literature has been reviewed in detail and the presence of voucher specimens checked in the Western Australian Museum and WA Herbarium. A technical report has been developed to bring this information into the scientific literature. At the moment, the report is 70 single spaced pages and includes 101 species. The report has been sent to experts in particular groups for checking the accuracy of the information in their groups. It will be submitted for publication in the near future.

Popular publication. The technical report will serve as the basis for a popular publication that will outline the natural values of the Western Australian marine environment, the threat presented by introduced marine species, and what we can do about it. Information will be presented on a number of selected species known to have been introduced into Western Australia, including a photograph or drawing of the species, scientific name, common name (if any), where the species came from, where it occurs in Western Australia and the habitat in which it lives. The same information will be given for species that could be introduced into WA.

Risk analysis. As you know, we are doing an analysis of the current risks to WA ports and marinas based on assessment of vessel movements. This project that has been contracted to URS Australia. Mike Travers has done substantial work with the various WA ports to assemble 2006 data on what ships visited WA ports, where they came from and their next port of call. Data collection is complete and the analysis is currently being done. We expect to have this project completed in July. We would like to acknowledge the considerable support and assistance we received from all WA ports in compiling this information.

Trial marine area. A major part of the project is a trial of the new National Introduced Marine Species Monitoring Manual in a WA marine area. In February the Steering Committee decided that Albany on the south coast was the best the best location. In March, Fred Wells and Mike Travers went to Albany to talk to stakeholders and investigate where sampling could occur and how it should be done. Mike developed the proposed sampling program, which was agreed to by NIMCPG. He then led a team of four to Albany for 10 days in early June to undertake the first of the field surveys. Fortunately, the weather held at that time of year, and the team was able to complete almost all of the tasks. The group received considerable support from a number of stakeholders in Albany, particularly the Albany Port Authority, for which we are very appreciative.

Communications are a key component of the project. The following activities have been undertaken since the last quarterly report in March:

- The article in *Western Fisheries* has appeared.
- This quarterly report has been circulated to stakeholders.

The communications program has deliberately been fairly low key to date. The decision was made to let people know what we are planning to do with the project, but not undertake major communications until substantial progress was made and initial results available. This is now drawing nearer and the activities will be increased in the coming months.

Dampier was singled out by NIMCPG as a major gap in the pre 2003 set of national surveys for introduced marine species. We are exploring possibilities with the Dampier Port Authority for using existing published information on the Dampier region combined with new surveys in order to meet the requirements of the original broad survey methodology and the new targeted approach. This would ensure that the work is done in the most cost effective manner possible. To this end, Fred Wells and Steph Turner went to Dampier on 25 and 26 June to meet with the CEO of the Dampier Port Authority, Steve Lewis and Peter Smith, the environmental officer. The trip was very beneficial and we benefited considerably from the tour through the harbour arranged by the DPA.

Emily Gates has been appointed a technical officer on the project for three months. Emily assisted Mike Travers in the development of the Albany program and will work with him to process the samples.

Invasive Marine Species. The symposium has been scheduled for Friday, 13 July as part of the Australian Marine Sciences Association annual conference in Melbourne. Fred Wells will present a paper describing the overview of the NHT funded project and Mike Travers will present on the Albany work. John Polglaze of URS will talk about the assessment techniques URS uses.

Actions to implement and complement the National System for the Prevention and Management of Introduced Marine Pests in Western Australia

Report to Stakeholders

September 2007

Invasive Marine Species Symposium. The symposium on invasive marine species, organised by Fred Wells, was held on Friday, 13 July as part of the Australian Marine Sciences Association annual conference in Melbourne. The symposium was very well attended, with 25 papers being presented on a wide variety of topics. It was so large that it spilled over into the companion symposium on the environmental effects of ports. It was pleasing to have a number of papers presented by colleagues from New Zealand. As part of the symposium, fred presented a paper describing the broader aspects of the WA introduced marine species project. Mike Travers presented on the specifics of the Albany trial. Please contact Fred for a copy of abstracts of the papers if you want one.

Existing information. The literature review and analysis of existing collections is virtually complete. It is currently being reviewed.

Risk analysis. The analysis of the current risks to WA ports and marinas based on assessment of vessel movements was delayed while URS obtained updated information on a worldwide analysis from Canada. This information has now been obtained and the report can be finalized. All necessary data from WA ports has been obtained.

A second analysis will be on the potential threats to environmentally sensitive areas and whether such areas should be incorporated into the overall monitoring program. In 1994, the WA Department of Conservation and Land Management published a Statewide analysis of marine environments that recommended that 72 areas be further considered for development of a statewide system of marine parks and reserves. Over the last 13 years this has been refined into the existing marine parks and some which are currently being developed. We have used the Statewide system as a basis for selecting marine areas for consideration. Emily Gates has developed considerable background information on the current and developing marine parks. This will be brought into a single document that will be used for an assessment of whether additional areas should be monitored as part of the monitoring system.

Trial marine area. A signigicant part of the project is a trial of the new National Introduced Marine Species Monitoring Manual in Albany. As reported in the June report, a major sampling project was undertaken in early June. Emily Gates has spent a considerable part of her time since then sorting the material into phyla and then into lower taxonomic groups. This work is nearly complete. The next step will be to examine the material for the target species.

Some of the Albany trial will involve an analysis of the biota settling on test panels. To this end, Mike Travers deployed four replicate 10x10 cm test panels at 29 sites in the Albany harbour system in August. The sites chosen were nodes of vessel activity, including the Albany Port Authority wharves, town jetty, Princess Royal Harbour sailing club and the Emu Point marina. The panels will be recovered early in 2008.

As a separate effort funded by the South Coast NRM, similar panels were established in the

Esperance marine area.

Dampier was singled out by NIMCPG as a major gap in the pre 2003 set of national surveys for introduced marine species. We are exploring possibilities with the Dampier Port Authority for using existing published information on the Dampier region combined with new surveys in order to meet the requirements of the original broad survey methodology and the new targeted approach. As part of this investigation, Mike Travers went to Dampier in July to examine logistical aspects of the potential project. This will be used as a basis for developing a budget for the proposed work.

Fremantle marine area. We have anecdotal reports that the polychaete Sabella spallanzanii is not as abundant as in previous years in the system. In April, we had a brief look for the mussel Musculista senhousia in the lower Swan River. The species was first reported from the area in the 1980s, but we could find no specimens earlier this year. The scallop Scaeochlamys lividus is known to occur in Fremantle Harbour, Rous Head and Cockburn Sound, but has not yet been formally reported. The European shore crab Carcinus maenas is known in the area from a single specimen collected in the 1960s. A survey was started in late September to establish current populations levels of all four species in the Fremantle marine area. This includes the lower Swan River, Fremantle Harbour, Rous Head and Cockburn Sound. We are working closely with the Fremantle Port Authority on this project.

As mentioned, the scallop *Scaeochlamys lividus* has not been formally reported from the Fremantle marine area. Hugh Morrison, an honorary associate of the Western Australian museum, and Fred Wells have completed a draft of a paper recording the species in Western Australia. The paper has been sent to colleagues for review. It is important as a reminder that species can be introduced from other parts of Australia as well as overseas.

Actions to implement and complement the National System for the Prevention and Management of Introduced Marine Pests in Western Australia

Actions to implement and complement the National System for the Prevention and Management of Introduced Marine Pests in Western Australia

Report to Stakeholders

February 2008

The period since the last stakeholder report in September 2007 has been a very active one for the introduced marine species project. Below are the major events in the last few months:

Geraldton. In October 2002, the dredge *Leonardo da Vinci* arrived in Geraldton directly from the Caribbean. The vessel had considerable hull fouling, including potential pest species. Following a detailed assessment of the risks involved, and methods for handling the issue, the vessel was cleaned in the harbour. A number of methods were used to minimise the risk of introducing the pest species. A survey one year later failed to detect any of the pest species. The port was resurveyed in October 2007, five years after the event, with molluscs and crustaceans being collected. Identification of the material collected has now been completed. The following Caribbean molluscs were present on the *Leonardo da Vinci*: *Thais haemastoma floridana*; *T. rustica*; *Crepidula plana*; *Brachidontes exustus* and an unidentified oyster. None of these were found in the October 2003 or 2007 surveys. The following barnacles were identified from the vessel: *Lepas anserifera*; *Striatobalanus amaryllis*; *Amphibalanus reticulatus*; *Balanus trigonus*; and *Megabalanus coccopoma*. Of these, all except *M. coccopoma* were previously known from Western Australia. The primary concern was over the invasive *Megabalanus coccopoma,* which was not found in either survey. *Amphibalanus reticulatus* was found in Geraldton in October 2007, but could have been transported from a WA port to the north or south. While there is a possibility of small populations of other species being in Geraldton that were too small to detect, the evidence is that measures taken to prevent introductions in October 2002 worked effectively. The port of Geraldton provided considerable assistance with this project.

The **risk assessment** of WA ports due to shipping has been completed. This assessment updates the initial compilation some time ago that determined that three WA ports should be included on the national monitoring system of 18 ports. While there were minor changes in the relative rankings, the analysis confirmed that Dampier, Port Hedland and Fremantle are still the ports of greatest risk for introductions of marine species through shipping.

Staffing. Research Scientist Mike Travers and Technical Officer Emily Gates both left the project in late 2007 for better positions at the Australian Institute of Marine Science. Naturally the departure of both has considerably hampered the development of the project. We were fortunate that Dr Justin McDonald was hired for additional support and started just after Mike left. Fiona Webster recently started on the project in a casual capacity, and a new research scientist will be commencing shortly on a six month appointment.

Trial marine area. Before he left, Mike completed the planned resurvey of Albany, so we have contrasting seasonality of June and November samples. Most of the material has now been identified, with dinoflagellates the major group still to be done. Geoff Bastyan of Albany retrieved the settlement panels in early February. The panels will be analysed over the next few months. Two reports will be prepared: a survey of Albany using the new NIMCPG methodology and a report on the strengths and weaknesses of the methodology. Again we thank the Port of Albany for considerable assistance with this project.

Fremantle survey. The survey of the Fremantle marine area for four species was completed in October. Neither the European shore crab *Carcinus maenas* or the Japanese mussel *Musculista senhousia* were found. As only a single specimen of the European shore crab is in the WA Museum, the absence of this species was not surprising. However, the absence of the Japanese mussel is puzzling. It was very common in the lower Swan River in the 1980s, but appears to have disappeared. There may still be residual populations in the river, but none were found. The relative abundance of the Eueopean fanworm *Sabella spallanzanii* also has decreased. A preliminary identification of scallops collected indicates that the eastern Australian *Scaeochlamys lividus* appears to have largely replaced the native *Chlamys asperrimus.* Preliminary identifications indicate 518 of 521 specimens collected were *S. lividus* and only 3 were *C. asperrimus.* The port of Fremantle provided considerable assistance with this project.

Kimberley symposia. Fred Wells presented a talk in January on introduced marine species at a symposium on scientific knowledge of the Kimberley organised by the Marine and Coastal Communications Network in association with the North West Research Association. He later participated in a Kimberley workshop in Broome organised by the World Wildlife Fund, and used the opportunity to meet with the CEO of Broome Port, Captain Vic Justice, and his staff.

Indonesian prahus. Indonesian fishermen poaching in Australian waters have been an important issue in the northwest for a very long time. For many years apprehended vessels have been taken to Willie Creek, just north of Broome. The vessels have been detained in the water or on shore while prosecutions have gone through the courts. The boats have sometimes remained in the area for months. Many apprehended boats have had the black striped mussel, *Mytilopsis sallei,* and possibly also the Asian green mussel, *Perna viridis*. The trip to Broome offered an opportunity to visit Willie Creek to see if these species had become established. Fortunately, none were found. Diana Jones, the barnacle expert at the WA Museum, searched the area for barnacles. While nothing was obviously out of place in the field, formal identifications can only be completed after the animals are dissected. The trip benefited considerably from assistance provided by Willie Creek Pearls.

Risk assessments. Active work has commenced on two further risk assessments: commercial fisheries and environmentally sensitive areas. Preliminary plans are to have two separate workshops about these projects, with commercial fisheries being done on the morning of Friday, 2 May. The analysis of environmentally sensitive areas will be undertaken about a month later. In both cases a discussion document will be sent out to stakeholders about a month before the meeting.

Stakeholders meeting. Present plans are to have the next stakeholders meeting on the afternoon of Friday, 2 May at the WA Fisheries and Marine Research Laboratories at Hillarys. The draft program is for the meeting to start at 1:30 p.m. and run to 5:00 p.m., with refreshments afterwards. Three talks are planned of about 40 minutes each plus time for questions:

- Dr Fred Wells: project overview and results to date.
- Dr Justin McDonald: species of concern and issues with their identification.
- Dr Stephanie Turner: management of the marine pest issue from a Department of Fisheries perspective.

Please pencil in the date: 2 May 2008. Full information will be sent later. This formal will allow individual stakeholders to participate in the morning or afternoon session or both.

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