National priority pests: Part II Ranking of Australian marine pests

Keith Hayes, Cathryn Sliwa, Sasha Migus, Felicity McEnnulty and Piers Dunstan

An independent report undertaken for the Department of Environment and Heritage by CSIRO Marine Research

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EXECUTIVE SUMMARY

This report is the final report of a two year study designed to identify and rank introduced marine species found within Australian waters (potential domestic target species) and those that are not found within Australian waters (potential international target species). In this context, potential domestic target species are defined as ship-vectored, established, non-native (or cryptogenic) species that have demonstrated significant impact on human health, economic interests or environmental values in the Australian marine environment. Potential international target species are similarly defined as ship vectored, non-native (or cryptogenic) species that have demonstrated significant impacts outside of Australia.

The invasion database collated for this project currently records 1593 marine and estuarine species that have been transported by human-mediated activities or have human-mediated invasion histories around the world. 212 of these species do not have a known invasion history but have been reported in either ballast water (130, hull fouling (53) samples, or on another vector (29). 534 of the species are known to be established in Australian waters of which: 100 are native; 133 are non-native; 175 are cryptogenic; whilst the invasion status of the remaining 126 species is unknown. Just over 290 of the species in the database are known to be absent from Australian waters, whereas the establishment status in Australia of the remaining 766 species is uncertain.

This report identifies 23 of the 133 non-native species, and 5 of the 175 cryptogenic species, that satisfy the definition of a potential domestic target species for ballast water. These species could be managed as part of the new National System for the Prevention and Control of Marine Pest Incursions in Australia. Australian regulatory authorities are currently designing a Single National Interface for the management of domestic ballast water. It is proposed that this interface will operate on a species-specific basis, managing ballast water discharge in relation to the translocation risk of designated target species between Australian ports. The appropriate regulatory authority should evaluate the significance of the impacts associated with each of the potential domestic target species identified in this report by consulting industry, stake-holders, other interest groups and the analysis conducted in this study. None of the potential domestic target species are eradicable with current technology but they are all, with a few notable exceptions, amenable to control via ballast water exchange.

This report also identifies 48 of the 133 non-native species, and 17 of the 175 cryptogenic species, that satisfy the definition of a potential domestic target species for hull fouling, but notes that species-specific hull fouling control is not currently envisaged by Australian authorities. All of the non-native potential target species identified in this report are ranked as high, medium and low priority, based on their invasion potential and impact potential.

The invasion potential of a species is expressed as the weighted sum of ship movements, and ballast discharge, from ‘infected’ bioregions to ‘uninfected’ bioregions. Lloyds Maritime Information Unit records 22,286 ship visits to Australian ports in 2002. More than half of these vessels (59%) recorded their last port of call as an Australian port or terminal. We define these vessels as domestic ship arrivals. The remaining vessels recorded an international last port of call. We define these vessels as international ship arrivals. The Australian Quarantine and Inspection Service (AQIS) recorded a further 603 international yacht visits to Australia in 2002, originating from 29 IUCN bioregions. We also define these vessels as international ship arrivals.

In this analysis domestic ship arrivals are aggregated by donor Interim Marine Coastal and Regional Area (IMCRA) bioregion. There are 60 IMCRA bioregions around the Australian coast. The pattern of domestic commercial ship movements around these bioregions, however, is highly skewed – the last port of call of 80% of the ships is situated in just nine bioregions (in descending order): VES, HAW, BGS, TMN, SCT, CWC, SVG, LMC and BAT. The invasion potential of domestic target species is determined by their distribution relative to this pattern of shipping activity.

This analysis suggests that the ten potential domestic target species most likely to be spread to uninfected bioregions by are: *Schizoporella errata, Watersipora arcuata, Cordylophora caspia,*

Ciona intestinalis, Alexandrium minutum, Sphaeroma walkeri, Pseudopolydora paucibranchiata, Tridentiger trigonocephalus, Bugula neritina and *Gymnodinium catenatum*. The environmental similarity between the donor and recipient bioregions has only a small effect on the invasion potential rank of these species: *Alexandrium minutum* drops from fifth (β = 0.2) to eighth (β = 3), *Pseudopolydora paucibranchiata* rises from seventh (β = 0.2) to fifth (β = 3), *Tridentiger trigonocephalus* rises from eighth (β = 0.2) to seventh (β = 3), whilst *Bugula neritina* and *Gymnodinium catenatum* swap ninth and tenth positions.

It is important to note that these results are do not reflect the larval duration or population densities of the species concerned in each of the infected bioregions. They also do not incorporate the domestic movements of small commercial and recreational vessels (as this data is currently unavailable for the nation as a whole). The implications of this are that the invasion potential reported here for domestic hull fouling species is not reflective of their actual hull fouling translocation potential.

The impact potential of a species is expressed in terms of their actual (or potential) human health, economic and environmental impacts. These were estimated using interval analysis and a web-based questionnaire sent to international and domestic experts. Judging the significance of the impacts associated with an invasive species is a value-laden and often highly uncertain process. This analysis forced assessors to score impacts on a scale of 0 to 1 (divided into 10 intervals), and used interval analysis to aggregate scores across standardised impact categories, whilst maintaining the assessor(s) uncertainty.

We received 126 questionnaire returns for the potential domestic target species, with three or more questionnaires completed for more than 40% of the species. We did not obtain responses for two of the 53 species. The overall impact potential, expressed as the simple sum of the intervals for human, economic and environmental impacts suggests that the ten most damaging species are *Gymnodinium catenatum, Alexandrium minutum, Asterias amurensis, Sabella spallanzanii, Crassostrea gigas, Ciona intestinalis, Bugula neritina, Polysiphonia brodiaei, Schizoporella errata* and *Codium fragile* ssp*. tomentosoides*. The impact interval of *Undaria pinnatifida* and *Carcinus maenas* extend beyond that of *Bugula neritina* and *Schizoporella errata* such that *U. pinnatifida* and *C. maenas* would be ranked ninth and tenth respectively if the ranking were performed on the maximum (rather than the mid) impact score.

The potential domestic target species are prioritised by their location in the invasion potential/impact potential space. In the absence of active eradication programs, we argue that the hazard ranking should be based on invasion potential from infected to uninfected bioregions. With this approach all the potential domestic target species cluster in the bottom left quadrat of the hazard space. It is important to note, however, that this is not an absolute measure of risk but rather a relative measure of hazard. Priority species must therefore be identified relative to each other – i.e. from their relative location in hazard space. A visual examination of the hazard space suggests the following three groups:

1. High priority: *Gymnodinium catenatum* and *Alexandrium minutum* – both of these species have reasonably high invasion potential and their impact potential is the highest of all the potential domestic target species;

2. Medium-high priority: *Sabella spallanzanii, Asterias amurensis, Crassostrea gigas, Bugula neritina, Ciona intestinalis, Schizoporella errata, Codium fragile tomentosoides, Polysiphonia brodiaei, Hydroides ezoensis, Watersipora arcuata, Undaria pinnatifida, Styela clava, Musculista senhousia* and *Carcinus maenas* – these species have reasonably high impact and/or invasion potential.

3. Medium-low priority; *Polydora websteri, Varicorbula gibba, Theora lubrica, Polydora cornuta, Boccardia proboscidea, Euchone limnicola, Sphaeroma walkeri, Tridentiger trigonocephalus, Pseudopolydora paucibranchiata, Cordylophora caspia, Bugula flabellata, Watersipora subtorquata, Tricellaria occidentalis* and *Megabalanus rosa* – these species have a medium impact or medium invasion potential relative to the other domestic NIS identified here.

This ranking would most likely change if the invasion potential analysis were able to include the movements of small recreational and commercial vessels. The hull fouling potential (coupled with the large number) of these vessels would undoubtedly have some influence on the relative ranking of potential domestic target species. Note also that these results group human health impacts with economic and environmental impacts without any additional significance weighting. Management authorities may wish to isolate all species which have potential human health impact (mid-impact score > 0.1) and elevate the status of these species. In this case authorities may wish to re-examine *Pseudopolydora paucibranchiata*, *Polydora websteri, Polydora cornuta* and *Crassostrea gigas* in more detail.

This report also identifies 36 of the 1059 species that are known, or thought, to be absent from Australian waters, that satisfy the definition of an international potential target species. Again these species are ranked as high, medium and low priority, based on invasion potential and impact potential. In this context, however, the invasion potential of a species is expressed as the weighted sum of commercial ship movements, recreational vessel movements (international yachts) and ballast discharge from all 'infected' bioregions around the world to any Australian location. The impact potential is calculated in the same manner described above.

In this analysis international ship arrivals are aggregated by donor International Union for the Conservation of Nature (IUCN) bioregion. In 2002 Australia traded with, or had ship visits from, 71 IUCN bioregions. The balance of this trade, however, is highly skewed – more than 85% of international ship arrivals originate from just ten bioregions (in descending order): NWP-3b; EAS-VI; NWP-3a; NZ-IV; NWP-2; NWP-4a; EAS-II; EAS-I; SP-I; and, NWP-4b. The invasion potential of marine pests from around the world to Australia is critically determined by their distribution relative to these ten bioregions. The environmental similarity between the donor and recipient ports, measured in terms of latitudinal difference, has a relatively marked effect on their invasion potential (as compared to the invasion potential of domestic target species).

The ten most likely invaders using the most conservative environmental similarity index (i.e. when β = 3.0) are: *Perna viridis, Mytilopsis sallei, Hemigrapsus sanguineus, Tridentiger bifasciatus, Limnoperna fortunei, Charybdis japonica, Pseudodiaptomus marinus, Balanus eburneus, Potamocorbula amurensis* and *Balanus improvisus*. When β = 0.2, however, the species rank for invasion potential changes to (in descending order): *Hemigrapsus sanguineus, Tridentiger trigonocephalus, Perna viridis, Limnoperna fortunei, Charybdis japonica, Mytilopsis sallei, Pseudodiaptomus marinus, Balanus eburneus, Potamocorbula amurensis* and *Eriocheir sinensis*. When β = 1.0, *Perna viridis* moves rank to first, and *Mytilopsis sallei* moves to fourth. *Eriocheir sinensis* is not ranked within the ten species with relation to invasion potential, when β = 1.0 or 3.0.

We received 60 questionnaire covering 29 of the 36 of the potential international target species. In the majority of cases (22 out of 29) there are at least two questionnaire returns for each species. The ten potentially most damaging species are *Eriocheir sinensis, Pseudo-nitzschia seriata, Potamocorbula amurensis, Neogobius melanostomus, Perna viridis, Petricolaria pholadiformis, Dinophysis norvegica, Blackfordia virginica, Perna perna* and *Charybdis japonica*. The impact interval of *Siganus rivulatus* extends beyond that *Charybdis japonica* such that it may be the tenth most damaging species. Similar uncertainty is prominent in *Pseudo-nitzschia seriata* and *Dinophysis norvegica*.

There are five potential international target species that have not had a questionnaire completed. They are: *Siphonaria pectinata, Rapana thomasiana, Hypania invalida, Bonnemaisonia hamifera* and *Alexandrium monilatum*. We are unable to rank the impact potential of these species. It is important to note that these species may have a greater impact potential then the top ten listed here. *Alexandrium monilatum*, for example, may cause Paralytic Shellfish Poisoning in humans and would therefore score highly in this analysis if we were able to include it.

Again the potential international target species are prioritised by their location in the invasion potential/impact potential space. The results of this analysis suggest the following hazard groups:

1. High priority: only one species - *Perna viridis* - resides in the top right quadrant of the hazard analysis space. This analysis therefore re-affirms the results of the first year of the project, wherein *P. viridis* was identified as the only high priority species.

2. Medium priority: species that reside in the top-left or bottom-right quadrants of the hazard analysis space are: *Mytilopsis sallei, Limnoperna fortunei, Hemigrapsus sanguineus, Charybdis japonica*, *Pseudodiaptomus marinus*, *Balanus eburneus*, *Tridentiger bifasciatus*, *Eriocheir sinensis, Neogobius melanostomus* and *Potamocorbula amurensis.*

3. Low priority: species that reside in the bottom left quadrant of the hazard analysis space are: *Acartia tonsa, Alexandrium monilatum, Ampelisca abdita*, *Balanus improvisus*, *Beroe ovata*, *Blackfordia virginica*, *Bonnemaisonia hamifera*, *Callinectes sapidus*, *Chaetoceros concavicornis*, *Chaetoceros convolutus*, *Crepidula fornicata*, *Dinophysis norvegica*, *Ensis directus, Grateloupia doryphora, Hydroides dianthus, Liza ramada, Mnemiopsis leidyi, Mya arenaria, Perna perna, Petricolaria pholadiformis*, *Pseudo-nitzschia seriata*, *Rapana thomasiana, Siganus rivulatus, Siphonaria pectinata, Tortanus dextrilobatus* and *Womersleyella setacea*.

It is important to note that these results group human health impacts with economic and environmental impacts without any additional significance weighting. Again, management authorities may wish to isolate all species which have potential human health impact (mid-impact score > 0.1) and elevate the status of these species. In this case authorities may wish to re-examine *Blackfordia virginica*, *Balanus eburneus*, *Charybdis japonica*, *Dinophysis norvegica*, *Eriocheir sinensis*, *Neogobius melanostomus*, *Perna perna*, *Petricolaria pholadiformis, Potamocorbula amurensis*, *Pseudodiaptomus marinus* and *Pseudo-nitzschia seriata* in more detail.

CONTENTS

1 INTRODUCTION

Over the past ten years, CSIRO Marine Research (CMR) personnel have been collecting information on species that have been introduced to, or are known as cryptogenic in, Australian marine and estuarine environments. CMR has also been collecting information on species that have an invasion history overseas but were yet to be found in Australia.

In February 1999, CMR started a project (National Priority Pests – Part I) to identify "priority pests" with financial assistance from the Department of Environment and Heritage (DEH) through the Natural Heritage Trust. During this project CMR completed an analysis of marine species currently not recorded in Australia that pose a potentially high risk to human health, the marine environment and/or the commercial interests operating within that environment. The analysis adopted a simple deductive approach based on prior invasion history, and was subsequently published in the international literature (Hayes and Sliwa, 2003). A second inductive analysis was subsequently performed to rank these species according to: a) their potential impact on human health, the marine environment and/or the commercial interests that operate within that environment; and b) their potential to arrive in Australia and reach an environment suitable for their establishment (Hayes *et al.*, 2002).

In February 2003, CMR received additional funding from DEH for a second part of the project (National Priority Pests – Part II). The objectives of the second part were: a) to update the work completed on priority pests not recorded in Australia; and, b) to assess the pest status of introduced species that were already established in Australia. The indiscriminant methods by which previous pest/trigger/interim species lists had been compiled highlighted the need for a hazard analysis approach similar to that used in the first project to identify which species already present in Australia posed a threat. A transparent, rigorous and defensible approach to identifying priority target species is seen as an essential component of any system designed to manage aquatic invasive species within a nation's border.

The approach adopted in this, the second project, is similar to that adopted in the first priority pest project. We use a deductive analysis that relies on previous invasion history to identify potentially high risk species and then we rank these species based on their impact and invasion potential. The difference between this project and the first project is the division into two lines of inquiry: international and domestic. The international approach aims to update the existing next pest list created in part I of the project. The domestic approach aims to establish which species, of those already present in Australia, should be prioritised for management action. The separate analysis completed for both these lines of inquiry is detailed in the methods section of this report.

The species lists detailed in the results section of this report and its appendices are designed to assist in the on-going development of the new National System for the Prevention and Control of Marine Pest Incursions in Australia. Ideally these lists should be maintained and updated under Section 301A of the Environmental Protection and Biodiversity Conservation Act 1999 (the EPBC Act). Control plans can now be designed for listed species, using EPBC Act regulations in cases where such regulations would be an effective and efficient means of implementing control plans.

The two lines of inquiry adopted for this project are designed to support two goals of the new National System for the Prevention and Control of Marine Pest Incursions in Australian waters: The international analysis will assist in the development of surveillance and monitoring regimes designed to detect new incursions at the border – i.e. a new introduction into an Australian port. The domestic analysis will help identify target species for National Control Planning purposes, which may include, for example, the implementation of mandatory management regimes for domestic ballast water discharge in Australian waters.

2 OBJECTIVES

The objectives of this project are:

1. to provide a list of marine species in Australia, other than native species, whose members do or may threaten biodiversity in the Australian jurisdiction;

2. to provide a list of marine species that would be likely to threaten biodiversity in the Australian jurisdiction if they were brought into the Australian jurisdiction.

3. to assess the species in the list specified in (1) and (2) for their:

   a) current or potential impacts on the Australian environment, if any;

   b) current or potential impacts on the Australian economy, if any;

   c) current or potential impacts on human health in Australia, if any;

   d) potential for spread or introduction to Australia via ballast water and hull fouling;

   e) for the species in the list specified in (1) comment on their amenability to control of spread based on currently available management of potential vectors (e.g. ballast water exchange);

   f) for the species in the list specified in (1) comment on their amenability to impact mitigation and eradication; and,

4. for the species in the list specified in (1) recommend a priority list of species that may be the subject of potential national control plans for domestic ballast water management.

3 METHODS

3.1 Domestic species

Lists of non-native and cryptogenic (i.e. native or introduced status is uncertain *sensu* Carlton, 1996) species in Australian waters were compiled prior to a survey of available information on introduced marine species in Australia. These lists came from a variety of sources. For example, CMR already possessed a number of species lists compiled during various other projects such as Furlani (1996) and Hewitt *et al.*, (1999). The species on these lists were used as the starting point for a single consolidated list of non-native and cryptogenic species in Australian marine and estuarine environments.

In many cases there was considerable uncertainty regarding the date of introduction, taxonomy and/or invasion status of the species on the existing CMR lists. We contacted experts from all of the major Australian museums, marine departments and marine research institutes, together with international experts, for each of the taxonomic groups, in order to resolve these issues. It is important to note that this project represents the first concerted effort to gather the collective knowledge of all relevant experts in order to determine the non-native marine and cryptogenic species in Australian waters. The project could not have been completed without their assistance (see Appendix A).

This project also collated and standardised vector and impact information for each of the species on the domestic (and international) list. The vector and impact codes are summarised in Tables 1 and 2 respectively.

3.2 Domestic hazard analysis

The second stage of the domestic analysis selects a sub-set of species from the domestic lists. These species are then ranked by invasion and impact potential. These species represent a potential “target list” for domestic vector management. The potential “target list” comprises species that:

1. have a ballast water or hull fouling mediated invasion history in Australia;
2. have recorded impacts on human health, the environment or economic interests in Australian waters; and,
3. are recorded as non-native and established in Australian waters.

This process was repeated for species recorded as cryptogenic in Australian waters (but these species have not been ranked). These species can be added to the potential “target list” at the discretion of the relevant management authorities. Species on the potential “target list” can be further discriminated by:

4. the date of first record or introduction into Australia;
5. their current range in Australia; and,
6. the extent to which they are amenable to domestic vector management (e.g. ballast water exchange).

Table 1 Marine pest vector categories used in this project

Code	Description
B1	Biocontrol: deliberate translocation as a biocontrol agent
B2	Biocontrol: accidental translocation with deliberate biocontrol release
C	Canals: natural range expansion through man-made canals
D	Debris: transport of species on human generated debris
F1	Fisheries: deliberate translocations of fish or shellfish to establish or support fishery
F2	Fisheries: accidental with deliberate translocations of fish or shellfish
F3	Fisheries: accidental with fishery products, packing or substrate
F4	Fisheries: accidental as bait
IR1	Individual release: deliberate release by individuals
IR2	Individual release: accidental release by individuals (e.g. aquarium discards)
NB	Navigation buoys and marina floats: accidental as attached or free-living fouling organisms
P1	Plant introductions: deliberate translocation of plant species (e.g. for erosion control)
P2	Plant introductions: accidental with deliberate plant translocations
RE	Recreational equipment: accidental with recreational equipment
S1	Ships: accidental as attached or free-living fouling organisms
S2	Ships: accidental with solid ballast (e.g. rocks, sand, etc)
S3	Ships: accidental with ballast water, sea water systems, live wells or other deck basins
S4	Ships: accidental associated with cargo
SP	Seaplanes: accidental as attached or free-living fouling organisms
SR1	Scientific research: deliberate release with research activities
SR2	Scientific research: accidental release with research activities
U	Unknown

Table 2 Marine pest impact categories used in this project

Impact category	Code	Description
Human health	H1	Human health
Economic	M1	Aquatic transport
Economic	M2	Water abstraction/nuisance fouling
Economic	M3	Loss of aquaculture/commercial/recreational harvest
Economic	M4	Loss of public/tourist amenity
Economic	M5	Damage to marine structures/archaeology
Environmental	E1	Detrimental habitat modification
Environmental	E2	Alters trophic interactions and food-webs
Environmental	E3	Dominates/out competes and limits resources of native species.
Environmental	E4	Predation of native species
Environmental	E5	Introduces/facilitates new pathogens, parasites or other NIS
Environmental	E6	Alters bio-geochemical cycles
Environmental	E7	Induces novel behavioral or eco-physiological responses
Environmental	E8	Genetic impacts: hybridisation and introgression
Environmental	E9	Herbivory

Many of the non-native and cryptogenic species on the domestic target list have been present in Australian waters since the time of European settlement without noticeable impact. These species may be of less concern than species introduced since the advent of ballast water transport (approximately 1950) who may still be experiencing an “invasion lag”. These species could potentially spread further and/or dramatically increase in abundance and thereby inflict higher levels of economic or environmental damage than is currently recorded.

The extent to which a species is amenable to vector control (by currently available methods) is important to the development of National Control Plans under the new National System. The cost of vector management can only be justified in the event that the management action results in demonstrable risk reduction. If current vector control (e.g. ballast water exchange) does not demonstrably reduce the risk of translocation or harmful impacts, then authorities must seek alternative management methods for the species concerned.

Invasion potential

The patterns of ship movements into and around Australian waters have important implications for the introduction and translocation of marine pests. In terrestrial environments the probability of successful introduction is known to be positively correlated with propagule supply and the climate/habitat similarity between donor and recipient regions (Hayes, 2003). This proposition is assumed to hold for the marine environment although it has not been as extensively tested (but see for example Kolar and Lodge, 2001). Propagule supply is a function of the frequency of introductions into a given location and the total quantity, density and condition of organisms introduced on each occasion (Lonsdale, 1999; Ruiz *et al.*, 2000). 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, the frequency of introduction is (perhaps) most closely correlated with the volume of ballast water discharged into recipient ports and the fouled surface area of vessels that enter the port. In this analysis we estimate the volume of ballast water discharged into Australian ports by commercial vessels over 250 gross tonnes, aggregated by donor bioregion, using records of ships visits to Australia gathered from Lloyds Maritime Intelligence Unit (LMIU), and simple relationships based on the type of ship, its dead weight tonnage (DWT), and the export/import statistics of the donor and recipient port (Appendix B). We assume that the volume of ballast discharged by recreational vessels is negligible.

The surface area of a vessel’s hull and sea chest is correlated with DWT (Ruiz *et al.*, 2000) and could therefore be used a proxy for hull fouling propagule supply. It would be misleading, however, to assume that the surface area of the hull and sea chest is correlated with number or density of fouling organisms. In reality fouling organisms are often most numerous in small nooks and crannies in and around the vessel (Hayes, 2002b; Hayes *et al.*, 2004). Furthermore, the extent of fouling upon a vessel is highly dependant on the vessel’s activity patterns, the time since it was last cleaned and antifouled, and the type of antifoulant used (Hayes *et al.*, 2004). This type of information, however, is not readily available for commercial and recreational) vessels operating in Australian waters. Therefore for the purposes of this analysis we assume that hull fouling propagule supply is a simple linear, monotonically increasing, function of the number of large commercial vessel visits from infected donor bioregions. Data on the domestic movements of small recreational and commercial craft (i.e. pleasure craft and fishing vessels) is not currently available, and therefore cannot be included in this analysis.

The condition and viability of organisms introduced with each possible incident is also difficult to predict. It is determined by a large number of possible ‘infection scenarios’, the number and type of organisms at the start of the journey, conditions during the journey, which may or may not include management intervention, and the journey duration. Infection scenarios refer to the ways in which marine organisms ‘infect’ vectors. In this context we are only concerned with hull fouling and ballast water but these broad categories hide a multitude of infection possibilities (Hayes and Hewitt, 1998; Hayes, 2002a). It is impossible to assess the influence of these variables on the condition of species introduced into a new locality without a detailed analysis supported by relatively large amounts of data. This type of analysis is appropriate in a risk assessment applied to a limited number of highly hazardous species but is not suitable for a hazard assessment that aims to screen a large number of species.

Data on journey duration, however, is available and can be easily incorporated into a simple hazard analysis. Ballast water samples taken before, after or during a voyage suggest that the condition and number of most organisms in the ballast water declines exponentially with journey duration (Hayes and Hewitt, 2000). This is not the case, however, for species with resistant or diapause life-stages, such as dinoflagellate cysts. Furthermore the effect of journey duration on the survival of hull-fouling organisms is not well understood. In this analysis we assume that the condition and viability of organisms transported around Australia is a simple linear, monotonically decreasing, function of journey duration. This assumption is simple and conservative for most species. It is also easy to investigate the effect of alternative approaches - e.g. viability and number of organisms is independent of journey duration for cyst-producing species, or a linear decreasing function of the natural logarithm of journey duration.

Detailed information on the environmental/habitat similarity between donor and recipient ports is not currently available. The approach adopted in this analysis assumes that environmental similarity (*ES*) is a monotonically decreasing function of the difference between the latitude of the recipient port and the donor port described by:

$$ES = f(d) = 1 - \left(\frac{d}{90}\right)^{\beta} \quad 0 \leq ES \leq 1 \quad , \qquad [1]$$

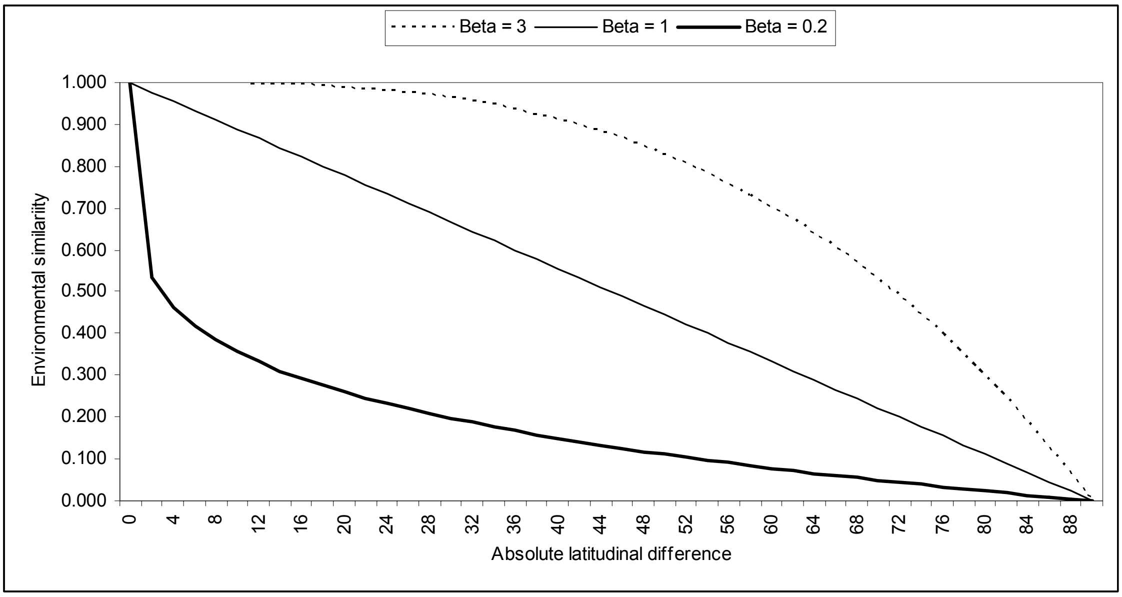
where d is the absolute difference between the latitude of the donor port and recipient port (ignoring the effect of hemisphere), and β is a parameter that adjusts the "strength" of this relationship. Figure 1 shows the effect of changing the parameter β on the environmental similarity. Expressing environmental similarity in this fashion allows us to easily investigate the effect of changing the strength of this relationship on the overall hazard analysis (see results section).

The invasion potential (*IP*) of each species on the potential domestic "target list" is calculated by comparing its IMCRA bioregion distribution with the sum total of ship movements and ballast water discharges (in 2002) that originate in these 'infected' bioregions weighted by the journey duration and the environmental similarity of the donor and recipient ports. Hence for those species translocated by both ballast water and hull fouling

$$IP = \frac{1}{c} \cdot \sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{v_{ij} \cdot ES_{ij}}{t_{ij}} \right) + \sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{b_{ij} \cdot ES_{ij}}{t_{ij}} \right) \quad , \qquad [2]$$

where v_{ij} is the number of ship movements to recipient Australian port (i) from donor port (j) summed over all ports and terminals in the infected bioregions (m), b_{ij} is the volume of ballast water discharged in Australian port (i) from donor port (j) summed over all ports and terminals in the infected bioregions, ES_{ij} is the environmental similarity between the recipient and donor ports, t_{ij} is the journey duration in days, and c is a normalising constant given by the sum of the hull fouling and ballast water invasion score across all bioregions. If the journey duration for any given movement (i, j) is unknown or negative (due to errors in the Lloyds database) then journey duration is conservatively assumed to be 1 day. The hull fouling component of equation [2] is set to zero if the species is only translocated by ballast water and vice-versa.

Figure 1 The environmental similarity function (equation 1) for various values of the parameter β



For the domestic hazard analysis this process was repeated twice. In the first approach invasion potential was calculated for all recipient bioregions – i.e. without reference to the infection status of the recipient bioregion. In the second approach, only ship movements between infected IMCRA bioregions and uninfected bioregions counted towards the invasion potential score. The resolution of the analysis could be improved by using port (rather than bioregion) infection status. At the moment, however, there is insufficient information to do this for all Australian ports and all the species on the potential domestic "target list".

Impact potential

There is currently no universally accepted way to measure or estimate the potential impact of non-native species. Indeed this is often the least objective part of any bio-invasion debate because stakeholders and interest groups have different values and opinions about what is 'harmful' and what therefore constitutes a negative impact. Harm is most easily defined, and most easily agreed upon, when it refers to human-health impacts or refers to impacts on certain species, particularly commercially valuable species or endangered ones. Harm is most difficult to define when it refers to potential impacts on species that are of no direct value to man, or to impacts on community structures and ecosystem processes. There may therefore be little debate about impacts upon human health or economically important resources. Identifying species that cause ecological harm, however, is ultimately a subjective process (Hayes and Sliwa, 2003).

The deductive stages of this project distinguished three types of impacts: human health, economic and ecological. Economic and ecological impacts were further sub-divided into several categories to give a total of 15 potential impact categories (Table 2). This analysis designed a web-based questionnaire around these categories, amalgamating herbivory (E9) and predation (E4) to give a total of 14 impact categories: five economic, eight ecological and one human health (See Table 2 and Appendix C).

Biologists and ecologists around Australia and the world, experts in the invasion-history or biology of the potential target species, were invited to complete the questionnaire. Each assessor was asked to score the potential impacts of species they were most familiar with on a scale of 0 to 1 (divided into ten intervals), in order to record the expected level of impact and the uncertainty associated with it. The results of the questionnaire were aggregated using interval arithmetic in order to capture the uncertainty associated with the potential impacts of each species.

Interval arithmetic belongs to a family of mathematical techniques known as bounding. It is used when the upper and lower bounds of a continuous variable are real and are known, or can be estimated. All the usual mathematical operations can be easily performed with intervals allowing the analyst to specify the possible range of a function or model output. If X and Y are non-negative real random variables on the interval [x1, x2], [y1, y2] then sum, subtraction, multiplication and division are simple and intuitive operations. For example Z = X + Y is given by

$$Z = X + Y = [x_1, x_2] + [y_1, y_2] = [x_1 + y_1, x_2 + y_2] \quad , \qquad [3]$$

whilst C = Z/N is simply

$$C = \frac{Z}{N} = \left[\frac{x_1 + y_1}{N}, \frac{x_2 + y_2}{N} \right] \quad , \qquad [4]$$

so long as N is a non-negative real number. If X, Y or N take negative values then the process is slightly more complicated (Kaufman and Gupta, 1985). The approach is rigorous, intuitive and easy to perform. Interval analysis does not, however, provide any information on the likelihood of values within the range.

Impact potential is calculated separately for potential human health, ecological and economic impacts. Equations [3] and [4] were used to aggregate the intervals returned in the questionnaires for the 5 economic and 8 ecological impact categories – i.e. to calculate the overall impact interval aggregated over the 5 economic and 8 ecological impact categories. Overall impact intervals for each species were also averaged (using equation [4]) if there were two or more questionnaires returned for the same species. The total impact potential is calculated by simply summing the overall interval associated with human health, ecological impact and economic impact (using equation [3]).

Hazard ranking

Species on the potential domestic “target list” are ranked by plotting their invasion potential against their impact potential. The position of each species in the two dimensional Cartesian space defined by invasion potential and impact potential is used to group species into high, medium and low hazard categories. It is also possible to combine the invasion and impact potential scores into a single hazard score to rank the species. The individual rank of a species, however, is extremely sensitive to uncertainty surrounding its potential impact. This approach would not therefore offer much advantage over a broad grouping and is not warranted in this context.

3.3 International species

During the first year of this project we compiled records of marine invasions from around the world that were published between 2000 and 2003 and thereby updated the analysis of international bio-invasions completed during the first priority pest project. At the completion of the first priority pest project we had compiled a list of 851 marine species with a reported invasion history in areas of the world other than Australia (Hayes and Sliwa, 2003). This list was used as the basis for the addition of new information during this project.

During this project we gathered additional information on species invasions from: Hawaii, Italy and the Mediterranean, the Adriatic Sea, the North Sea, the North East Atlantic, the Black Sea and the Caspian Sea. We also collected additional vector information from hull fouling studies conducted in the North Sea and Hawaiian Islands, and from a number of other studies that reported the results of ballast water samples. The additional references used in this project are:

Godwin (2003); Occhipinti Ambrogi (2002); Gollasch (2002); Eldredge and Smith (2001); Carlton *et al.*, (2001); Zaitsev and Ozturk (2001); Boudouresque and Verlaque (2002); Hopkins (2001); Piercey *et al.*, (2000); Grigorovich *et al.*, (2002); Bij deVaate *et al.*, (2002); Orensanz *et al.*, (2002); Toft *et al.*, (2002); Leppakoski *et al.*, (2002); Zabin and Hadfield (2002); Coles and Eldredge (2002); Dick *et al.*, (2002); and Smith *et al.*, (2002).

3.4 International hazard analysis

The second stage of the international hazard analysis selects a sub-set of species from the international list. These species form the updated "next pest" list. These species are again ranked by invasion and impact potential. The "next pest" list comprises those species which satisfy the following selection criteria:

1. have a reported shipping vector or a ship-mediated invasion history;
2. the vector still exists;
3. have recorded impacts overseas on human health, the environment or economic interests; and,
4. are not currently recorded in Australia, or are present in Australia but subject to official control.

Invasion potential

The invasion potential for the international hazard analysis was completed in the same way as for the domestic hazard analysis. A small difference between the two methods was the use of the worldwide IUCN distribution of the international species. None of the species on the international list are found in Australian waters, hence only international vessel arrivals were used in the international analysis of invasion potential. Domestic vessel movements were not incorporated. LMIU records include all vessels over 250 gross tonnes who report to Lloyds but do not include visits by international yachts or fishing vessels. The Australian Quarantine and Inspection Service (AQIS), however, records international yacht arrivals – these data were added to the LMIU data and incorporated into the analysis.

Impact potential

The impact potential for the international hazard analysis was completed in the same way as for the domestic hazard analysis. We contacted biologists and ecologists around the world, experts in the invasion-history or biology of the next pest species, and invited them to complete the questionnaire. Each assessor was asked to score the potential impacts of species they were most familiar with on a scale of 0 to 1 (divided into ten intervals) in order to record the expected level of impact and the uncertainty associated with it. The results of the questionnaire were aggregated using interval arithmetic in order to capture the uncertainty associated with the potential impacts of each species. See section 3.2 for details.

Hazard ranking

The hazard ranking for the international hazard analysis was completed in the same way as for the domestic hazard analysis. See section 3.2 for details.

4 RESULTS

4.1 Invasion database

The invasion database collated for this project currently records 1593 marine and estuarine species with invasion histories – 734 being added since the previous project. 212 of the species do not have a recorded invasion history but have been reported in either ballast water (130) or hull fouling (53) samples, or on another vector (29). The breakdown of species held in the database with regards to their establishment and invasion status in Australia is detailed in Table 3.

Table 3 The invasion and establishment status (in Australia) of the 1593 marine and estuarine species on the CMR database.

Established in Australia	Invasion status in Australia		Number of species
Yes	Native		100
	Non-native		133
	Cryptogenic		175
	Unknown		126
		Sub-total	534
No	Native		0
	Non-native		17
	Cryptogenic		2
	Unknown		274
		Sub-total	293
Unknown	Native		0
	Non-native		11
	Cryptogenic		3
	Unknown		752
		Sub-total	766
		Grand total	1593

450 of the 1593 species held in the database have a ballast water mediated invasion history, whilst 600 have a hull fouling mediated invasion history. 173 species have been recorded as both hull fouling and ballast water invaders.

4.2 Domestic lists

Ballast water

23 of the 133 non-native species known to be established in Australia satisfied all of the selection criteria for a potential domestic target species associated with ballast water. These species are listed in Table 4. Of the 175 cryptogenic species known to be established in Australia, only 5 satisfied all of the selection criteria for a potential domestic target species associated with ballast water. These species are listed in Table 5. None of the 126 species of unknown invasion status that are established in Australia satisfied all of the ballast water selection criteria.

Only 1 of the 11 non-native species of unknown establishment status satisfied the domestic ballast water selection criteria. This species is listed in Table 6. Similarly none of the cryptogenic species, or species of unknown invasion status, and unknown establishment status satisfied all of the selection criteria for domestic ballast water target species.

The 5 cryptogenic and one non-native species of unknown establishment status may be considered as potential “target list” candidates at the discretion of the relevant national authority. It is unlikely that any of these species can be successfully eradicated from Australian waters, but they are all amenable to control via ballast water exchange except for the cyst producing dinoflagellates *Alexandrium catenella*, *A. tamarense* and *Pfiesteria schumwayae*.

The 23 non-native species listed in Table 4 that satisfied the ballast water selection criteria are potential “target list” candidates. Again it is very unlikely that any of these species can be successfully eradicated from Australian waters, and they should therefore be considered as candidates for domestic ballast water control. All of these species are amenable to control via ballast water exchange, unless otherwise stated. The impacts, invasion history and Interim Marine and Coastal Regionalisation for Australia (IMCRA) distribution of each of these species is summarised below.

Alexandrium minutum is a toxic dinoflagellate found as single cells (pairs of cells are occasionally observed). The toxins produced by *A. minutum* are toxic to some zooplankton and avoided as a food source by others, can affect copepod reproduction (Lush and Hallegraeff 1996; Bagoien *et al.*, 1996; Frangoulos *et al.*, 2000), or result in fish kills (Labib and Halim 1995; Oshima *et al.*, 1989). Blooms can result in extended closures of shellfish farms with severe economic losses (Bagoien, 1996; Le Doux *et al.*, 1989). Closure to wild harvesting also has the potential to have a significant impact on local populations that may rely on shellfish as a major food source. The toxins produced by *A. minutum* are bio-accumulated in zooplankton, shellfish and crabs, and consumption of contaminated organisms can result in paralytic shellfish poisoning (PSP) in humans and other mammals (Hallegraeff, 1993). *A. minutum* was first recorded in Australia in 1983 and is currently known from the following IMCRA bioregions: HAW, LNE, SVG and VES. In VES and HAW, it’s status is cryptogenic following genetic analyses distinguishing an "eastern genotype" similar to New Zealand and possibly native, however in LNE and SVG it’s status is non-native as genetic analysis shows that it has the same genotype as that found in the Mediterranean (Chris Bolch, University of Tasmania, personal communication November 2003). It is important to note that ballast water exchange may not provide effective risk reduction for this species.

Alitta succinea (formerly known as *Neathes succinea*) is a sedentary worm, growing up to 190 mm in length. This worm usually resides in U-shaped burrows in the sediment. *A. succinea* is commonly found in estuaries in Australia and south-western Africa, however, it is not restricted to estuarine salinities. It is found as a fouling species and as benthic infauna in soft sediments. This worm can modify biogeochemistry (available nutrients and oxidation state) of the sediments and promote bacterial activity by feeding on and burrowing through sediments (Bartoli *et al.*, 2000). It was first recorded in Australia in 1930 and is currently known from the following IMCRA bioregions: HAW, LNE, SVG and VES.

Asterias amurensis is a large seastar native to the northern Pacific with a small central disc and five distinct arms that taper to pointed tips. It is predominantly yellow in colour and often seen with purple or red detail on its upper surface. This seastar is a voracious predator and in its native range is a major pest of the Japanese shellfish farming industry (Hatanaka and Kosaka, 1959; Kim, 1968; Nojima *et al.*, 1986). In Australia, the seastar feeds on a wide range of native animals and can have a major effect on the recruitment of native shellfish populations that form important components of the marine food chain (Ross *et al.*, 2002). Recent reports indicate that the seastar is now affecting oyster production on some marine farms in southeast Tasmania. *A. amurensis* was first recorded in Australia in 1986 in Tasmania and is currently known from the following IMCRA bioregions: BRU, FRT, VES and CVA.

Boccardia proboscidea is a spionid worm that creates burrows of varying shape and size. These burrows are made in sediments, soft rock and mollusc shells. This species is an indicator species for organic enrichment of sediments and is often a numerically dominant species (Johnson, 1970; Blake and Kudenov, 1978). It can form shallow burrows of mud tubes nestled under shell lamina on the exterior surface of bivalves, including for example *Ostrea edulis* (Bailey-Brock, 2000), *Crassostrea gigas* (Sato-Okoshi, 2000) and gastropods (Blake and Evans, 1972). These burrows can contain egg capsules with developing larvae (Bailey-Brock 2000). It was first recorded in Australia in 1975 in Western Australia and is currently known from the following IMCRA bioregions: CVA, EYR, LNE, OTW and VES.

Table 4 Potential non-native target species that are established in Australia (ballast water vector)

Scientific name	Common name	Control in AUS†	ID in AUS‡	# BR*	IMPACT CATEGORIES														
					H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Alexandrium minutum	Dinoflagellate	Yes	1980	4	1			1											
Alitta succinea	Pile worm	No	1930	4												1			
Asterias amurensis	Northern Pacific seastar	Yes	1985	4				1					1	1					
Boccardia proboscidea	Spionid polychaete	No	1975	5			1	1											
Bugula neritina	Bryozoan	No	1880	16			1						1						
Carcinus maenas	European green crab	Yes	1890	10				1					1	1					
Ciona intestinalis	Sea vase	No	1899	8			1	1											
Cordylophora caspia	Hydroid	No	1931	4			1						1						
Crassostrea gigas	Pacific oyster	Yes	1947	11			1		1	1	1		1						
Euchone limnicola	Sabellid polychaete	No	1984	5							1	1	1			1			
Gymnodinium catenatum	Dinoflagellate	Yes	1970	11	1			1											
Hydroides ezoensis	Serpulid polychaete	No	1996	2		1	1	1					1						
Musculista senhousia	Asian bag mussel	Yes	1982	5							1	1	1						
Polydora cornuta	Spionid polychaete	No	1975	2				1											
Polydora websteri	Spionid polychaete	No	1885	1				1											
Pseudopolydora paucibranchiata	Spionid polychaete	No	1971	6							1		1						
Sabella spallanzanii	European fan worm	Yes	1965	6			1	1			1	1							
Sphaeroma walkeri	Marine pill bug	No	1924	3			1												
Styela clava	Sea squirt	No	1972	1	1		1	1					1						
Theora lubrica	Asian semelid bivalve	No	1958	6									1			1			
Tridentiger trigonocephalus	Japanese goby	No	1973	4									1						
Undaria pinnatifida	Japanese kelp	Yes	1988	3			1	1					1			1			
Varicorbula gibba	Clam	Yes	1987	4				1					1						

†Species is on current ABWMAC target pest list

‡Year the species was first introduced or identified in Australia

*Number of infected IMCRA bioregions out of a total of 60

Table 5 Potential cryptogenic target species that are established in Australia (ballast water vector)

Scientific name	Common name	Control in AUS[†]	ID in AUS[‡]	IMPACT CATEGORIES H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Alexandrium catenella	Dinoflagellate	Yes	No data	1			1											
Alexandrium tamarense	Dinoflagellate	Yes	No data	1			1											
Balanus amphitrite	Barnacle	No	1854			1												
Hydroides elegans	Serpulid tubeworm	No	No data			1												
Pfiesteria schumwayae	Dinoflagellate	No	No data	1														

Table 6 Potential non-native target species whose establishment status in Australia in unknown (ballast water vector)

Scientific name	Common name	Control in AUS[†]	ID in AUS[‡]	IMPACT CATEGORIES H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Molgula manhattensis	Solitary ascidian	No	1976				1					1			1			

[†]Species is on current ABWMAC target pest list

[‡]Year the species was first introduced or identified in Australia

Bugula neritina is an erect, bushy, red-purple-brown coloured bryozoan. It has a cosmopolitan distribution. *B. neritina* is an abundant fouling organism. This species will colonise heavily any freely available substratum including many artificial underwater structures and vessel hulls. It is one of the most abundant bryozoans in ports and harbours and an important member of the fouling community. It grows well on pier piles, vessel hulls, ship's intake pipes and condenser chambers, buoys and similar submerged surfaces (Foster, 1982). In North America *B. neritina* occurs on rocky reefs and seagrass leaves. In Australia, it occurs primarily on artificial substrata. It was first recorded in Australia in the 1880s in Victoria and is currently known from the following IMCRA bioregions: ANB, BAT, CVA, EYR, FLI, HAW, LMC, LNE, OTW, PIN, SCT, SGF, SVG, TWO, VES and WSC.

Carcinus maenas is a medium-sized crab that attains a width across the carapace of up to 80mm, but more typically 65 mm. It is native to Europe. *C. maenas* is a voracious predator with a broad diet and has been implicated in the decline of native shellfish populations, some of commercial importance (Cohen *et al.*, 1995). In the northwest Atlantic it consumes a wide variety of native species, out competing most for food and habitat (Vermeij, 1982; Williams, 1984). On mainland Australia, *C. maenas* has been present for over 100 years but its impact is difficult to gauge due to the lack of pre-invasion baseline data. The impacts that it may have had when it first reached Australia are likely to have been substantial based on its document impacts around world. In Tasmania, *C. maenas* has been present for about 20 years and is a major cause of mortality in native crab and mollusc populations. (see Thresher, 1997 and references therein). It was first recorded in Australia in the 1890s in Victoria and is currently known from the following IMCRA bioregions: BGS, BRU, COR, CVA, FLI, FRT, LNE, SVG, TWO and VES.

Ciona intestinalis is a solitary ascidian, commonly found in dense aggregations. It usually hangs vertically upside-down in the water column. It is presumably native to one or both coasts of the North Atlantic. *C. intestinalis* has high clearance rates and large numbers can reduce turbidity and food availability in shallow waters and out-compete native species for food and space (Cohen *et al.*, 2001). Since appearing in southern California in 1917 the native species of ascidians previously found in the harbours have disappeared or are much rarer in abundance (Lambert and Lambert, 1998). It is a nuisance fouling species in aquaculture facilities such as mussel rope culture, oyster farms and suspended scallop ropes in Nova Scotia and North America, the Mediterranean, South Africa, Korea and Chile (Kang *et al.*, 1978; Cayer *et al.*, 1999; Hecht and Heasman, 1999; Clarke and Castilla, 2000). It was first recorded in Australia in 1899 in New South Wales and is currently known from the following IMCRA bioregions: BRU, HAW, LNE, OTW, SCT, SVG, VES and WSC. Australian populations appeared to be in decline in the 1950s-1960s, disappearing from port areas where the species was previously dominant. Port surveys conducted throughout the 1990s, however, have confirmed that this species is still found in some Australian ports.

Cordylophora caspia is a colonial hydroid with upright, irregularly branched stems up to 100 mm high. It is a Ponto-Caspian species, native to the Black Sea and Caspian Sea. *C. caspia* has been recorded clogging intake pipes of power plants in Europe and the United States. It has also been suggested that this hydroid impacts freshwater/estuarine communities, causing changes in species composition (see Folino, 1999 and references therein). *C. caspia* can withstand a high degree of eutrophication and is present in areas with high levels of run-off and pollution. *C. caspia* was first recorded in Australia in 1931 and is found mainly in inland and brackish rivers and lakes of Australia. These lakes and rivers are adjacent to the following IMCRA bioregions: CVA, HAW, OTW and TMN.

Crassostrea gigas is an important aquaculture species throughout the world. It has a white elongated shell, with an average size of 150-200 mm. *C. gigas* settles in dense aggregations in the intertidal zone, resulting in the limitation of food and space available for other intertidal species. *C. gigas* will attach to almost any hard surface in sheltered waters. Whilst they usually attach to rocks, the oysters can also be found in muddy or sandy areas. Oysters will also settle on adult oysters of the same or other species. They prefer sheltered waters in estuaries where they are found in the inter-tidal and shallow sub-tidal zones, to a depth of about three metres. *C. gigas* was first introduced to Western Australia for aquaculture purposes in 1947 but this attempt was unsuccessful. It was successfully introduced into Tasmania in 1948. It is currently known from the following IMCRA bioregions: BGS, BRU, COR, CVA, EYR, FRT, HAW, SVG, TWO, WSC and VES. Only a small number of C. *gigas* have been found in Westernport (IMCRA region VES) and the population of this species may not yet be self-sustaining, as its population density is much lower (<5%) than the density at which this species is typically found in other infested areas (Cohen *et al.*, 2000).

Euchone limnicola is a sedentary worm, growing to 12 mm in length. It is native to the north-east Pacific. This species establishes dense populations within the sediments, possibly competing with native species for food and space. The process of tube building consolidates the sediments, thereby altering the habitat for other organisms (Wilson, 1999). *E. limnicola* is abundant enough (mean density of 2127 m^{-2}) in Portland harbour to cause a significant ecological effect as a filter feeder (Parry *et al.*, 1997). It was first recorded in Australia in 1984 in Victoria and is currently known from the following IMCRA bioregions: BGS, BRU, HAW, OTW and VES.

Gymnodinium catenatum is a toxic, bloom forming species of micro-algae. It is found in bays and estuaries throughout the world. Vegetative cells can be distributed throughout the whole water column with cysts being found in sediments. Toxins produced by *G. catenatum* can cause Paralytic Shellfish Poisoning (PSP). The toxins are accumulated in shellfish (oysters, mussels and scallops) which then become toxic to humans and other organisms. In extreme cases, PSP causes muscular paralysis, respiratory difficulties, and can lead to death (Ochoa *et al.*, 1998). *G. catenatum* also threatens wild and aquaculture shellfish industries, due to economic losses resulting from farm closures (Hallegraeff and Sumner, 1986; Mackenzie and Beauchamp, 2001). *G. catenatum* was first recorded in Australia in the 1970s in Tasmania and is currently classified as non-native in IMCRA bioregions BRU and FRT. It has also classified as cryptogenic in the following IMCRA bioregions: BAT, CVA, DAV, EYR, FLI, HAW, OTW, TWO and VES. The difference in invasion status is due to uncertainty surrounding the species distribution and mode of introduction. In BRU and FRT (which run along the east coast of Tasmania) there is good evidence that the cysts were not present in sediments before 1972 and 1973 (McMinn *et al.,* 1997; Bolch *et al.*, 1999) suggesting that the species was in fact introduced to these locations probably by ballast water. In the other regions further studies are required to determine the invasion status of the species.

Hydroides ezoensis is a fouling organism native to Japan, Russia, China and Korea. It has been introduced to the United Kingdom, France and Australia (Imajima 1976; Zibrowius and Thorp, 1989). *H. ezoensis* attaches to virtually any submerged structure with a microbial film in low intertidal to shallow sub-tidal regions, including: rocks, shells, macro-algae, ship hulls, buoys, mariculture equipment and species (scallops, oysters), pipes and jetties. In northern Japan it occasionally forms large aggregations on intertidal rocky shores (Miura and Kajihara, 1984). It is recorded in the literature as a nuisance fouler (hulls and seawater cooling systems; Zibrowius and Thorp, 1989). In the United Kingdom fouling of *H. ezoensis* (up to 30 cm thick) has caused navigation problems by reducing the flotation of navigation buoys (Eno *et al.*, 1997). *H. ezoensis* was first recorded in Australia in 1996 in the port surveys of Port Kembla, Newcastle and Port Phillip Bay. It is therefore known from the following IMCRA bioregions: HAW and VES.

Musculista senhousia is a small mussel with a maximum length of around 30 mm with dark radial lines or zigzag markings (Lamprell and Healy, 1998; Hoenselaar and Hoenselaar, 1989). It can dominate benthic communities and potentially exclude native species as it settles in dense aggregations known as byssal mats (Willan 1987; Campbell and Hewitt, 1999). These byssal mats may restrict the growth of some species of seagrass (Reusch and Williams, 1999) and may also increase infaunal density and species richness because they provide additional habitat for many species (Crooks and Khim, 1999). *M. senhousia* prefers to settle in groups on soft substrata, but is capable of fouling wharf pilings and other man made structures. It is a highly adaptive species, and is able to tolerate low salinities and low oxygen concentrations (Willan 1987). *M. senhousia* is native to Japan and China (Kikuchi and Tanaka, 1978; Kulikova, 1978; Cohen and Carlton, 1995) and was first recorded in Australia in 1982 (Slack-Smith and Brearley, 1987). It was introduced to Washington and California with Japanese oysters, but is also thought to be transported by ballast water and/or ship fouling (Cohen and Carlton, 1995). The species has also been introduced to the Mediterranean and the north-east Pacific (Cohen and

Carlton, 1995). It has established populations in the following IMCRA bioregions: BGS, LNE, SVG and VES, with additional records from OTW.

Pseudopolydora paucibranchiata is a burrowing, sedentary worm which constructs its tube from sand and silt (Blake and Woodwick, 1975). This species can be a dominant member of the infaunal community and can cause changes in habitat and faunal composition, with recorded densities of up to 60,000 individuals per square metre (Levin, 1981). A number of potential vectors have been suggested for the transfer of this species including ballast water, hull fouling and Japanese oysters (Cohen and Carlton, 1995). *P. paucibranchiata* inhabits oyster shells and fouling communities and has the potential to be spread as both larvae and adults (Wilson, 1999). The type locality of *P. paucibranchiata* is Japan but the species is distributed throughout the Pacific, including introductions in Australia (Blake and Kudenov, 1978; Hutchings and Murray, 1984; Hutchings and Turvey, 1984), New Zealand (Read, 1975) and California (Light, 1977). The first Australian record of *P. paucibranchiata* is from 1971 (Blake and Kudenov, 1978), and the species is now recorded from the following IMCRA bioregions: HAW, VES, BAT, EYR, SVG and TWO.

Polydora cornuta is a small spionid polychaete native to the northern Atlantic (Cohen and Carlton, 1995). It is found in mudflats and oyster beds, and other soft sediment habitats. It is found throughout the world, and is likely to disperse via ballast water (Radashevsky, 1999). In the USA, these worms are sometimes so abundant that they bury the oysters in several inches of mud tubes (see USGS Nonindigenous Aquatic Species Database and references therein). It was first found in Australia in 1975 in Victoria and is currently found in the following IMCRA bioregions: SVG and VES.

Polydora websteri is a small spionid polychaete with a type locality from New England, USA. It is found on the east and west coasts of North America, in the Gulf of Mexico, Hawaii and also in Australia (Blake, 1996). It is commonly found in the shells of commercial oysters and other bivalves of estuaries and near shore environments (Blake, 1996). The spread of *P. websteri* along the east coast of Australia (associated mortalities first recorded in 1880) forced Sydney rock oyster producers into an intertidal stick and tray culture system (Bower, 2001). It was first recorded in Australia (as *Polydora ciliata*) in the 1880s in New South Wales. It is now found in the IMCRA bioregion HAW. It was also recorded in 1977 at Tuross Lake from *Crassostrea commercialis* (Blake and Kudenov, 1978).

Sabella spallanzanii is a large tube dwelling worm with a crown of feeding tentacles formed in two layers. One layer of tentacles is distinctly spiraled. *S. spallanzanii* is generally found in shallow subtidal areas between 1-30 m 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 (Clapin and Evans, 1995). There is some evidence to suggest that dense beds of *S. spallanzanii* may intercept settling organic material and thus interfere with nutrient cycles. Experiments have shown that recruitment of some taxa to settlement panels is reduced under *S. spallanzanii* canopies, while other taxa increase relative to worm free areas. No taxa were excluded altogether from areas with *Sabella* (Holloway and Keough, 2002a; 2002b). At high densities, it may impact other filter feeding organisms. It was first recorded in Australia in 1965 in Western Australia (Clapin and Evans, 1995) and is now found in the following IMCRA bioregions: BGS, LNE, SVG, TWO, VES and WSC.

Sphaeroma walkeri is an isopod that grows to up to 10 mm in length. It is found among fouling communities on vessel hulls and other man-made structures and has been recorded in high densities of up to 12,521 per square metre on mariculture cages (Mak *et al.*, 1985). In addition to hull fouling, it has been suggested that ballast water is a possible dispersal mechanism for this species (Carlton, 1985). *S. walkeri* is a fully marine species but it is occasionally reported from estuaries and hyper-saline lagoons (Carlton and Iverson, 1981). It is native to the Indian Ocean but has invasion histories in Australia, Florida, Hawaii, Mediterranean, north-east Pacific and south-west Atlantic (Carlton and Iverson, 1981). It was first introduced to Australia in 1924 (Baker, 1928) and has established populations in the following IMCRA bioregions: HAW, LMC and WTC.

Styela clava is a large, club-shaped solitary ascidian with a tough leathery body wall (Knight-Jones and Ryland, 1996). It is fast growing, and can reach densities of 500 to 1500 individuals per square metre (Osman and Whitlach, 1999). It is known to foul vessels, aquaculture and fishing equipment and other artificial structures (Parker *et al.*, 1999), and may also be translocated with oyster spat and oyster transfers (Lutzen, 1999). *S. clava* has a pelagic larval life of only 24-28 h (at 20°C) (Holmes, 1969 in Lutzen, 1999), hence introductions via ballast water are possible (Carlton and Geller 1993; Cohen and Carlton, 1995) but much less likely than introduction via fouling. As fouling species, *S. clava* can have negative impacts on native species and aquaculture species through competition for space and food as well as predation of larvae from the water column (Osman and Whitlach, 1999). In Japan it has been known to impact human health causing an asthmatic condition in oyster shuckers when hammering open fouled oysters in poorly ventilated areas (Abbott and Newberry, 1980). *S. clava* is native to the north-western Pacific (Holmes, 1976; Millar, 1960), and has invasion histories in Europe and the United Kingdom (Christiansen and Thomsen, 1981; Lutzen 1999), the north-west Atlantic (Lutzen, 1999), and Coos Bay (Ruiz *et al.*, 2000). The first Australian record is from Port Phillip Bay in 1972 (Holmes, 1976). Its Australian distribution is currently limited to IMCRA bioregion VES.

Theora lubrica is a small bivalve with an almost transparent shell. It is thought to be native to Asia, however there has been some confusion over the nomenclature of this species and a review of the genus is required (Boyd, 1999). In Japan, *T. lubrica* has an extended breeding season and continuous recruitment (Kikuchi and Tanaka, 1978), making it susceptible to uptake in ballast water (Boyd, 1999). Larvae have been collected in the ballast water of Japanese ships arriving in Oregon, USA (Carlton *et al.*, 1990). It can dominate an area within a short time period (Boyd, 1999) and can alter habitats and biogeochemical cycles by liberating nitrogenous compounds from bottom sediments (Yamada and Kayama, 1987). It has invasion histories in New Zealand (Boyd, 1999) and the north-east Pacific (Carlton, 1985; Ferraro and Cole, 1997; Seapy, 1974). The first published Australian record of *T. lubrica* is from Port Phillip Bay in 1958 where it was recorded as *Theora fragilis* (Macpherson, 1966). It is now established in the following IMCRA bioregions: HAW, LNE, NSG, OTW and VES, and has also been recorded in BGS though its population status is unknown there.

Tridentiger trigonocephalus is a grey-brown coloured goby with a white speckled head and two characteristic black stripes (Hoese and Larson, 1994). It has specific habitat requirements and it is therefore possible that it will compete with species sharing their preferred habitat. The goby may be introduced via ballast water (Carlton, 1985), ships' seawater systems or as eggs laid on hull fouling organisms (Hoese 1973; Haaker 1979). *T. trigonocephalus* is native to Japan, China and Korea (Masuda *et al.*, 1984; Fowler 1960). It has been recorded as invasive in California (Haaker, 1979). Given that *T. trigonocephalus* occurs in widely separated bioregions in southern Australia, it may have been translocated by commercial or recreational vessels (Lockett and Gomon, 1999). It was first recorded in Australia in Sydney Harbour in 1973 (Hoese, 1973), and has been found in BAT, LNE, HAW and VES bioregions, with the apparent establishment of self-sustaining populations in both Sydney (HAW) and Melbourne (VES) (Matthew Lockett *pers. comm.* 2003).

Undaria pinnatifida is a brown seaweed that can reach an overall length of 1-3 m. It is an annual species with two separate life stages (Lewis, 1999). *U. pinnatifida* is highly invasive, grows rapidly and has the potential to overgrow and exclude native algal species (Sanderson, 1990). The presence of *U. pinnatifida* may therefore alter the food resources of herbivores that would normally consume native species. In some areas of Tasmania it is a common species, growing in large numbers around areas in which sea urchins have depleted stocks of native algae (Talman *et al.*, 1999). It also has the potential to become a problem for marine farms by increasing labour costs due to fouling (Sanderson, 1990). The species is thought to be transported in ballast water, as hull fouling, or with imported oysters (Lewis, 1999). *U. pinnatifida* is native to Japan, Korea and China (Akiyama and Kurogi, 1982). It was first discovered on the east coast of Tasmania in 1988 (Sanderson, 1990) and was probably introduced in the ballast water or hull fouling of vessels transporting woodchips to Japan (Lewis, 1999). *U. pinnatifida* has been introduced to New Zealand (Hay and Luckens, 1987), California (Thornber *et al.*, 2004; ICES, 2004), Argentina (Casas and Piriz, 1996) and Europe (Floc'h *et al.*, 1996; Cecere *et al.*, 2000). It's current Australian distribution encompasses the following IMCRA bioregions: BRU, FRT and VES.

Varicorbula gibba is a small bivalve mollusc whose shell is usually creamy white with brown patches or bands (Boyd, 1999). It is regarded as a pest due to its growth rate and high tolerance of many environmental conditions. It achieves very high population densities and therefore has the potential to compete with native species for food and space, including commercial species such as scallops, possibly affecting their recruitment (Talman *et al.*, 1999). *V. gibba* is native to Europe and the United Kingdom (Talman *et al.*, 1999) and was most likely introduced to Australia as larvae in ballast water (Boyd, 1999). It should be noted, however, that adult specimens were found in the sea chest of the Spirit of Tasmania whilst in dry dock in Sydney (Coutts *et al.*, 2003). *V. gibba* was identified in archived samples collected in Port Phillip Bay as early as 1987 (N. Coleman *pers. comm.* in Currie *et al.*, 1998). The species has invasion histories in Belgium, France and the Netherlands (ICES, 2004) and is established in the following IMCRA bioregions: BGS, BRU, OTW and VES.

Hull fouling

48 of the 133 non-native species, and 17 of the 175 cryptogenic species, known to be established in Australia satisfied all of the selection criteria for hull fouling. These species are listed in Tables 7 and 8 respectively. None of the species whose invasion and establishment status in Australia is unknown satisfied the hull fouling selection criteria.

Vector management under the new National System for the Prevention and Control of Marine Pest Incursions is not (currently) species specific. Again it is very unlikely that any of the species listed in Table 7 or 8 could be successfully eradicated from Australian waters. Hence if species specific assessments were to be performed for hull fouling then the species listed in Table 7 would be potential "target list" candidates. The cryptogenic species listed in Table 8 may also be considered as potential target species at the discretion of the appropriate national authority. In this context it is important to note that (to date) there have been no proposals to manage hull fouling on a species by species basis. As a result all of the species in Table 7 and 8 that are currently controlled in Australia (i.e. previously listed) are controlled because they are also vectored via ballast water. Species specific management may, however, form an important component of the new monitoring and surveillance system under the new national regime.

Many of the species that satisfy the selection criteria for hull fouling have the impact of nuisance fouling – the definition of this impact is rather broad in its context and can be interpreted in a number of ways, for example, from total dominance of a species to small populations that cause an increase in the amount of time spent cleaning fishing gear. The impacts, invasion history and Interim Marine and Coastal Regionalisation for Australia (IMCRA) distribution of each of these species which do not have a ballast water vector and are therefore summarised above, are summarised below.

Antithamnionella spirographidis is a small filamentous red alga with creeping prostrate axes that could easily be transported on the hull of a vessel. It was first described in 1916 from the Adriatic Sea, although its origin is not certain. This species spreads by fragmentation and the rapid production of new thalli and can cause fouling problems in marinas (Eno *et al.*, 1997). The first Australian record was in Port Adelaide in 1957 (Wollaston, 1968 cited in Lewis, 1999). This species is found in the following IMCRA bioregions: SVG and VES.

Apocorophium acutum is a small amphipod, often found among algae (coralline and holdfasts of kelp), sponges and ascidians and fouling communities (Crawford, 1937; Bellan-Santini *et al.*, 1982). *Apocorophium* species are distinguished from other amphipods by being dorso-ventrally flattened rather than the typical laterally flattened shape of most species (Kozloff, 1993). They are tube-building amphipods and are found inter-tidally or in shallow water. They are a dominant part of the fouling community on man-made installations (Crawford, 1937; Bellan-Santini *et al.*, 1982). This species is found in the following IMCRA bioregion: HAW (Pollard and Pethbridge, 2002).

The circumtropical fouler *Balanus reticulatus* has been recorded from Yanchep Marina, Western Australia (Jones, 1990, 1991; Jones *et al.*, 1990) and, more recently, at Dampier (Jones, 2003). The means of introduction of *B. reticulatus* into Australian waters is unknown but Utinomi (1967) has suggested that ship transport is responsible for the widespread distribution of this Japanese species. This species is found in the following IMCRA bioregions: CWC, PIN and WTC. It was first recorded in Australia at the North Barnard Islands (as *B. amphitrite*) (Lewis, 1981).

Barentsia benedeni is a kamptozoan found as pale colonies of interconnected zooids. *B. benedeni* is a cosmopolitan species found in communities of fouling organisms in harbours and bays around the world. It fouls many living (worm tubes, mussel shells, encrusting bryozoans, etc.) and non-living (wood, bark, styrofoam floats etc.) substrata. It can withstand extremes of temperature and salinity, which may explain its effectiveness as an invasive species (NIMPIS, 2002). This species can be a nuisance fouler. This species is found in the following IMCRA bioregions: HAW and SVG. It was first found in Australia in 1952, though misidentified as *B. gracilis* by Chittleborough (unpublished) (see Wasson, 2002).

Bougainvillia muscus consists of bushy colonies 5 cm high, with irregular, branching stems forming an acute angle with the main stem. This species has a cosmopolitan distribution and has been identified in New South Wales and Victoria. Colonies have been found in Port Phillip Bay, Point Wilson and Explosives Jetty in the Geelong Arm growing among mussels and intergrown with a bryozoan, *Bugula* sp. (Watson, unpub. 1998). This species is common in temperate waters but is known to exist subtropically from Brazil, Kaneohe Bay and Oahu, Hawaii. This species is found in the following IMCRA bioregions: BGS, BRU, HAW, LNE, VES and WSC. It was first recorded in Australia from Sydney Harbour in 1931 (Watson, 1999).

Bugula flabellata is an erect bryozoan with broad, flat branches. It is a major fouling bryozoan in ports and harbours, particularly on vessel hulls, pilings and pontoons. It has also been reported from off shore oil platforms. Quite often it is found growing with other erect bryozoan species such as *B. neritina* or growing on encrusting bryozoans. Vertical, shaded, sub-littoral rock surfaces also form substrata for this species. It has been recorded down to 35m. This species is found in the following IMCRA bioregions: BAT, EYR, HAW, LNE, MAN, OTW, SCT, SVG, TWO, VES and WSC.

Chiton glaucus is a chiton with an ovate shape that is highly arched, dorsally flattened and grows up to 50mm long. It has 8 very finely sculptured, smooth, overlapping valves surrounded by a tough girdle (mantle) with prominent scales. In its introduced range in south-eastern Tasmania it is now one of the most conspicuous and common chiton species and hence must be having some impact on the native species (Kershaw, 1956; Edgar, 1997). This species is found in the following IMCRA bioregion: BRU.

Cladophora prolifera is a filamentous green alga that forms dense spreading tufts up to 15 cm high. It is found throughout warm temperate Europe, the Mediterranean, African and American tropics, the Solomon Islands and New Zealand (Womersley, 1984). The occurrence of this species in Australia has been linked with that of the introduced opisthobranch *Aplysiopsis formosa* considered to be an introduction from the North Atlantic/Mediterranean (Fuhrer *et al.*, 1988). The local distribution of this alga differs to that of many other recognised introductions in that it has colonised and is locally abundant on exposed coastal rock platforms and in deep water. However, these locations are close to international shipping lanes and shipping must be considered a potential vector for the introduction of this species (Lewis, 1999). This species is found in the following IMCRA bioregions: COR, HAW, LMC, LNE, OTW, SVG and VES.

Codium fragile ssp. *tomentosoides* is a large, dark green macroalga with one to several thick upright branches arising from broad, spongy, basal disc attached to the substrata. Fronds are generally annual and dieback in winter and arise from the perennial basal portion in spring. *C. fragile* ssp. *tomentosoides* is regarded as a pest because of its invasive capabilities and its reported impacts on shellfish farms in the northwest Atlantic (see Trowbridge, 1998 for details and references therein). It is recorded as preventing the re-establishment of native algal species in New Zealand but can not competitively exclude them. In Australia it is reported to settle on native algae and shellfish and to foul commercial fishing nets. In some areas overseas large wracks of the alga accumulate and rot on beaches after storms (Dromgoole, 1975). The alga has wide environmental tolerances, including temperature and salinity, and is found in estuarine to full marine waters. It is found in a wide variety of areas, from very protected through to intermediately wave exposed in both intertidal and subtidal habitats. This species is present in the following IMCRA bioregions: BRU and VES.

Cryptosula pallasiana is an encrusting bryozoan, white-pink in colour with orange crusts. In the USA, it has been noted as one of the most competitive fouling organisms in ports and harbours where it can cover several centimetres in a few days (Soule *et al.* 1996). Within Australia, colonies generally do not reach a large size or cover large areas of substrata. *C. pallasiana* is a common fouling organism on a wide variety of substrata. Typical habitats include seagrasses, drift algae, oyster reef, artificial structures such as piers and breakwaters, man-made debris, rock, shells, ascidians, glass and vessel hulls. It has been reported from depths of up to 35 m. This species is found in the following IMCRA bioregions: BGS, EYR, HAW, LNE, SCT, SVG, TWO, VES and WSC.

Ectopleura crocea is a colonial hydroid, growing in hand-sized tufts to approximately 12 cm high. *E. crocea* is found in low intertidal and subtidal areas to 40 m in depth. It appears to prefer areas with high water movement and can be found on wharves, floats and similar structures within harbours and bays. Clusters of this common fouling species grow rapidly over summer on hulls of vessels at moorings on the Victorian coast. It has also been recorded from the seawater cooling systems of submarines (Watson, 1999). This species is found in the following IMCRA bioregions: HAW, LNE and VES.

Gymnogongrus crenulatus is a small red alga that grows 3-8 cm high. Most collections of this species in Australia are from areas near harbours. *G. crenulatus* is also found in the British Isles (southern and western shores), the Mediterranean and the Northwest Atlantic (New Brunswick, Canada to N. Massachusetts, USA). This species is typically encrusted with species of bryozoans, foraminifera and calcareous algae and could therefore facilitate the invasion of other species in addition to its own impacts. This species is found in the following IMCRA bioregions COR, EYR, HAW, SVG and VES. It was first recorded in Port Phillip Bay in 1969 (Lewis, 1999).

Halisarca dujardini is a sponge native to the European Atlantic coasts. It is a cosmopolitan species found in harbours, usually on mussels, in North America, New Zealand and South Africa. It is a very thin and inconspicuous species and easily overlooked. Its colour ranges from yellow to fawn, with a grey or green tinge. Growth on mussels may cause problems with aquaculture operations. This species is found in the following IMCRA bioregions: HAW and VES. The first recorded collection was in Port Phillip Bay in 1996 (Keough and Ross, 1999).

Hydroides diramphus is one of the three *Hydroides* species responsible for widespread fouling within harbours and lagoons throughout the Mediterranean (Zibrowius, 1993). This species probably originates from tropical American seas. Records from around the world are from harbours and ships' hulls which ten Hove (unpublished data) suggests are indicative of a species transported by hull fouling. In high abundance, this species is capable of dominating fouling and encrusting communities. This species is found in the following IMCRA bioregions: ANB, HAW and LMC.

Hydroides sanctaecrucis is a sedentary fouling serpulid worm that constructs calcareous tubes approximately 20 mm long on hard substrata. *H. sanctaecrucis* is native to muddy coastal lagoons in the Caribbean and was originally described from Sainte Croix. Reliable scientific records indicate its range extends from South Florida (possibly South Carolina) to Brazil, including French Guiana (*pers. comm.* Harry ten Hove). *Hydroides* are considered nuisance species because of the excessive proliferation of calcareous tubes that can form extensive "reefs" on submerged structures, including wharves, pontoons, mariculture equipment and slow moving vessels. *H. sanctaecrucis* has a propensity for settling on substrata with low copper concentrations such as slow release antifouling paints and copper alloys including bronze propellers and cupro-nickel pipe work. It can therefore shorten the lifetime and effectiveness of antifouling paint. Direct economic impacts of other *Hydroides* species and possibly *H.*

sanctaecrucis, are mainly attributed to the cost of cleaning fouled surfaces, the increased drag on fouled vessels and blockages or inefficiencies in seawater cooling systems, for example in submarines. In addition it has the potential to modify ecosystem dynamics and species assemblages through competition for space and food. Introduction could have occurred via a number of ways including hull fouling, ballast water or associated with aquaculture species such as oysters. This species is found in the following IMCRA bioregion: WTC.

Megabalanus rosa has a smooth, pinkish red coloured shell, which is occasionally white. It grows to no more than 50 mm in height. *M. rosa* is classified as an open sea species in Japan but has been found on wharf pylons, vessel hulls and other artificial structures. It can be found to a depth of 300 m, and from waters ranging in temperature from 15-28 degrees Celsius (NIMPIS, 2002). In high abundance this species is responsible for nuisance fouling on artificial substrata. This species is found in the following IMCRA bioregions: BAT, CAN, EMB, HAW, MAN, NIN, PIN, PIO, SBY and ZUY.

Megabalanus tintinnabulum is a medium sized barnacle, growing to a height of 50 mm and having a diameter of about 65 mm. It is often striped and ribbed longitudinally along the shell, which is a pinkish-white to pinkish-purple in colour. *M. tintinnabulum* is a cosmopolitan fouling species, and one of the most common species of barnacle found fouling vessels (NIMPIS, 2002). This species is found in the following IMCRA bioregions: ANB, AWS, BAT, BON, CAB, CAN, COB, CVA, CWC, ECY, EMB, FLI, HAW, KIM, KSD, LMC, LNE, MAN, NIN, OTW, PIN, PIO, SCT, TWO, VDG, VES, WTC and ZUY.

Monocorophium acherusicum is a dorso-ventrally flattened amphipod that is yellowish-brown in colour. *M. acherusicum* occurs subtidally on sediments or where silt and detritus accumulate among fouling communities such as algae, ascidians and bryozoans, and man-made installations, e.g. wharf pylons, rafts and buoys. It is a tube-building species constructing conspicuous, fragile U-shaped tubes of silk, mud and sand particles. It can tolerate a wide range of salinities. It fouls surfaces such as harbour pylons, rafts and buoys by building mud tubes. It is also part of the fouling community on vessels as hull fouling and can reach high abundances on sediments or where silt and detritus accumulate among fouling communities (Smith and Carlton, 1975; Bellan-Santini *et al.*, 1982; Brock *et al.*, 1999; Poore and Storey, 1999). Invasion of *Monocorophium* in an area can alter sediment dynamics through the building of mud tubes on the sediment surface consolidating the sediments (Myers, 1977). This species is found in the following IMCRA bioregions: BGS, BRU, FRT, LNE, TWO and VES.

Monocorophium insidiosum is a flattened-cylindrical amphipod with small eyes on the lateral lobes of the head. *M. insidiosum* was first described from England, but has been reported from both sides of the North Atlantic and from the eastern Pacific (Poore and Storey, 1999). It is found primarily in estuarine habitats, occurring intertidally and subtidally on mud sediments or among algae or seagrasses (Poore and Storey, 1999). Invasion of *Monocorophium* in an area can alter sediment dynamics through the building of mud tubes on the sediment surface consolidating the sediments (Myers, 1977). A maximum abundance of 140, 000 individuals per square metre was recorded in Denmark (Birklund, 1977). This species fouls surfaces such as harbour pylons, rafts and buoys by building mud tubes and also forms part of the fouling community on vessels as hull fouling. It can reach high abundances on sediments or where silt and detritus accumulate among fouling communities (Smith and Carlton, 1975; Bellan-Santini *et al.*, 1982; Poore and Storey, 1999). *M. insidiosum* was first identified in Australia in 1973 in Port Phillip Bay and has subsequently also been identified in Western Australia, South Australia, New South Wales and other areas of Victoria (Storey, 1996). This species is found in the following IMCRA bioregions: BRU, CVA, HAW, LNE, OTW and VES.

Notomegabalanus algicola is a barnacle native to South Africa. It was first recorded in Australia from the Sydney region in 1943. The Australian Museum Faunal Database records it from Sydney Harbour in 1945. Allen (1953) recorded it from Eden to Port Stephens and suggested that it was transported to Australia via hull fouling. Ten years after its first sighting, Allen reported it as one of the most common sublittoral barnacles on the open coast. This species may have an impact on native encrusting communities. It is found in the following IMCRA bioregions: BAT, HAW and MAN.

Polysiphonia brodiei is a dark reddish brown macroalga, typically 4-12 cm high but occasionally growing to 40 cm. Commonly found in the subtidal zone just below low tide level. This species colonises wooden structures such as jetties and pylons, floating structures such as ropes, buoys and vessels and other fouling species such as mussels. *P. brodiei* seems to prefer moderately exposed localities. In Australia, New Zealand and California, specimens have been mostly collected from port environments. It is frequently found as hull fouling on slow moving vessels such as barges in California and New Zealand. It also occurs as nuisance fouling on ropes, buoys and other harbour structures such as pylons and boat ramps (Adams, 1991; Hollenberg, 1944 in Lewis, 1999). This species is found in the following IMCRA bioregions: BRU, CVA, FRT, OTW, SVG and VES.

Schizoporella unicornis is an encrusting bryozoan, ranging in colour from a whitish-pink to reddish-orange or brown. Typically, mature colonies range from 1-4 cm in diameter. It encrusts a broad range of substrata, including shell, stone and kelp holdfasts and often forms broad encrustations under boulders or sheltered overhangs (NIMPIS, 2002). In NSW collections, shell and stones were found to be the common substrata for its attachment. This species is found in the following IMCRA bioregions: BAT, BGS, EYR, HAW, LMC, LNE, SCT, SVG, VES and WSC.

Schottera nicaeensis is a light to medium brown-red coloured alga with flat, simple to proliferous fronds arising from slender branched stolons. This species is native to the Mediterranean, southern and western British Isles through to Portugal, and is believed to be introduced in South Africa and Australia. *S. nicaeensis* has been recorded in Victoria, South Australia, New South Wales and Tasmania. It is frequently found growing on pylons or in shaded areas under jetties (Lewis, 1999). This species is found in the following IMCRA bioregions: BRU, FRT, HAW, OTW, SVG, VES. The earliest record of this species in Australia dates to 1975, when it was discovered in Port Phillip Bay.

Scrupocellaria bertholetti is a small, straw-coloured arborescent bryozoan, with colonies usually less than 3 cm high (Keough and Ross, 1999). It has been observed in South Australia as one of the major fouling species in Port Adelaide (Brock, 1985) but has not been recorded in similar abundances in Victoria. It is a cosmopolitan species and has most likely been spread by shipping. The systematics of this genus in Australia is in need of further examination (Keough and Ross, 1999). *S. bertholetti* is found in the following IMCRA bioregions: BRU and VES.

Teredo navalis is a bivalve specialised for boring into wood, commonly known as a shipworm, although it is not a worm, but a mollusc. It has a small shell that is used for burrowing and feeding, with fine ridges used for rasping away wood. *T. navalis* creates burrows in wood that can be up to one metre long. It can be found in boats, piers, driftwood and any other wooden structure from below the high tide mark. It is able to survive in temperatures up to 30 degrees Celsius; however no growth occurs beyond 25 degrees. Estimates of damage caused by *T. navalis* are in excess of US$50 million per year (Nair and Saraswathy, 1971). The information we have for this species is a generalised distribution which covers the southern warm-temperate waters of Australia, this includes the following bioregions: BAT, COR, CVA, CWC, EUC, EYR, HAW, LNE, MAN, MUR, NSG, OTW, SGF, SVG, TMN, TWO, VES and WSC (Turner, 1971).

Tricellaria occidentalis forms fragile, straw-coloured colonies, with a colony diameter of approximately 8 cm (Keough and Ross, 1999). This species is from the northern hemisphere, where it has been recorded from British Columbia to southern California, Baja California, China, Japan and Europe. It is also found in New Zealand, where it is classified as introduced, and is likely to be introduced to Australia. *T. occidentalis* has been recorded in Sydney in New South Wales, Port Adelaide in South Australia and has also been identified at numerous localities in Victoria. It is widely distributed in Port Phillip Bay and occurs on the outer Victorian coast (Keough and Ross, 1999). This species is typically found on wharf pylons and other artificial structures, but also commonly occurs amongst sessile assemblages dominated by native species. In Victoria, *T. occidentalis* is regarded as probably the most successful invader of the introduced bryozoans (Keough and Ross, 1999). This species is found in the following IMCRA bioregions: BAT, BRU, EYR, HAW, LNE, SVG, VES and WSC.

Watersipora subtorquata is an encrusting bryozoan, typically dark red-brown in colour, with a red or orange growing edge, and is typically found on wharf pylons near the low water mark (Gordon and Mawatari, 1992). The native range of this species is uncertain due to taxonomic difficulties, although the type locality has been listed as Rio de Janeiro and it has a wide international distribution, including Brazil, the West Indies, Japan, Torres Strait and New Zealand (Keough and Ross, 1999). This species can achieve a high percentage cover, although its distribution is generally restricted to habitat within approximately 1 m of the low water mark. This species is found in the following IMCRA bioregions: OTW and VES.

Zoobotryon verticillatum is an erect bryozoan species, growing in the form of translucent colonies with irregular branching. The colonies of this species may cover large areas. It is a fouling species that lives in warmer waters worldwide, and is now a major fouling organism in New South Wales, South Australia and Western Australia. Masses of *Z. verticillatum* and drift algae frequently become entangled around submerged hard surfaces, and may significantly impact the settlement and fitness of hard-bottom sessile invertebrates (Walters and Abgrall, 2000). Large masses of *Z. verticillatum* can be sucked into cooling systems of power stations causing serious operational difficulties (Gitay and Glazer, 1979). This species is found in the following IMCRA bioregions: CWC, HAW, LMC, LNE, PIN, SCT, SGF, SVG and WSC.

Other vectors

During the data collection stage of this project we collected information on species introduced to Australia via vectors other than hull fouling or ballast water. This information, however, is by no means comprehensive because our research focused on the two vectors of interest to this project. Species which satisfy the selection criteria discussed above for these other vectors are listed in Appendix D. These species lists are incomplete and should be interpreted with care. In addition it should be noted that a species can be spread by more than one vector, so the numbers are not mutually exclusive for each vector type.

Table 7 Potential non-native target species that are established in Australia (hull fouling vector)

		Control in	ID in	#	IMPACT CATEGORIES														
Scientific name	Common name	AUS†	AUS‡	BR*	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Alitta succinea	Pile worm	No	1930	4												1			
Antithamnionella spirographidis	Red macroalgae	No	1953	2			1												
Apocorophium acutum	Amphipod	No	1937	1			1									1			
Asterias amurensis	Northern Pacific seastar	Yes	1985	4				1					1	1					
Balanus reticulatus	Barnacle	No	1981	3			1												
Barentsia benedeni	Nodding head	No	1952	2			1												
Boccardia proboscidea	Spionid polychaete	No	1975	5			1	1											
Bougainvillia muscus	Sea anemone	No	1918	6			1												
Bugula flabellata	Bryozoan	No	1933	11			1												
Bugula neritina	Bryozoan	No	1880	16			1						1						
Carcinus maenas	European green crab	Yes	1890	10				1					1	1					
Chiton glaucus	Chiton	No	1910	1									1						
Ciona intestinalis	Sea vase	No	1899	8			1	1											
Cladophora prolifera	Green macroalgae	No	1956	7									1						
Codium fragile tomentosoides	Green macroalgae	Yes	1995	2				1	1				1						
Cordylophora caspia	Hydroid	No	1931	4			1						1						
Crassostrea gigas	Pacific oyster	Yes	1947	10			1		1	1	1		1						
Cryptosula pallasiana	Bryozoan	No	1880	9			1						1						
Ectopleura crocea	Athecate hydroid	No	1885	3			1												
Euchone limnicola	Sabellid polychaete	No	1984	5							1	1	1			1			
Gymnogongrus crenulatus	Red macroalgae	No	1969	5											1				
Halisarca dujardini	Sponge	No	1996	2			1	1											
Hydroides diramphus	Serpulid tubeworm	No	2000	3			1												
Hydroides ezoensis	Serpulid tubeworm	No	1996	2		1	1	1					1						
Hydroides sanctaecrucis	Serpulid tubeworm	No	1999	1			1						1						

†Species is on current ABWMAC target pest list

‡Year the species was first introduced or identified in Australia

*Number of infected IMCRA bioregions out of a total of 60

Table 7 cont…

		Control in	ID in	#	IMPACT CATEGORIES														
Scientific name	Common name	AUS†	AUS‡	BR*	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Megabalanus rosa	Barnacle	No	1981	10				1											
Megabalanus tintinnabulum	Barnacle	No	1949	28				1											
Monocorophium acherusicum	Amphipod	No	1921	6			1									1			
Monocorophium insidiosum	Amphipod	No	1973	6			1						1			1			
Notomegabalanus algicola	Balanomorph barnacle	No	1943	3									1						
Polydora cornuta	Spionid polychaete	No	1977	2				1											
Polydora websteri	Spionid polychaete	No	1885	1				1											
Polysiphonia brodiaei	Red macroalgae	No	1940	6			1												
Pseudopolydora paucibranchiata	Spionid polychaete	No	1971	6							1		1						
Sabella spallanzanii	European fan worm	Yes	1965	6			1	1			1	1							
Schizoporella errata	Bryozoan	No	1982	3									1						
Schizoporella unicornis	Bryozoan	No	1925	10									1						
Schottera nicaeensis	Red macroalgae	No	1970	6				1					1						
Scrupocellaria bertholetti	Bryozoan	No	1970	2			1												
Sphaeroma walkeri	Marine pill bug	No	1924	3			1												
Styela clava	Sea squirt	No	1972	1	1		1	1					1						
Teredo navalis	Shipworm	No	No data	24						1									
Tricellaria occidentalis	Bryozoan	No	1880	8			1						1						
Tridentiger trigonocephalus	Japanese goby	No	1973	4									1						
Undaria pinnatifida	Japanese kelp	Yes	1988	3			1	1					1			1			
Watersipora arcuata	Bryozoan	No	1940	11			1						1						
Watersipora subtorquata	Bryozoan	No	1970	11			1						1						
Zoobotryon verticillatum	Bryozoan	No	1970	9			1						1						

†Species is on current ABWMAC target pest list

‡Year the species was first introduced or identified in Australia

*Number of infected IMCRA bioregions out of a total of 60

Table 8 Potential cryptogenic target species that are established in Australia (hull fouling vector)

		Control in	ID in	IMPACT CATEGORIES														
Scientific name	Common name	AUS[†]	AUS[‡]	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Ascidiella aspersa	Solitary ascidian	No	No data			1						1						
Balanus albicostatus	Barnacle	No	1984			1												
Balanus amphitrite	Barnacle	No	1854			1												
Balanus trigonus	Balanomorph barnacle	No	1854			1												
Botrylloides leachi	Colonial ascidian	No	No data			1						1						
Botryllus aurantius	Colonial ascidian	No	No data			1				1								
Botryllus schlosseri	Colonial ascidian	No	No data			1				1		1						
Caulerpa filiformis	Green macroalgae	No	No data									1						
Conopeum seurati	Bryozoan	No	No data									1						
Dipolydora armarta	Spionid polychaete	No	1978				1											
Dipolydora flava	Spionid polychaete	No	1978				1											
Dipolydora socialis	Spionid polychaete	No	1978			1	1											
Hydroides elegans	Serpulid tubeworm	No	No data			1												
Lepas (Anatifa) anserifera	Pedunculate barnacle	No	1851		1	1												
Obelia longissima	Hydroid	No	No data									1						
Styela plicata	Sea squirt	No	No data			1	1					1						
Ulva fasciata	Green macroalgae	No	1966									1						

†Species is on current ABWMAC target pest list

‡Year the species was first introduced or identified in Australia

4.3 Domestic hazard analysis

Invasion potential

Lloyds Maritime Information Unit (LMIU) records 22,286 ship arrivals in Australian ports in 2002. More than half of these vessels (59%) recorded their last port of call as an Australian port or terminal. We define these vessels as domestic ship arrivals. Table 9 summarises domestic ship movements in Australia in 2002. The data are aggregated by donor IMCRA bioregion. The table shows the vessel count and vessel/ballast scores weighted by journey duration and environmental similarity.

There are 60 IMCRA bioregions around the Australian coast. The pattern of domestic commercial ship movements around these bioregions, however, is highly skewed – the last port of call of 80% of the ships is situated in just nine bioregions (in descending order): VES, HAW, BGS, TMN, SCT, CWC, SVG, LMC and BAT (Figure 2). Figure 3 shows the locations of these (and the other) bioregions. The translocation potential (invasion potential) of domestic target species is determined by their distribution relative to this pattern of shipping activity.

Figure 4 summarises the invasion potential of the potential domestic target species given by equation [2] for all bioregions – i.e. irrespective of the infection status of the recipient bioregion. Figure 5 shows the invasion potential for uninfected recipient bioregions – i.e. vessel movements and ballast discharges are only counted for journeys between infected donor bioregions and uninfected recipient bioregions. See Table 10 for the species codes used in both of these figures.

This analysis suggests that the ten potential domestic target species most likely to be spread to uninfected bioregions by are: *Schizoporella errata, Watersipora arcuata, Cordylophora caspia, Ciona intestinalis, Alexandrium minutum, Sphaeroma walkeri, Pseudopolydora paucibranchiata, Tridentiger trigonocephalus, Bugula neritina* and *Gymnodinium catenatum*. It is important to note that these results are do not reflect the larval duration or population densities of the species concerned in each of the infected bioregions. The environmental similarity between the donor and recipient bioregions has only a small effect on the invasion potential rank of these species: *Alexandrium minutum* drops from fifth (β = 0.2) to eighth (β = 3), *Pseudopolydora paucibranchiata* rises from seventh (β = 0.2) to fifth (β = 3), *Tridentiger trigonocephalus* rises from eighth (β = 0.2) to seventh (β = 3), whilst *Bugula neritina* and *Gymnodinium catenatum* swap ninth and tenth positions.

Impact potential

126 questionnaire returns were collated for the species on the potential domestic “target list”. Three or more questionnaires were returned for more than 40% of the species (23 out of 53) on this list. *Alitta succinea* and *Monocorophium insidiosum* are the only two species for which a questionnaire was not completed.

Table 11 lists the results of the impact questionnaires completed, including information on the number of returns for each species (*n*) and the human health, economic and environmental impact scores generated by the interval analysis outlined in section 3.4. The overall impact potential, expressed as the simple sum of the intervals for human, economic and environmental impact is shown in Table 11 and plotted in Figure 6. The ten most damaging species, based on the opinion of the experts consulted, are *Gymnodinium catenatum, Alexandrium minutum, Asterias amurensis, Sabella spallanzanii, Crassostrea gigas, Ciona intestinalis, Bugula neritina, Polysiphonia brodiaei, Schizoporella errata* and *Codium fragile* ssp. *tomentosoides*.

Table 9 Weighted vessel visits and ballast water discharge in 2002 by IMCRA bioregion

dBioRegRef	dBioRegName	Count	VScore1†	VScore2	VScore3	BScore1‡	BScore2	BScore3	AvJD*	SDJD**
554	VES	3073	1151	2271	2375	819194	1597651	1702653	2.6	9.1
526	HAW	2435	867	1526	1602	1100704	2083045	2248027	5.1	15.7
505	BGS	1202	563	1103	1145	638548	1259252	1309275	1.5	1.8
549	TMN	972	302	597	640	697800	1352269	1459989	2.7	3.8
546	SCT	771	188	350	372	386205	637208	673099	6.7	12.7
516	CWC	755	189	373	395	519860	1037112	1117049	6.1	18.0
548	SVG	632	183	326	336	351396	616442	639345	3.8	9.3
530	LMC	446	118	243	259	211283	439496	471094	5.7	20.7
504	BAT	443	166	263	273	687698	1108556	1168537	4.5	6.8
AU	Australia	405	147	271	283	88306	175220	186115	7.1	29.1
555	WCY	400	85	192	210	366	742	824	3.9	3.8
501	ANB	377	65	82	86	27806	60998	66543	12.8	28.9
558	WTC	273	90	163	173	2270	4676	5046	3.7	2.2
507	BRU	232	76	138	146	65138	136687	146717	4.7	7.5
539	OTW	140	57	98	101	140093	240670	248900	7.7	12.1
536	NSG	131	36	69	72	101555	185371	192323	3.4	1.8
531	LNE	86	36	64	66	43705	76650	78709	5.7	13.1
557	WSC	85	31	56	58	17706	33212	34707	14.9	48.6
542	PIO	82	13	24	26	1058	2179	2433	10.8	9.7
534	MUR	77	15	31	33	0	0	0	3.8	2.4
541	PIN	67	24	47	52	0	0	0	6.8	7.2
527	KAN	60	28	36	38	1032	2039	2340	17.0	26.7
547	SGF	39	20	33	34	38603	62519	63297	1.7	1.1

†Sum of all domestic ship visits from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

‡Sum of ballast water discharge (tonnes) from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

*Average journey duration

**Standard deviation of journey duration

Table 9 cont…

dBioRegRef	dBioRegName	Count	VScore1[†]	VScore2	VScore3	BScore1[‡]	BScore2	BScore3	AvJD*	SDJD**
521	EYR	33	13	21	21	4795	7836	7985	2.7	1.8
525	GRO	30	5	9	10	16158	41227	47969	8.8	7.7
509	CAN	23	8	18	20	7842	19825	22893	6.3	4.2
529	KSD	21	2	4	4	0	0	0	5.7	2.4
514	CRF	11	3	6	7	0	0	0	3.3	2.4
544	RBN	7	3	6	6	0	0	0	1.2	0.4
201	AUS-I	4	1	3	4	0	0	0	no data	no data
508	CAB	4	1	1	1	3	5	6	8.8	6.4
538	OSS	4	0	0	0	0	0	0	8.8	5.3
212	AUS-XII	2	1	2	2	0	0	0	no data	no data
552	TWO	2	1	1	1	0	0	0	2.0	1.4
559	ZUY	2	0	1	1	0	0	0	10.0	na
204	AUS-IV	1	0	1	1	0	0	0	no data	no data
524	FRT	1	1	1	1	0	0	0	no data	no data
537	NWS	1	0	0	0	0	0	0	1.0	na
540	PEL	1	0	1	1	2741	5552	5785	no data	no data

[†]Sum of all domestic ship visits from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

[‡]Sum of ballast water discharge (tonnes) from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

*Average journey duration

**Standard deviation of journey duration

Figure 2 Domestic commercial vessel movements in Australia in 2002, aggregated by IMCRA bioregion

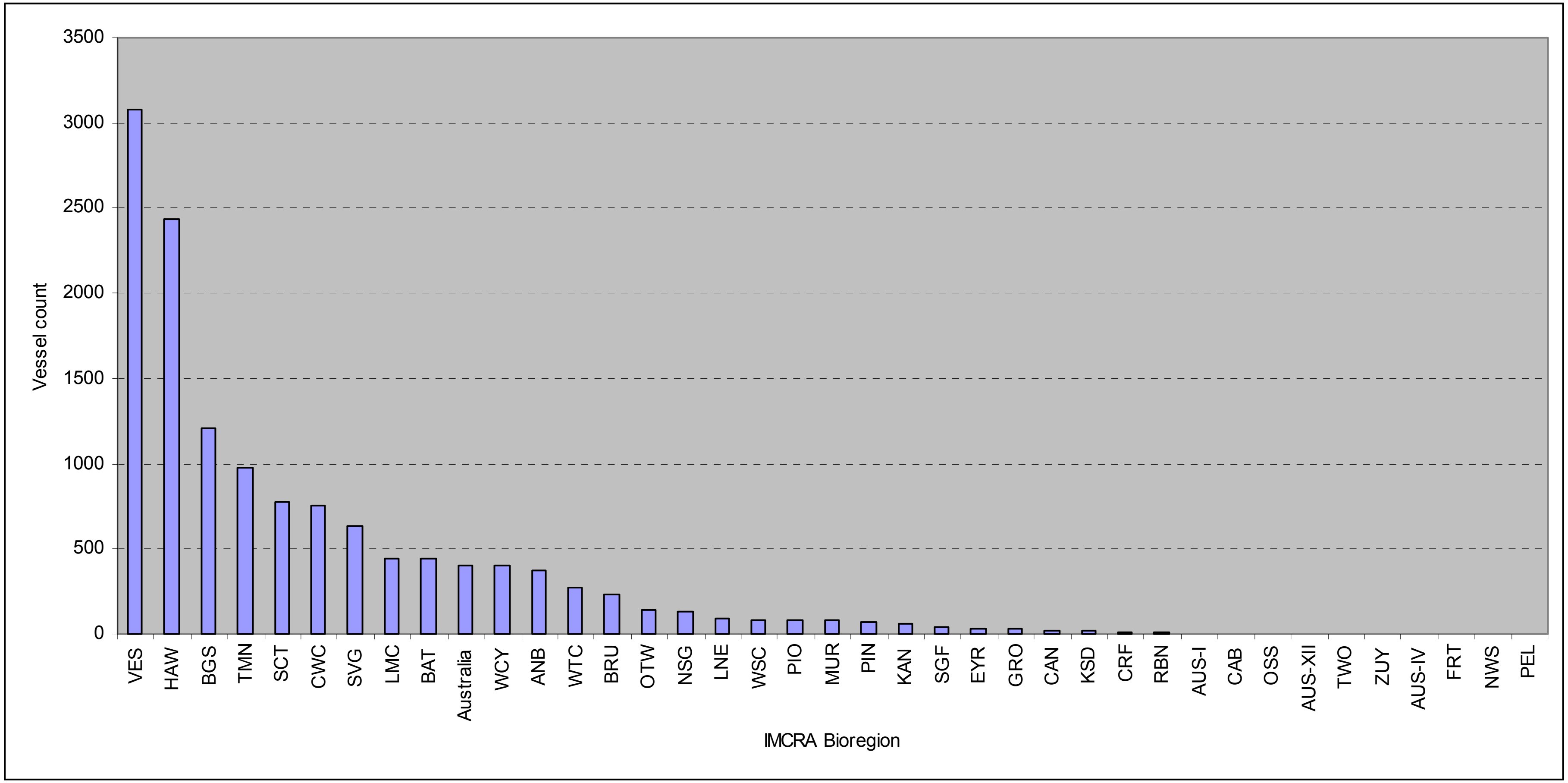


Figure 3 IMCRA bioregions of Australia

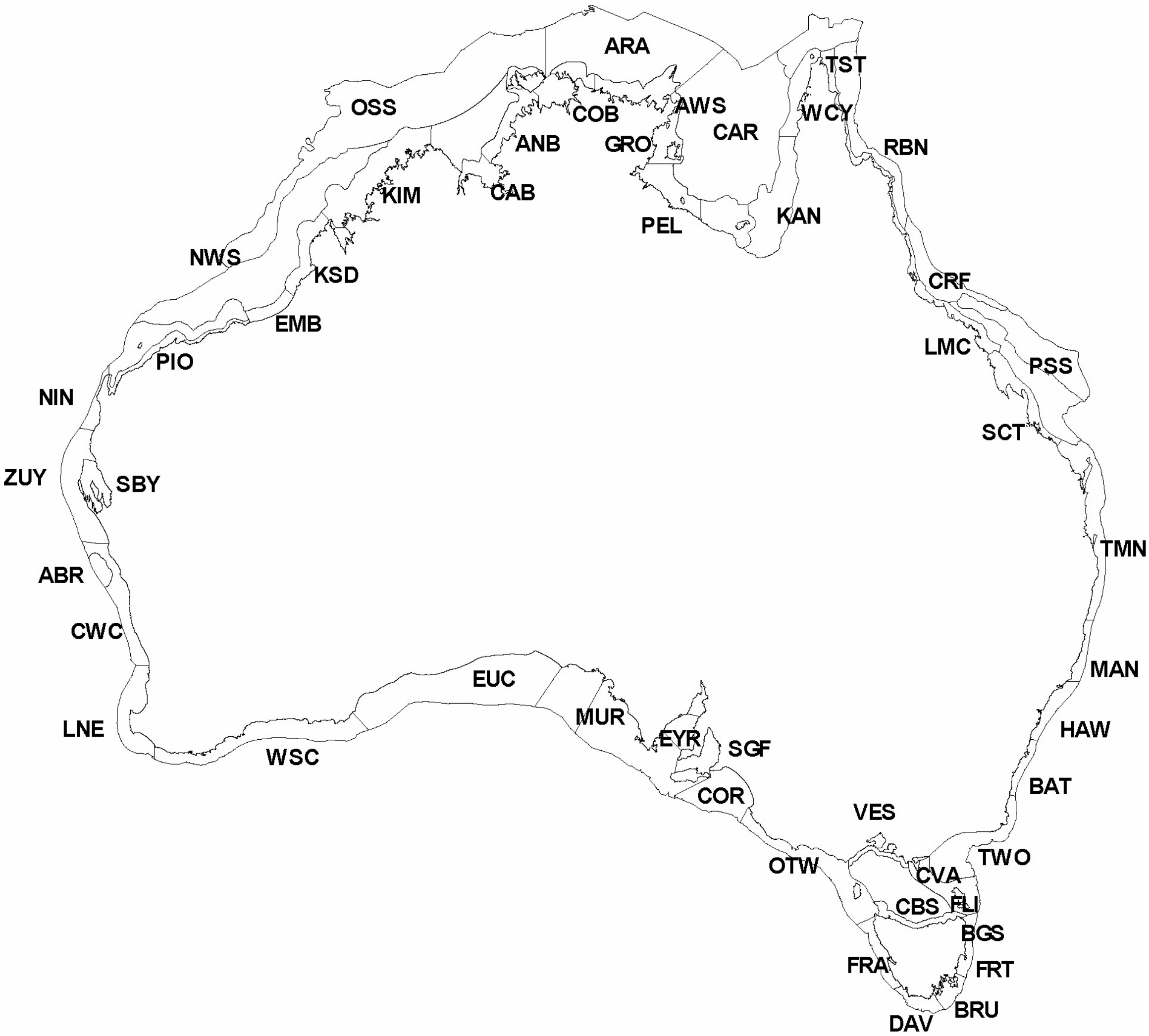


Table 10 Potential domestic target species and codes

Code	Species name
Aa1	Asterias amurensis
Aa2	Apocorophium acutum
Am	Alexandrium minutum
As1	Alitta succinea
As2	Antithamnionella spirographidis
Bb	Barentsia benedeni
Bf	Bugula flabellata
Bm	Bougainvillia muscus
Bn	Bugula neritina
Bp	Boccardia proboscidea
Br	Balanus reticulatus
Cc	Cordylophora caspia
Cft	Codium fragile tomentosoides
Cg1	Crassostrea gigas
Cg2	Chiton glaucus
Ci	Ciona intestinalis
Cm	Carcinus maenas
Cp1	Cladophora prolifera
Cp2	Cryptosula pallasiana
Ec	Ectopleura crocea
El	Euchone limnicola
Gc1	Gymnodinium catenatum
Gc2	Gymnogongrus crenulatus
Hd1	Halisarca dujardini
Hd2	Hydroides diramphus
He	Hydroides ezoensis
Hs	Hydroides sanctaecrucis
Ma	Monocorophium acherusicum
Mi	Monocorophium insidiosum
Mr	Megabalanus rosa
Ms	Musculista senhousia
Mt	Megabalanus tintinnabulum
Na	Notomegabalanus algicola
Pb	Polysiphonia brodiaei
Pc	Polydora cornuta
Pp	Pseudopolydora paucibranchiata
Pw	Polydora websteri
Sb	Scrupocellaria bertholetti
Sc	Styela clava
Se	Schizoporella errata
Sn	Schottera nicaeensis
Ss	Sabella spallanzanii
Su	Schizoporella unicornis
Sw	Sphaeroma walkeri
Tl	Theora lubrica
Tn	Teredo navalis
To	Tricellaria occidentalis
Tt	Tridentiger trigonocephalus
Up	Undaria pinnatifida
Vg	Varicorbula gibba
Wa	Watersipora arcuata
Ws	Watersipora subtorquata
Zv	Zoobotryon verticillatum

Figure 4 Invasion potential (all bioregions) of domestic target species for three values of the environmental similarity parameter β

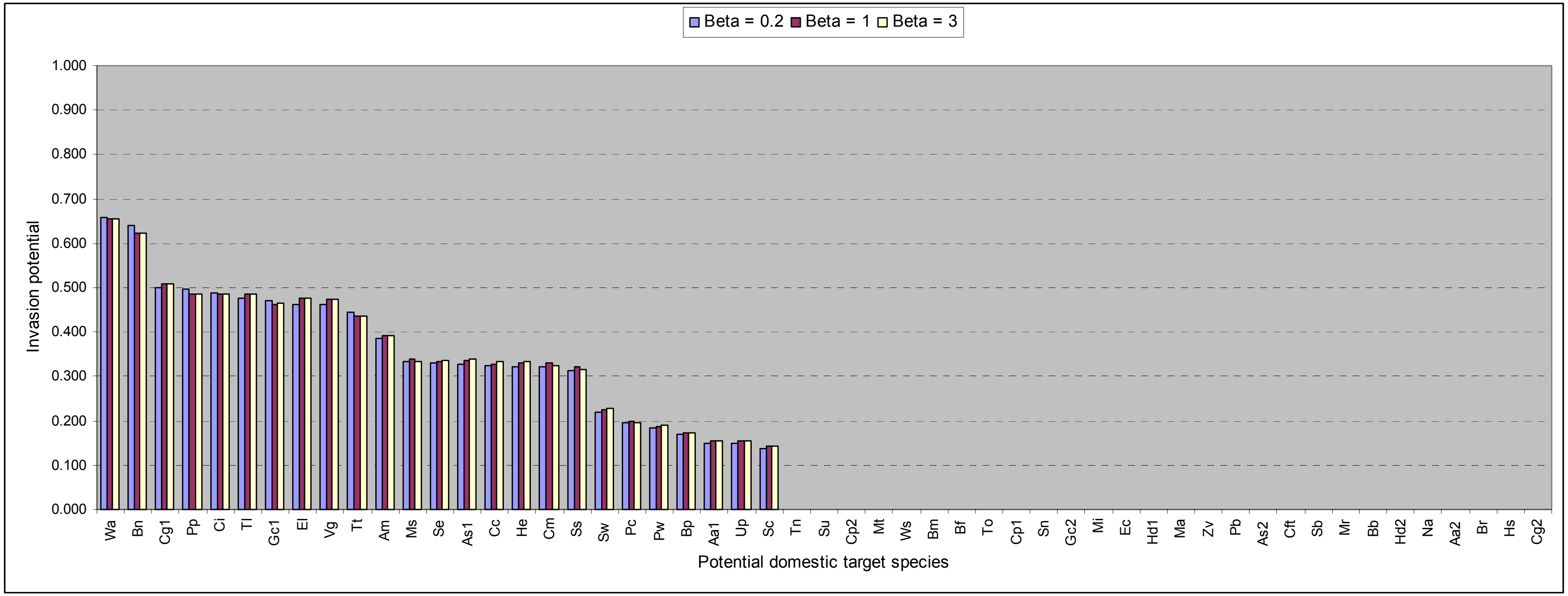


Figure 5 Invasion potential (uninfected bioregions) of domestic target species for three values of the environmental similarity parameter β

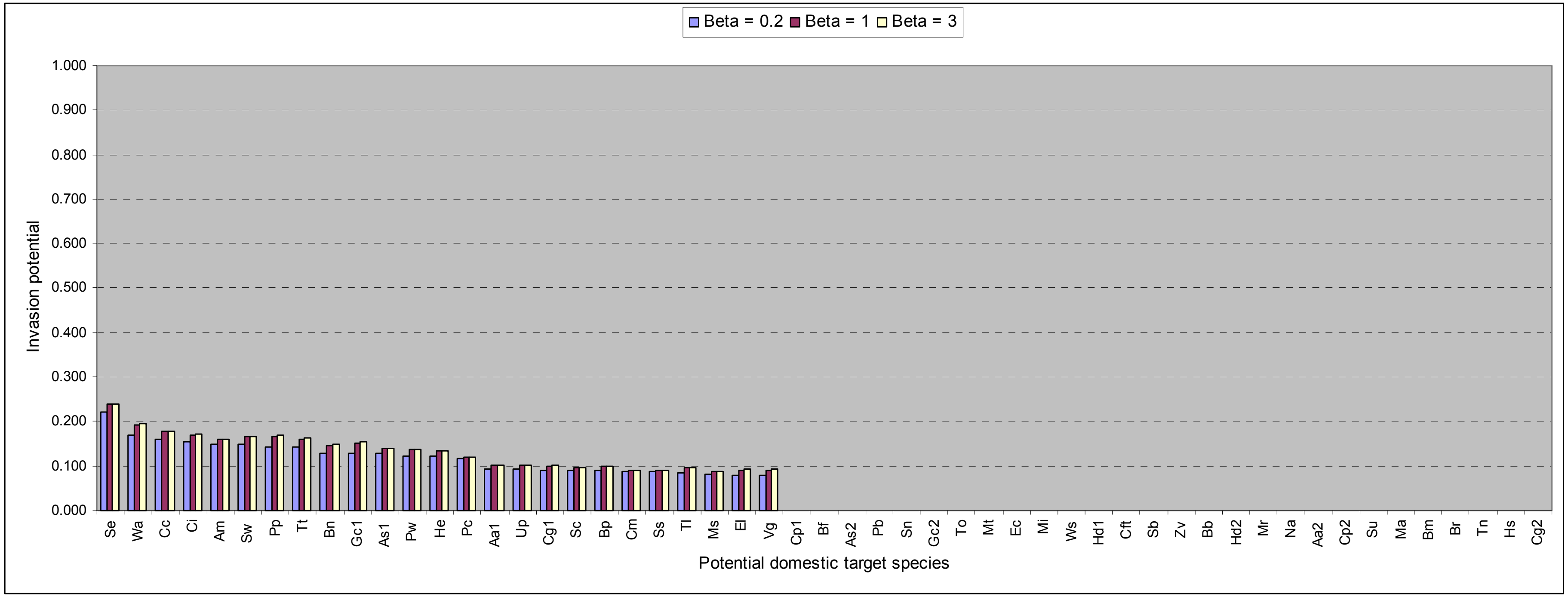


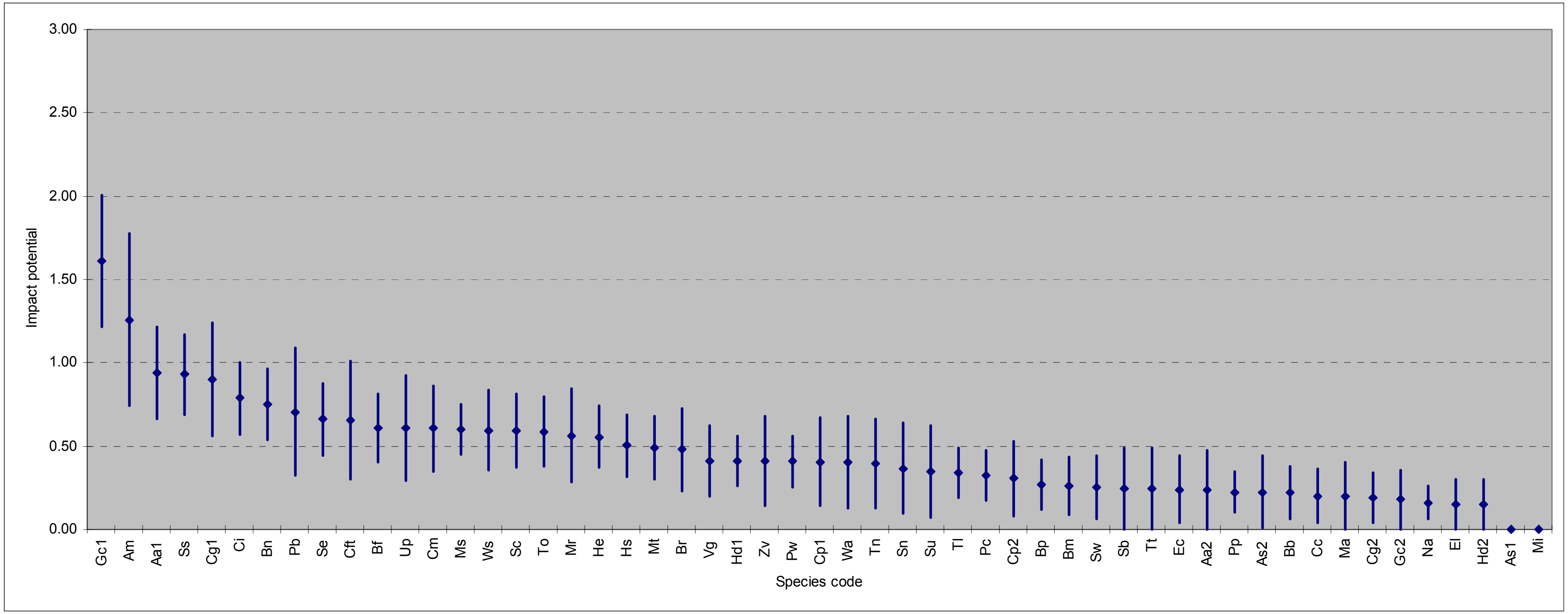
Table 11 Impact questionnaire results for the potential domestic target species

Code	n*	Min Himp†	Max Himp	Mid Himp	Min Mimp‡	Max Mimp	Mid Mimp	Min Eimp**	Max Eimp	Mid Eimp
Am	3	0.50	0.97	0.73	0.12	0.41	0.26	0.13	0.40	0.26
As1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As2	2	0.00	0.10	0.05	0.00	0.18	0.09	0.01	0.16	0.08
Aa2	1	0.00	0.10	0.05	0.00	0.10	0.05	0.00	0.28	0.14
Aa1	6	0.02	0.13	0.08	0.23	0.41	0.32	0.42	0.67	0.55
Br	2	0.00	0.10	0.05	0.17	0.39	0.28	0.06	0.24	0.15
Bb	2	0.00	0.10	0.05	0.02	0.13	0.08	0.04	0.15	0.10
Bp	2	0.00	0.10	0.05	0.08	0.18	0.13	0.04	0.14	0.09
Bm	1	0.00	0.10	0.05	0.06	0.20	0.13	0.03	0.14	0.08
Bf	3	0.03	0.13	0.08	0.19	0.33	0.26	0.18	0.35	0.27
Bn	3	0.03	0.13	0.08	0.26	0.41	0.33	0.24	0.42	0.33
Cm	5	0.00	0.12	0.06	0.08	0.22	0.15	0.27	0.52	0.39
Cg2	1	0.00	0.10	0.05	0.00	0.10	0.05	0.04	0.14	0.09
Ci	3	0.03	0.13	0.08	0.28	0.46	0.37	0.26	0.41	0.34
Cp1	4	0.00	0.10	0.05	0.07	0.29	0.18	0.08	0.28	0.18
Cft	4	0.00	0.10	0.05	0.16	0.48	0.32	0.14	0.43	0.28
Cc	1	0.00	0.10	0.05	0.04	0.16	0.10	0.00	0.10	0.05
Cg1	4	0.15	0.33	0.24	0.21	0.47	0.34	0.20	0.45	0.32
Cp2	2	0.00	0.10	0.05	0.03	0.18	0.11	0.05	0.25	0.15
Ec	2	0.00	0.10	0.05	0.03	0.20	0.12	0.01	0.14	0.08
El	1	0.00	0.10	0.05	0.00	0.10	0.05	0.00	0.10	0.05
Gc1	3	0.73	1.00	0.87	0.23	0.40	0.31	0.25	0.60	0.43
Gc2	1	0.00	0.10	0.05	0.00	0.12	0.06	0.00	0.14	0.07
Hd1	1	0.00	0.10	0.05	0.16	0.26	0.21	0.10	0.20	0.15
Hd2	1	0.00	0.10	0.05	0.00	0.10	0.05	0.00	0.10	0.05
He	3	0.03	0.13	0.08	0.21	0.34	0.28	0.13	0.27	0.20
Hs	3	0.03	0.13	0.08	0.18	0.31	0.24	0.10	0.25	0.18
Mr	2	0.00	0.10	0.05	0.25	0.50	0.38	0.03	0.24	0.14
Mt	2	0.00	0.10	0.05	0.27	0.50	0.39	0.03	0.08	0.06
Ma	1	0.00	0.10	0.05	0.00	0.10	0.05	0.00	0.20	0.10
Mi	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ms	1	0.00	0.10	0.05	0.20	0.30	0.25	0.25	0.35	0.30
Na	2	0.00	0.10	0.05	0.03	0.08	0.06	0.03	0.08	0.06
Pc	2	0.10	0.20	0.15	0.01	0.11	0.06	0.06	0.16	0.11
Pw	3	0.10	0.20	0.15	0.07	0.18	0.12	0.08	0.18	0.13
Pb	1	0.00	0.10	0.05	0.16	0.50	0.33	0.16	0.49	0.33
Pp	3	0.07	0.13	0.10	0.01	0.12	0.07	0.03	0.09	0.06
Ss	6	0.03	0.13	0.08	0.30	0.48	0.39	0.35	0.55	0.45
Se	3	0.03	0.13	0.08	0.22	0.39	0.30	0.19	0.36	0.28
Su	2	0.00	0.10	0.05	0.03	0.24	0.14	0.04	0.28	0.16
Sn	2	0.00	0.10	0.05	0.05	0.30	0.18	0.04	0.24	0.14
Sb	1	0.00	0.10	0.05	0.00	0.18	0.09	0.00	0.21	0.11
Sw	1	0.00	0.10	0.05	0.04	0.22	0.13	0.02	0.12	0.07
Sc	4	0.03	0.13	0.08	0.18	0.34	0.26	0.17	0.35	0.26
Tn	2	0.00	0.15	0.08	0.11	0.38	0.25	0.01	0.13	0.07
Tl	1	0.00	0.10	0.05	0.00	0.10	0.05	0.19	0.29	0.24
To	3	0.03	0.13	0.08	0.19	0.35	0.27	0.15	0.32	0.23
Tt	2	0.00	0.10	0.05	0.00	0.12	0.06	0.00	0.27	0.13
Up	5	0.02	0.12	0.07	0.17	0.46	0.31	0.10	0.35	0.22
Vg	2	0.00	0.10	0.05	0.05	0.18	0.12	0.15	0.34	0.25
Wa	3	0.00	0.10	0.05	0.07	0.31	0.19	0.05	0.26	0.16
Ws	4	0.03	0.13	0.08	0.18	0.39	0.29	0.14	0.32	0.23
Zv	3	0.00	0.10	0.05	0.09	0.33	0.21	0.05	0.25	0.15

*The number of questionnaire returns collected; †Human health impacts; ‡Economic impacts

**Environmental impacts

Figure 6 Summed impact potential (human, economic and environmental) of the potential domestic target species



The interval associated with each species represents the assessor(s) uncertainty about the species' actual impact. The impact interval of *Undaria pinnatifida* and *Carcinus maenas* extend beyond that of *Bugula neritina* and *Schizoporella errata* such that *U. pinnatifida* and *C. maenas* would be ranked ninth and tenth respectively if the ranking were performed on the maximum (rather than the mid) impact score. Furthermore management authorities may wish to isolate all species which have potential human health impact and elevate the status of these species. If this was the case authorities may wish to examine the case for *Pseudopolydora paucibranchiata*, *Polydora websteri, Polydora cornuta* and *Crassostrea gigas* in more detail.

Unfortunately we are unable to rank the impact of the two species for which we do not have questionnaire returns *(Alitta succinea* and *Monocorophium insidiosum)*. It is possible that these species may have a greater impact than the top ten listed here. At present, however, we do not have any information that suggests these species have particularly high impacts.

Hazard analysis

The overall hazard analysis is completed by plotting the position of each species in invasion potential/impact potential space. Figure 7a plots the invasion potential (for all bioregions) against the impact potential for the 53 potential domestic target species identified in this analysis. Figure 7b focuses on the bottom-left quadrat of Figure 7a. Those species without impact data (*Alitta succinea* and *Monocorophium insidiosum*) are shown as having no impact potential, but as discussed above, this is not a real effect. Figure 8a plots the invasion potential of the domestic target species (for uninfected bioregions) against the impact potential of these species. Again species without impact data are shown as having no impact. Figure 8b focuses on the bottom left quadrat of Figure 8a in order to improve the discrimination between species. In the absence of active eradication programs, hazard ranking should be based on invasion potential from infected to uninfected bioregions (i.e. Figure 8a and 8b).

With this approach all the potential domestic target species cluster in the bottom left quadrat of the hazard space (Figure 8b). It is important to note, however, that this is not an absolute measure of risk but rather a relative measure of hazard. Priority species must therefore be identified relative to each other – i.e. from their relative location in hazard space. The tight clustering of the species makes this process difficult but an examination of Figure 8a and Figure 8b suggests the following three groups:

4. High priority: *Gymnodinium catenatum* and *Alexandrium minutum* – both of these species have reasonably high invasion potential and their impact potential is the highest of all the potential domestic target species;

5. Medium-high priority: *Sabella spallanzanii, Asterias amurensis, Crassostrea gigas, Bugula neritina, Ciona intestinalis, Schizoporella errata, Codium fragile tomentosoides, Polysiphonia brodiaei, Hydroides ezoensis, Watersipora arcuata, Undaria pinnatifida, Styela clava, Musculista senhousia* and *Carcinus maenas* – these species have a reasonably high impact and/or invasion potential.

6. Medium-low priority; *Polydora websteri, Varicorbula gibba, Theora lubrica, Polydora cornuta, Boccardia proboscidea, Euchone limnicola, Sphaeroma walkeri, Tridentiger trigonocephalus, Pseudopolydora paucibranchiata, Cordylophora caspia, Bugula flabellata, Watersipora subtorquata, Tricellaria occidentalis* and *Megabalanus rosa* – these species have a medium impact or medium invasion potential relative to the other domestic NIS identified here.

It is important to note that this ranking would most likely change if the invasion potential analysis included the movements of small recreational and commercial vessels. As stated earlier, this information is unavailable. The hull fouling potential (coupled with the large number) of these vessels would undoubtedly have an influence on the relative ranking of potential domestic target species.

Figure 7a Hazard analysis for potential domestic target species (all bioregions)

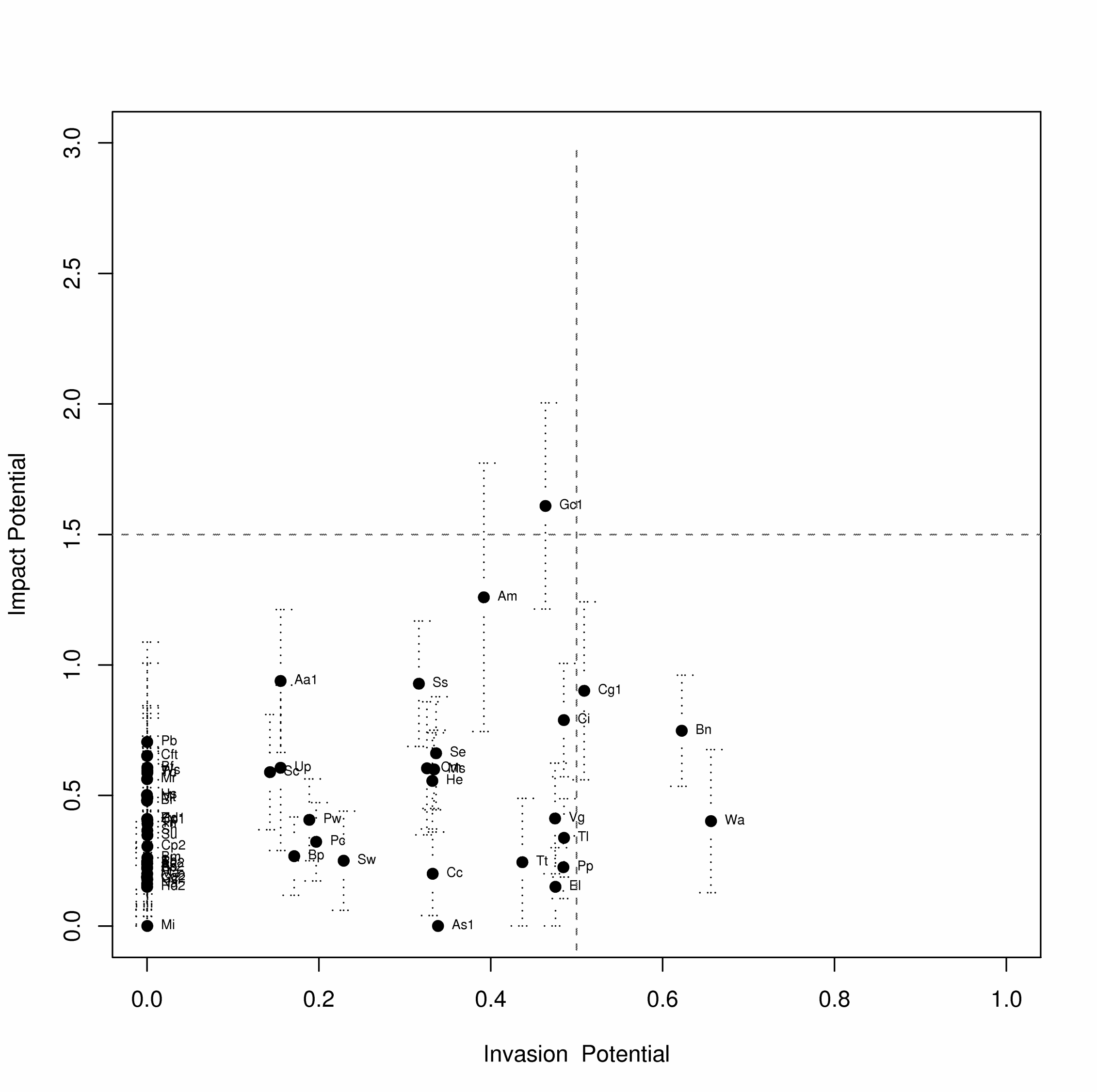


Figure 7b Bottom left quadrat of Figure 7a

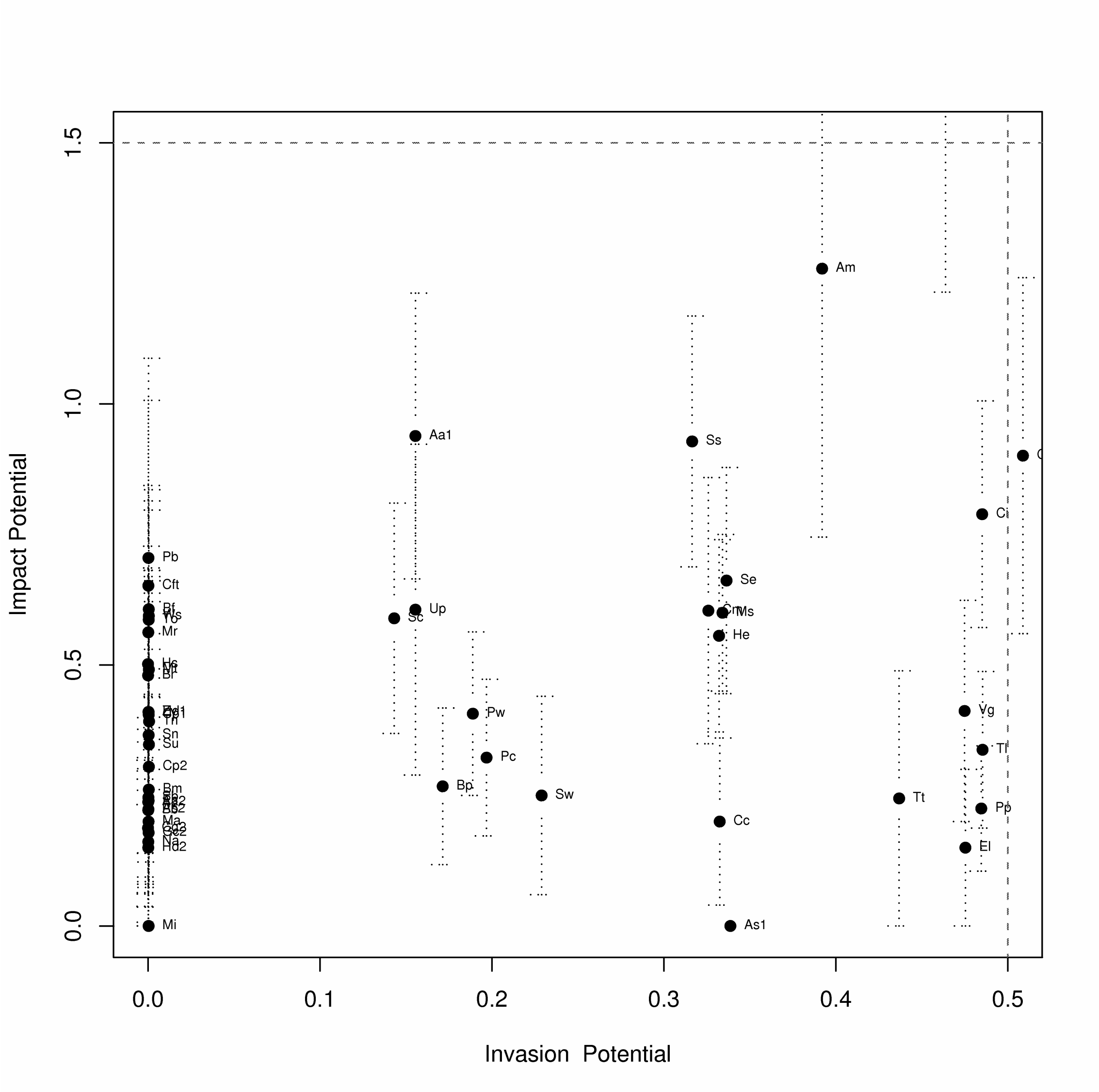


Figure 8a Hazard analysis for potential domestic target species (uninfected bioregions)

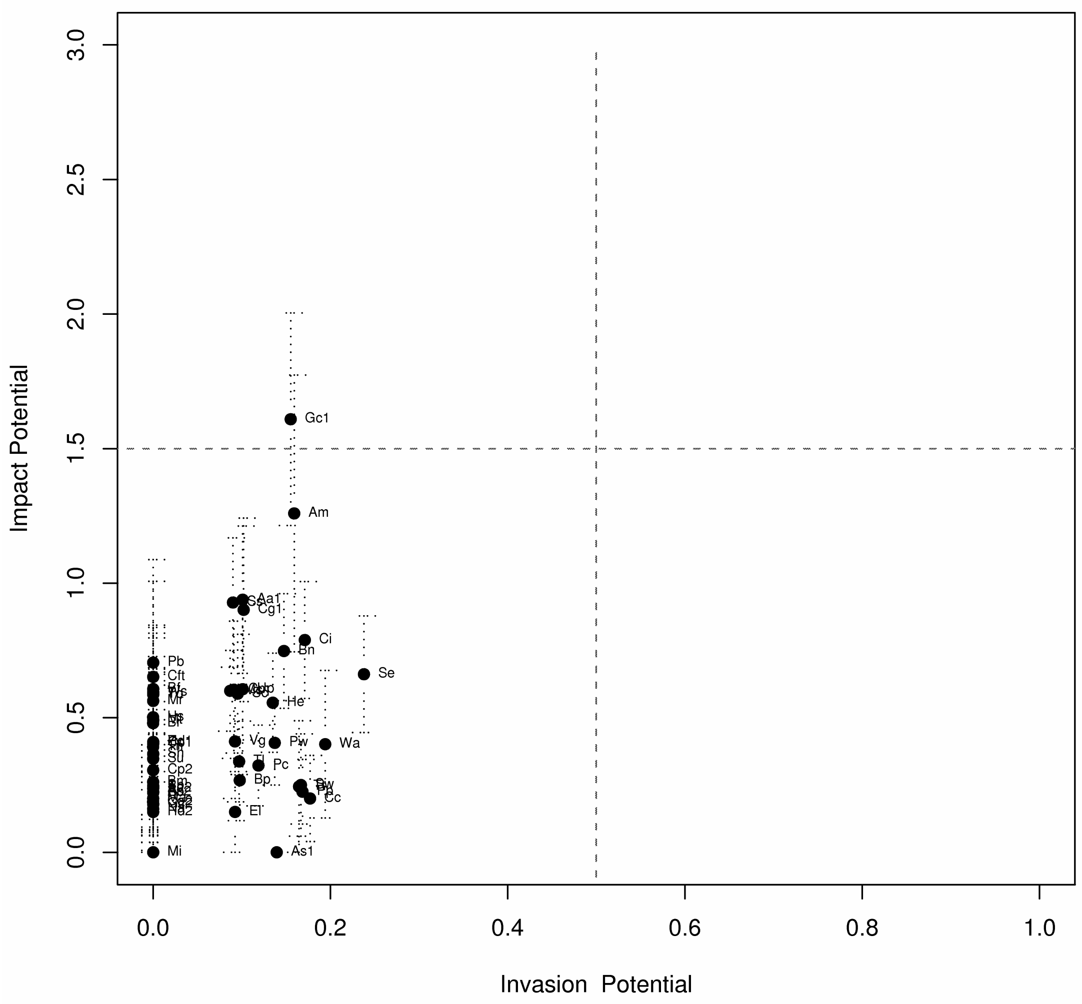
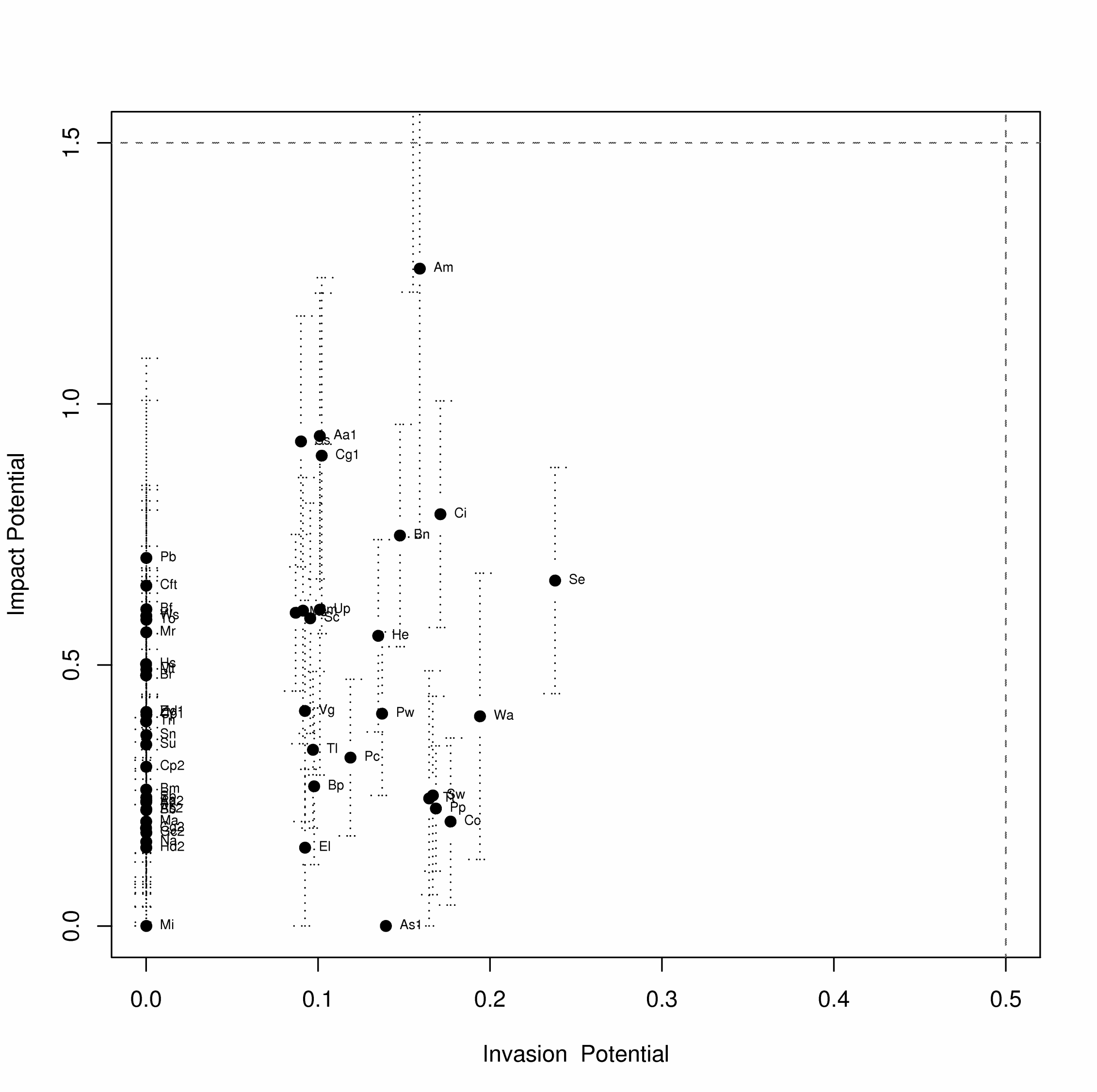


Figure 8b Bottom left quadrat of Figure 8a



4.4 International list

The CMR database contains more than one thousand species that are either known to be absent from Australian waters or whose establishment status is unknown (Table 1). These international species were filtered using the same selection criteria developed for the first next pest project (section 3.4). Table 12 lists those species that satisfy all of the selection criteria. This table represent an updated list of potential “next pests” that may threaten human health, economic interests or the environment if they became established in Australian coastal waters.

There are 36 species in the updated “next pest” list. Most of the species (72%) on the updated list appeared on the original “next pest” list (Hayes and Sliwa, 2003). There are 10 new species on the updated list, of which five were previously listed as “target species” by either the Australian Introduced Marine Pest Advisory Committee (AIMPAC) in 2001, the Joint Standing Committee on Conservation and Standing Committee on Fisheries and Aquaculture (Joint SCC/SCFA) in 1999, or the Australian Ballast Water Management Advisory Council (ABWMAC) in 1994. All previous species lists have been consolidated in this project, and these listed species satisfied the selection criteria and have therefore been added to the “next pest” list (see Table 12). Previously listed species have been identified as potential pests for a number of years and are therefore not discussed further here. The remaining six species are new additions to the “next pest” list and each is discussed briefly below.

Acartia tonsa is a copepod, typically found in brackish/euryhaline waters, and distributed through the water column from the surface down to 200 metres. It originates from North America (Jansson, 1994). The species is primarily dispersed through aquaculture, but has been recorded in ballast water (Carlton, 1985; Leppakoski, 1994). Recorded impacts for this species include the alteration of trophic interactions and food-webs; limiting resources of native species through competition and the predation of native species (Occhipinti Ambrogi, 2002).

Alexandrium monilatum is toxic dinoflagellate native to the coastal and estuarine areas of the Gulf of Mexico, the Caribbean Sea, and the Atlantic Ocean off Florida, Chesapeake Bay, and Ecuador (Zaitsev and Ozturk, 2001). From the 1950s to the end of the 1970s, this species was responsible for numerous fish kills near Florida (Steidinger *et al.*, 1998). The toxins produced by *A. monilatum* bioaccumulate in zooplankton, shellfish and crabs - consumption of contaminated organisms can result in paralytic shellfish poisoning (PSP) in humans.

Balanus improvisus is a barnacle native to the northwest Atlantic (Cranfield *et al.*, 1998) that can dominate brackish water and is commonly found in estuaries (Kawahara, 1963; Furman and Yule, 1991; Cohen and Carlton, 1995). This nuisance fouler has been found on oyster and mussel shells and has also had detrimental effects on cooling water circuits of factories in Japan. Likely vectors of dispersal include hull fouling and accidental introduction with deliberate translocations of shellfish (Kawahara, 1963; Cohen and Carlton, 1995). *B. improvisus* was reported by Bishop (1951) in Western Australia during the 1940s, however this could not be confirmed and there are no further records of this species occurring in Australian waters. It has been widely introduced with invasion histories in the west coast of North America (Cohen and Carlton, 1995; Ruiz *et al.*, 2000), Caspian Sea, Black Sea, Azov Sea (Grigorovich *et al.*, 2002), northeast Atlantic (Furman and Yule, 1991; Gollasch and Leppakoski, 1999; Pigeot *et al.*, 2000), Baltic Sea (Gollasch and Leppakoski, 1999; Leppakoski *et al.*, 2002) and Japan (Kawahara, 1963).

Beroe ovata is a ctenophore, thought to be native to the North and South American Atlantic, and also the Mediterranean. It has been introduced into the Ponto-Caspian region – i.e. the Black Sea, the Sea of Azov and the Caspian Sea (Zaitsev and Ozturk, 2001). This species is an efficient predator of native species of ctenophore, and also *Mnemiopsis leidyi* which has also been introduced to these regions.

Table 12 Updated "next pest" list

Code	Science Name	Common Name	Count†	Comment
At	Acartia tonsa	Calanoid copepod	4	New species
Am	Alexandrium monilatum	Dinoflagellate	3	New species
Aa	Ampelisca abdita	Amphipod	1	Existing NPL species
Be	Balanus eburneus	Ivory Barnacle	1	Existing NPL species
Bi	Balanus improvisus	Barnacle	13	New species
Bo	Beroe ovata	Ctenophore	5	New species
Bv	Blackfordia virginica	Black sea jelly fish	2	Existing NPL species
Bh	Bonnemaisonia hamifera	Red macroalgae	1	New species
Cs	Callinectes sapidus	Blue crab	10	Existing NPL species
Cc1	Chaetoceros concavicornis	Diatom (centric)	1	Existing NPL species
Cc2	Chaetoceros convolutus	Diatom (centric)	1	Existing NPL species
Cj	Charybdis japonica	Lady crab	2	Existing NPL species
Cf	Crepidula fornicata	Slipper limpet	12	Existing NPL species
Dn	Dinophysis norvegica	Dinoflagellate	1	Existing NPL species
Ed	Ensis directus	Razor clam	4	Existing NPL species
Es	Eriocheir sinensis	Chinese mitten crab	6	Previously listed species
Gd	Grateloupia doryphora	Red macroalgae	2	Existing NPL species
Hs	Hemigrapsus sanguineus	Japanese shore crab	1	Existing NPL species
Hd	Hydroides dianthus	Serpulid tubeworm	6	Existing NPL species
Lf	Limnoperna fortunei	Golden mussel	2	Existing NPL species
Lr	Liza ramada	Thin lip mullet	1	Existing NPL species
Ml	Mnemiopsis leidyi	Comb jelly	3	Previously listed species
Ma	Mya arenaria	Soft-shell clam	16	Existing NPL species
Ms	Mytilopsis sallei	Black striped mussel	2	Previously listed species
Nm	Neogobius melanostomus	Round goby	2	Existing NPL species
Pp1	Perna perna	S. African brown mussel	3	Existing NPL species
Pv	Perna viridis	Asian green mussel	8	Existing NPL species
Pp2	Petricolaria pholadiformis	False angelwing	5	Existing NPL species
Pa	Potamocorbula amurensis	Brackish-water corbula	1	Previously listed species
Pm	Pseudodiaptomus marinus	Calanoid copepod	3	Existing NPL species
Pns	Pseudo-nitzschia seriata	Diatom (pennate)	1	Existing NPL species
Rt	Rapana thomasiana	Rapa whelk	8	Previously listed species
Sr	Siganus rivulatus	Rabbit fish	1	Existing NPL species
Sp	Siphonaria pectinata	Striped false limpet	1	New species
Td	Tortanus dextrilobatus	Calanoid copepod	1	Existing NPL species
Tb	Tridentiger bifasciatus	Shimofuri Goby	1	Existing NPL species
Ws	Womersleyella setacea	Red macroalgae	1	Existing NPL species

†Number of separate invasion records in the CMR database

Bonnemaisonia hamifera is a red macroalgae native to Japanese waters. It has invaded all areas of Europe, and is well established. The species has a rapid growth rate, wide physiological tolerances and an ability to survive under a wide range of environmental conditions (Maggs and Stegenga, 1999). The species is also able to spread rapidly by vegetative reproduction and has aspect dominance characteristics, smothering native fauna and flora.

The native Eastern Atlantic gastropod *Siphonaria pectinata* is found in the warmer parts of the Western Mediterranean, Alboran Sea and Algeria. It has been introduced to the NW Atlantic in the 19th century or earlier and is found from Florida to Mexico, Caribbean Cuba, and northern South America (Carlton, 1992). In southern Florida this species has been thought responsible for contributing to the erosion of rock surfaces on beaches (Craig *et al.*, 1969).

During the course of this project we re-evaluated all of the species on the next pest list and removed the following five species from the original list: *Limulus polyphemus*, *Maeotias marginata*, *Marenzelleria cf. viridis*, *Nippoleucon hinumensis*, and *Pagrus major*. *Limulus polyphemus* has been removed because it has not become established in any of its introduced areas and does not therefore have any demonstrable impacts in its invaded range. *Maeotias marginata* and *Nippoleucon hinumensis* have been removed because we have been unable to confirm that the impacts recorded for these species have occurred in either their native or invaded range. Furthermore the impact questionnaire that was completed for *M. marginata* notes that there is virtually no ecological data on this species suggesting that it does not have a high profile in either its invaded or native range. *Marenzelleria cf. viridis* was removed from the database along with all other cf. species due to the uncertainty surrounding the identification of the species. *Pagrus major* was removed because we have subsequently discovered that it does not have a ballast mediated invasion history.

The status of 2 other species on the original next pest list: *Hemigrapsus penicillatus* and *Rhithropanopeus harrisii* is also questionable at this time. Both of these crabs are generalist predators that clearly have the potential to predate and out-compete native species. We have, however, been unable to confirm these impacts in the native or invaded range of these species. Beaulne (1997) notes that the benefits and/or losses to humans caused by *H. penicillatus* have yet to be established. We have provisionally removed the species from the list in light of this uncertainty but have retained them in the CMR database as a “watching brief” along with *Maeotias marginata* and *Nippoleucon hinumensis*.

4.5 International hazard analysis

Invasion potential

Lloyds Maritime Information Unit (LMIU) records 9,165 vessels arriving in Australia with an international last port of call. We define these vessels as international ship arrivals. Table 13 summarises international ship arrivals into Australia in 2002. The arrivals data are aggregated by donor International Union for the Conservation of Nature (IUCN) bioregion. Table 13 also includes the vessel count and weighted vessel and ballast scores (equation [2]). Vessel counts are plotted by IUCN bioregion in Figure 9.

In addition to the commercial vessels discussed above, Australia also received 601 recreational yachts whose last port of call was an international port. By and large the contribution of recreational yachts from any one bioregion is negligible compared to commercial vessels. This is not true, however, for SP-IV. Very few commercial vessels originate from this IUCN bioregion whereas the last port of call for more than one third of recreational vessels lies within SP-IV (Figure 9). This has important implications for the international hazard analysis because SP-IV lies within the distributional range of *Perna viridis*.

In 2002 Australia traded with, or had ship visits from, 71 IUCN bioregions. The balance of this trade, however, is highly skewed – more than 85% of international ship arrivals originate from just ten bioregions (in descending order): NWP-3b; EAS-VI; NWP-3a; NZ-IV; NWP-2; NWP-4a; EAS-II; EAS-I; SP-I; and, NWP-4b (Table 13 and Figure 10). The invasion potential of marine pests from around the world is critically determined by their distribution relative to these Australian trading patterns. The environmental similarity between the donor and recipient ports, measured in terms of latitudinal difference, has a relatively marked effect on their invasion potential (as compared to the invasion potential of domestic target species).

Figure 11 plots the invasion potential of the 36 potential "next pests" identified in this analysis using equation [2] in section 3.4. The ten most likely invaders using the most conservative environmental similarity index (i.e. when $\beta = 3.0$) are: *Perna viridis, Mytilopsis sallei, Hemigrapsus sanguineus, Tridentiger bifasciatus, Limnoperna fortunei, Charybdis japonica, Pseudodiaptomus marinus, Balanus eburneus, Potamocorbula amurensis* and *Balanus improvisus*. When $\beta = 0.2$, however, the species rank for invasion potential changes to (in descending order): *Hemigrapsus sanguineus, Tridentiger trigonocephalus, Perna viridis, Limnoperna fortunei, Charybdis japonica, Mytilopsis sallei, Pseudodiaptomus marinus, Balanus eburneus, Potamocorbula amurensis* and *Eriocheir sinensis*. When $\beta = 1.0$, *Perna viridis* moves rank to first, and *Mytilopsis sallei* moves to fourth. *Eriocheir sinensis* is not ranked within the ten species with relation to invasion potential, when $\beta = 1.0$ or 3.0.

Impact potential

The first project collected 34 questionnaire returns on impacts of potential next pests. In this analysis we collected 60 questionnaire returns, covering 29 of the 36 potential next pest species. In the majority of cases (22 out of 29) there are at least two questionnaire returns for each species. There are seven species that have not had a questionnaire completed. They are: *Acartia tonsa*, *Balanus improvisus*, *Liza ramada*, *Siphonaria pectinata, Rapana thomasiana, Bonnemaisonia hamifera* and *Alexandrium monilatum*.

Table 14 lists the results of the impact questionnaire completed by experts from around the world, including information on the number of returns for each species (*n*) and the human health, economic and environmental impact scores generated by the interval analysis outlined in section 3.4. The overall impact potential, expressed as the simple sum of the intervals for human, economic and environmental impacts shown in Table 14 are plotted in Figure 12. The ten potentially most damaging species, based on the data collected in both the first and second project, are *Eriocheir sinensis, Pseudo-nitzschia seriata, Potamocorbula amurensis, Neogobius melanostomus, Perna viridis, Petricolaria pholadiformis, Dinophysis norvegica, Blackfordia virginica, Perna perna* and *Charybdis japonica*.

The impact interval of *Siganus rivulatus* extends beyond that of *Charybdis japonica* such that it may be the tenth most damaging species (see Figure 12). The interval associated with each species represents the assessor(s) uncertainty about the species' actual impact – often this uncertainty is associated with the size of the invasive population, for example the significance of the impact is proportional to the size of the population. In this instance the size of the *S. rivulatus* interval indicates that the assessors were sufficiently uncertain about the significance of its impacts to alter its overall impact rank. Similar uncertainty is prominent in *Pseudo-nitzschia seriata* and *Dinophysis norvegica*.

Unfortunately we are unable to rank the impact potential of the seven species for which we have no questionnaire returns. It is important to note that these species may have a greater impact potential then the top ten listed here. *Alexandrium monilatum*, for example, may cause Paralytic Shellfish Poisoning in humans (section 4.3) and would therefore score highly in this analysis if we were able to include it.

Table 13 Weighted vessel visits and ballast water discharge in 2002 by IUCN bioregion using LMIU data

dBioRegRef	dBioRegName	Count	VScore1†	VScore2	VScore3	BScore1‡	BScore2	BScore3	AvJD*	SDJD**
197	NWP-3b	1560	110	243	269	3314445	7705524	8674057	13.6	9.0
181	EAS-VI	1324	91	261	341	866842	2548140	3320604	11.4	16.6
251	NWP-3a	907	97	212	234	2836368	6416290	7115501	14.4	7.2
257	NZ-IV	842	156	324	351	223678	473431	521118	4.9	4.1
199	NWP-2	756	89	197	217	1980964	3938798	4155320	12.2	12.8
198	NWP-4a	431	46	112	129	1459184	3603785	4160212	16.7	8.9
177	EAS-II	361	61	175	223	289400	880823	1160623	10.5	20.1
176	EAS-I	284	35	85	99	295403	742644	874023	13.4	6.9
235	SP-I	273	58	134	150	38538	99384	117760	6.5	16.9
196	NWP-4b	243	24	53	60	574995	1371899	1577409	15.7	9.5
237	SP-IV	235	105	222	235	0	0	0	no data	no data
178	EAS-III	131	32	76	88	116985	296247	356946	12.0	7.3
149	WA-V	122	13	27	29	69075	120105	123103	16.5	12.0
238	SP-V	107	39	85	93	2268	6388	7815	5.5	4.4
223	NZ-VI	104	10	26	30	56167	146277	172461	5.2	2.3
160	RS-3	102	7	14	15	28714	63865	70189	19.4	11.0
183	EAS-VIII	67	27	56	59	13326	28657	30864	9.8	7.4
241	SP-VII	65	11	26	30	14896	36700	41599	7.4	3.6
182	EAS-VII	62	22	50	56	47751	135755	167873	14.2	21.5
187	NEP-III	50	4	10	13	84375	246016	308389	32.5	11.5
190	NEP-VI	47	3	6	6	10305	19076	20133	23.0	8.5
170	AG-5	44	4	11	12	32738	80246	89679	19.4	6.2
168	AG-3	38	4	9	10	45795	101559	109083	18.1	4.0
239	SP-III	36	11	27	30	516	1343	1595	16.3	15.2
311	ISSG	30	1	4	4	3137	8138	9352	11.3	10.4

†Sum of all ship visits to Australia from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

‡Sum of ballast water discharge (tonnes) from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

*Average journey duration

**Standard deviation of journey duration

Table 13 cont…

dBioRegRef	dBioRegName	Count	VScore1[†]	VScore2	VScore3	BScore1[‡]	BScore2	BScore3	AvJD*	SDJD**
247	SP-XVI	25	1	4	5	2462	6455	7518	13.8	4.5
161	RS-2	23	6	17	19	21031	55890	65156	25.8	2.6
236	SP-II	22	3	8	11	2612	8151	10802	6.0	6.1
103	NEA-V	16	0	1	1	681	1389	1471	23.4	5.9
165	IP-1	15	1	3	4	10987	28266	32480	20.7	13.9
148	WA-IV	14	8	13	13	214	716	1024	23.0	na
154	CIO-I	14	3	6	6	33016	72081	77838	26.9	24.6
229	SEP-C	14	1	3	3	3447	8363	10064	29.7	11.6
155	CIO-II	13	2	4	4	38361	74625	77718	19.2	14.3
145	WA-I	12	2	4	4	20106	43390	45987	58.8	62.9
314	ARCH	12	6	9	10	1419	2147	2164	5.0	0.0
245	SP-IX	10	1	4	4	3438	10719	14180	12.3	5.3
156	CIO-III	9	1	1	1	8824	15761	16182	16.4	10.6
179	EAS-IV	7	0	1	2	1860	5189	6479	10.8	5.0
230	SEP-B	7	1	1	1	618	1245	1301	22.7	0.8
126	CAR-I	6	1	3	3	9464	19933	20982	40.3	3.1
233	SP-XII	6	0	0	0	0	0	0	11.0	4.4
150	SA-III	5	1	1	1	40819	56629	57013	54.3	13.8
151	SA-II	5	2	4	4	54981	105949	110356	50.0	na
163	GA	5	1	2	2	130	390	497	13.7	4.5
167	AG-2	5	1	1	1	12242	22024	22519	35.3	12.5
228	SEP-I	5	0	0	0	427	1344	1811	26.2	11.6
258	SP-XXI	5	1	2	2	10864	24421	26249	41.0	33.4
146	WA-II	4	0	1	1	3096	10449	15075	27.0	8.2
174	EA-III	4	0	1	1	140	481	709	24.3	9.2

[†]Sum of all ship visits to Australia from donor bioregion weighted by journey duration and environmental similarity for $\beta = 0.2$ (1); 1 (2) and 3 (3)

[‡]Sum of ballast water discharge (tonnes) from donor bioregion weighted by journey duration and environmental similarity for $\beta = 0.2$ (1); 1 (2) and 3 (3)

*Average journey duration

**Standard deviation of journey duration

Table 13 cont…

dBioRegRef	dBioRegName	Count	VScore1†	VScore2	VScore3	BScore1‡	BScore2	BScore3	AvJD*	SDJD**
319	SPSG	4	1	3	3	5978	8644	8740	3.0	na
112	MED-V	3	1	2	2	1911	3548	3643	5.0	5.7
129	CAR-III	3	1	2	2	10029	19989	20753	38.0	na
105	NEA-II	2	1	2	2	269	849	1135	no data	no data
116	NA-ET3	2	1	1	1	38	84	89	24.0	na
164	OM	2	1	2	2	4862	14030	17294	no data	no data
166	AG-1	2	0	0	0	302	675	724	20.5	7.8
189	NEP-V	2	0	0	0	152	297	307	23.0	9.9
104	NEA-IV	1	0	1	1	0	0	0	no data	no data
106	MED-I	1	0	0	0	41	77	78	11.0	na
108	MED-III	1	0	0	0	1050	2093	2173	6.0	na
109	MED-VII	1	0	0	0	29	52	53	29.0	na
120	NA-S3	1	0	0	0	332	930	1119	45.0	na
147	WA-III	1	0	1	1	17742	50440	61459	no data	no data
162	RS-1	1	0	1	1	177	537	691	no data	no data
180	EAS-V	1	0	1	1	347	1188	1745	no data	no data
214	AUS-XIV	1	1	1	1	0	0	0	no data	no data
255	AR-III	1	0	0	0	14	52	90	120.0	na
271	ANT-FR	1	0	1	1	0	0	0	no data	no data
309	MONS	1	0	1	1	0	0	0	no data	no data
315	WARM	1	0	1	1	207	609	763	no data	no data

†Sum of all ship visits to Australia from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

‡Sum of ballast water discharge (tonnes) from donor bioregion weighted by journey duration and environmental similarity for β = 0.2 (1); 1 (2) and 3 (3)

*Average journey duration

**Standard deviation of journey duration

Figure 9 Commercial and recreational vessel visits to Australia in 2002, aggregated by IUCN bioregion

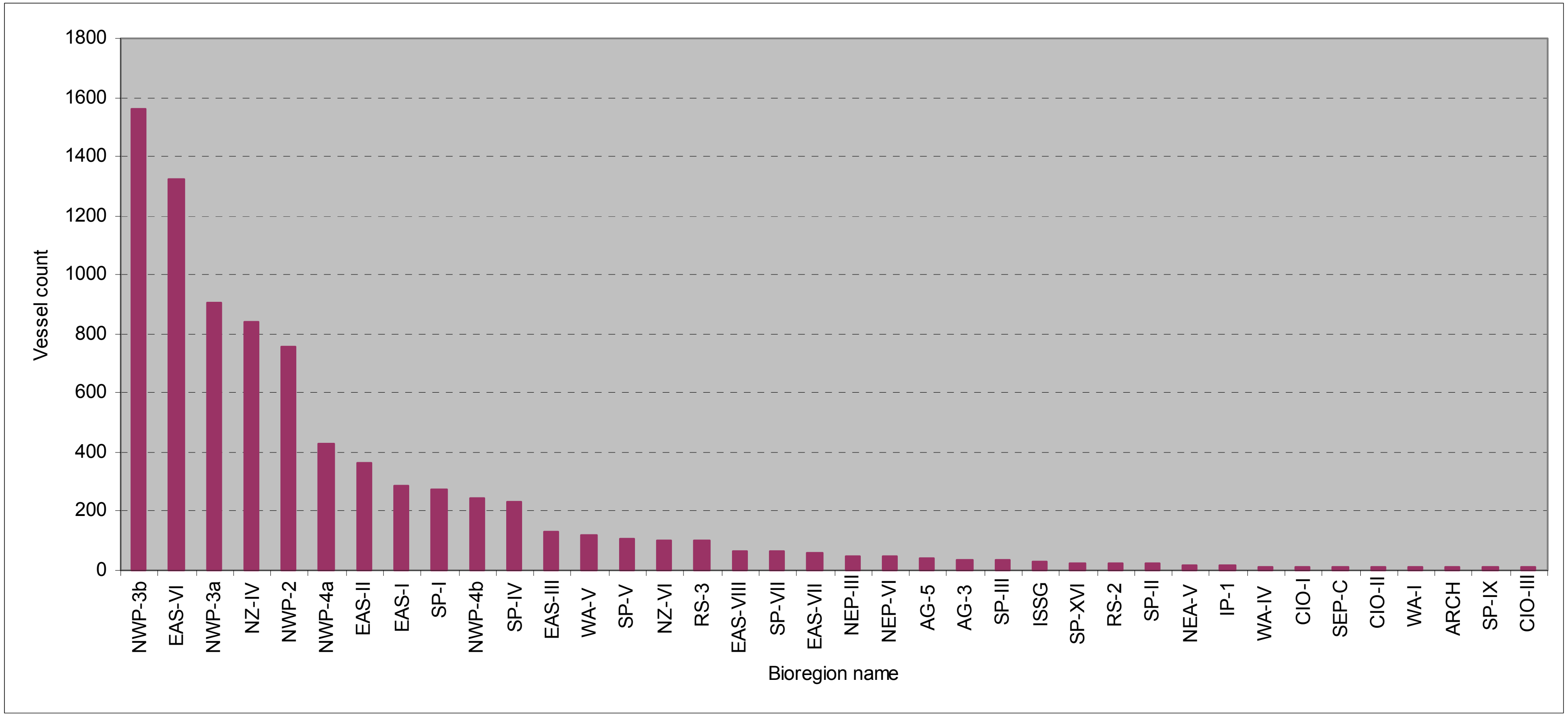
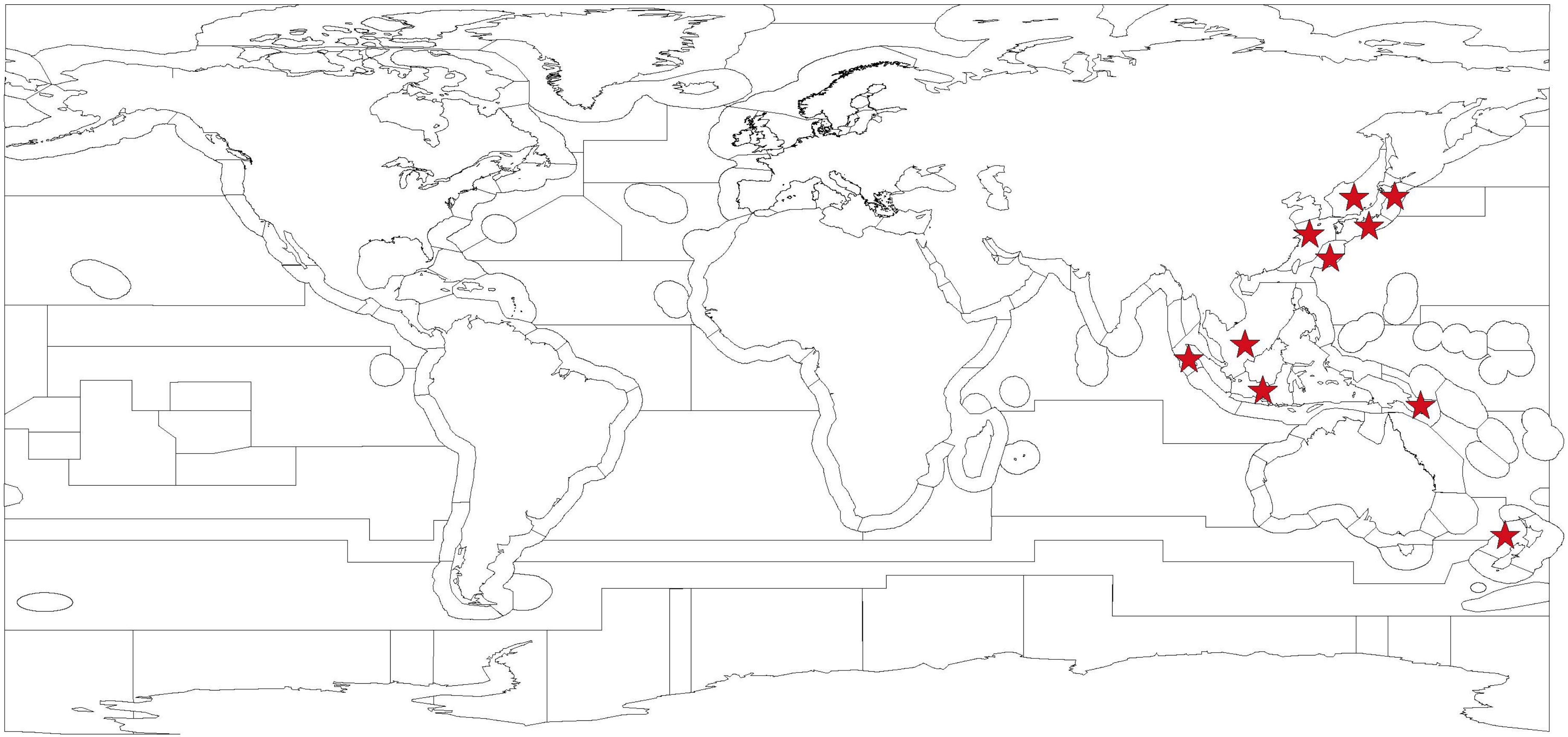


Figure 10 Location of the ten bioregions responsible for 85% of Australia's international shipping traffic



★ Location of NWP-3b; EAS-VI; NWP-3a; NWP-2; NZ-IV; NWP-4a; EAS-I; NWP-4b; SP-I and EAS-II

Figure 11 Invasion potential of the next pest list for three values of the environmental similarity parameter β

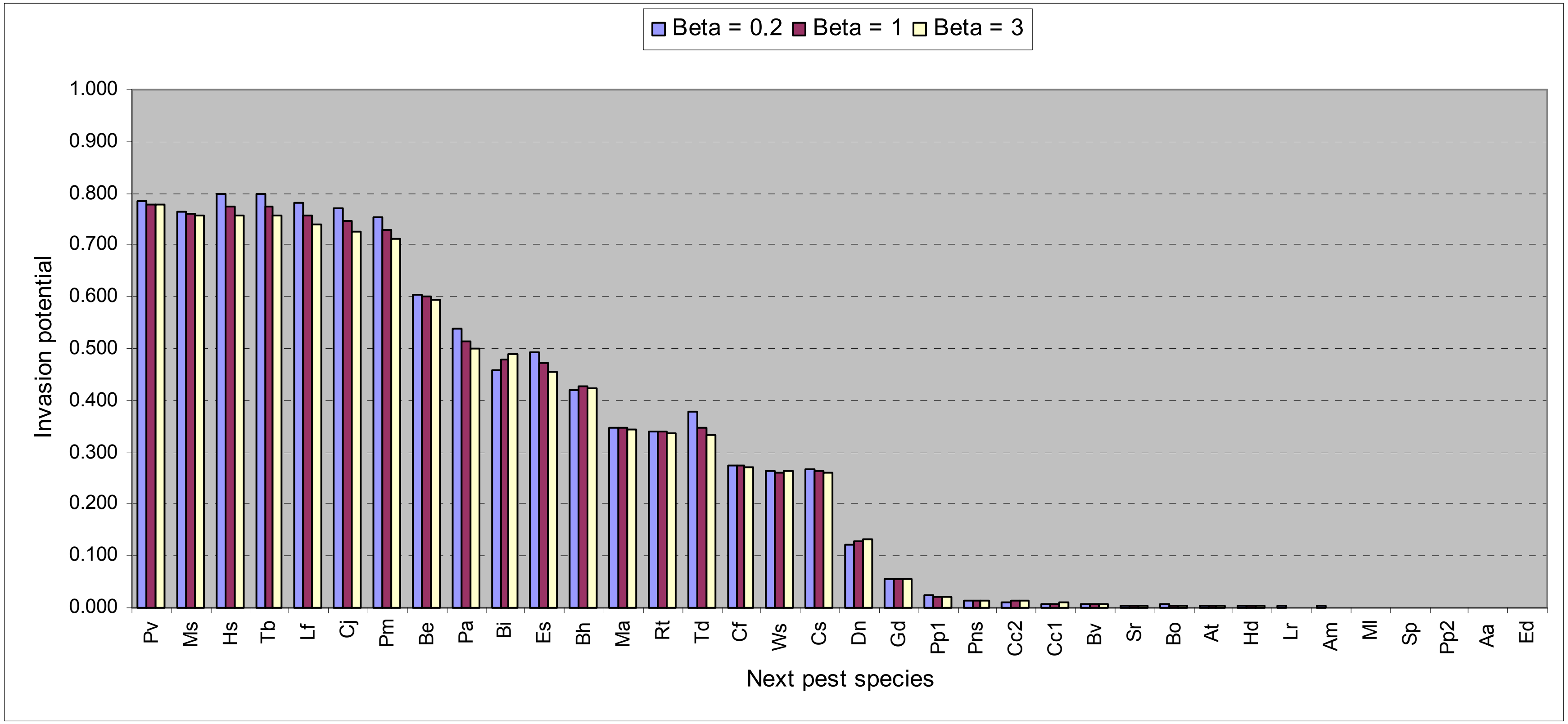


Table 14 Impact questionnaire results for the next pest species (see Table 12 for species codes)

Code	n*	Min Himp†	Max Himp	Mid HImp	Min Mimp‡	Max Mimp	Mid Mimp	Min Eimp**	Max Eimp	Mid Eimp
At	0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Am	0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Aa	1	0.00	0.10	0.05	0.04	0.26	0.15	0.24	0.56	0.40
Be	2	0.00	0.25	0.13	0.02	0.37	0.20	0.00	0.30	0.15
Bi	0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Be	1	0.00	0.10	0.05	0.03	0.27	0.15	0.04	0.34	0.19
Bv	1	0.10	0.30	0.20	0.18	0.52	0.35	0.29	0.71	0.50
Bh	0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Cs	3	0.00	0.10	0.05	0.06	0.19	0.13	0.17	0.30	0.23
Cc1	1	0.00	0.10	0.05	0.06	0.32	0.19	0.05	0.28	0.16
Cc1	1	0.00	0.10	0.05	0.02	0.38	0.20	0.00	0.23	0.11
Cc2	1	0.00	0.10	0.05	0.16	0.36	0.26	0.00	0.23	0.11
Cj	2	0.05	0.25	0.15	0.12	0.37	0.25	0.29	0.54	0.42
Cf	4	0.00	0.10	0.05	0.03	0.19	0.11	0.02	0.23	0.12
Dn	2	0.10	0.60	0.35	0.14	0.72	0.43	0.10	0.65	0.38
Ed	2	0.00	0.20	0.10	0.01	0.27	0.14	0.03	0.31	0.17
Es	2	0.40	0.50	0.45	0.59	0.74	0.67	0.67	0.82	0.74
Gd	3	0.00	0.10	0.05	0.04	0.17	0.11	0.05	0.18	0.12
Hs	2	0.00	0.10	0.05	0.03	0.20	0.12	0.16	0.38	0.27
Hd	3	0.00	0.10	0.05	0.00	0.13	0.07	0.00	0.13	0.07
Lf	3	0.00	0.10	0.05	0.09	0.25	0.17	0.02	0.16	0.09
Lr	0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Ml	2	0.00	0.10	0.05	0.12	0.32	0.22	0.19	0.41	0.30
Ma	4	0.03	0.13	0.08	0.03	0.15	0.09	0.04	0.18	0.11
Ms	1	0.25	0.60	0.43	0.13	0.30	0.22	0.28	0.60	0.44
Nm	2	0.25	0.60	0.43	0.30	0.72	0.51	0.45	0.92	0.68
Pp1	4	0.20	0.33	0.26	0.24	0.40	0.32	0.23	0.39	0.31
Pv	2	0.05	0.45	0.25	0.38	0.87	0.63	0.32	0.78	0.55
Pp2	1	0.10	0.30	0.20	0.34	0.80	0.57	0.36	0.86	0.61
Pa	1	0.20	0.30	0.25	0.38	0.70	0.54	0.68	1.09	0.88
Pm	3	0.00	0.10	0.05	0.00	0.13	0.07	0.01	0.16	0.09
Pns	2	0.20	0.90	0.55	0.25	1.02	0.64	0.21	0.97	0.59
Rt	0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sr	1	0.00	0.20	0.10	0.00	0.30	0.15	0.00	0.76	0.38
Sp	0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Td	2	0.00	0.10	0.05	0.00	0.15	0.08	0.02	0.17	0.09
Tb	1	0.00	0.10	0.05	0.00	0.28	0.14	0.13	0.60	0.36
Ws	1	0.00	0.10	0.05	0.02	0.30	0.16	0.16	0.53	0.34

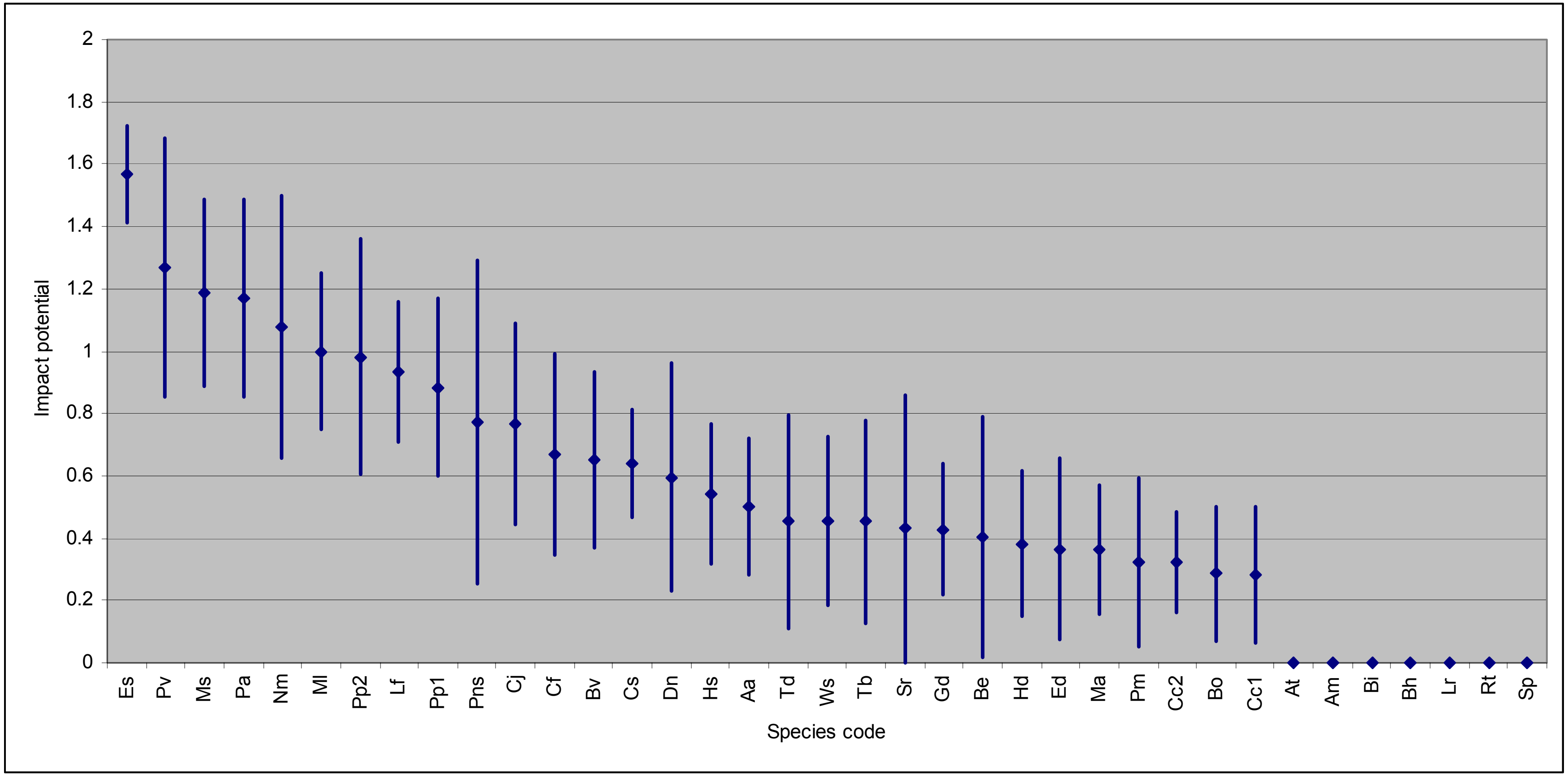
*The number of questionnaire returns collected

†Human health impacts

‡Economic impacts

**Environmental impacts

Figure 12 Summed impact potential (human, economic and environmental) of the next pest listed species



Hazard analysis

The overall hazard analysis is completed by plotting the position of each species in invasion potential/impact potential space. Figure 13 shows this plot for the 36 next pest species identified in this analysis. Species without impact data are shown as having no impact potential, but as discussed above, this is not a real effect. This analysis suggests the following hazard groups:

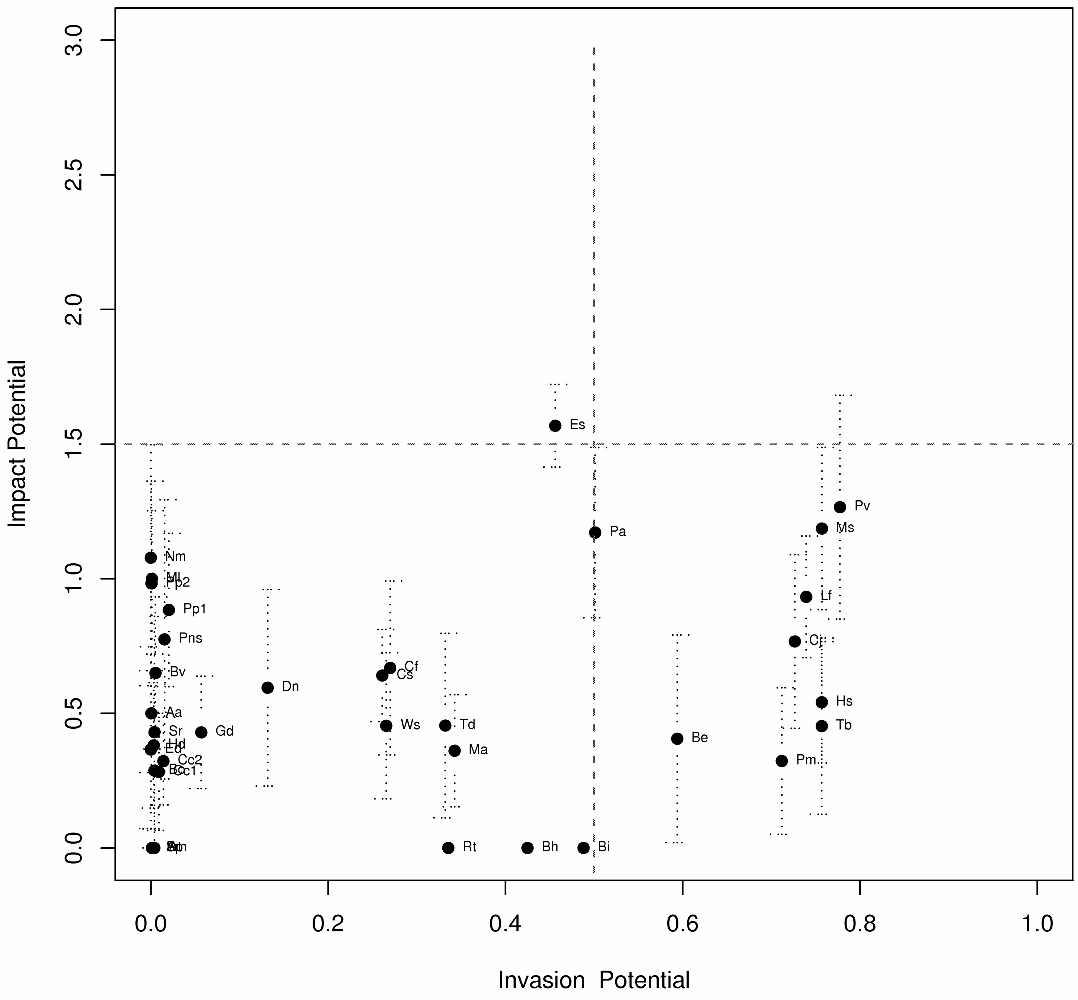
7. High priority*:* only one species - *Perna viridis* - resides in the top right quadrant of the hazard analysis space. This analysis therefore re-affirms the results of the first year of the project, wherein *P. viridis* was identified as the only high priority species.

8. Medium priority*:* species that reside in the top-left or bottom-right quadrants of the hazard analysis space are: *Mytilopsis sallei*, *Limnoperna fortunei, Hemigrapsus sanguineus, Charybdis japonica, Pseudodiaptomus marinus, Balanus eburneus, Tridentiger bifasciatus, Eriocheir sinensis, Neogobius melanostomus* and *Potamocorbula amurensis.*

9. Low priority: species that reside in the bottom left quadrant of the hazard analysis space are: *Acartia tonsa*, *Alexandrium monilatum*, *Ampelisca abdita*, *Balanus improvisus*, *Beroe ovata*, *Blackfordia virginica*, *Bonnemaisonia hamifera*, *Callinectes sapidus*, *Chaetoceros concavicornis*, *Chaetoceros convolutus*, *Crepidula fornicata*, *Dinophysis norvegica*, *Ensis directus*, *Grateloupia doryphora*, *Hydroides dianthus*, *Liza ramada*, *Mnemiopsis leidyi*, *Mya arenaria*, *Perna perna*, *Petricolaria pholadiformis*, *Pseudo-nitzschia seriata*, *Rapana thomasiana*, *Siganus rivulatus*, *Siphonaria pectinata*, *Tortanus dextrilobatus* and *Womersleyella setacea*.

It is important to note that Figure 13 groups human health impacts with economic and environmental impacts without any additional significance weighting. Management authorities may wish to isolate all species which have potential human health impact (mid-impact score > 0.1) and elevate the status of these species. If this were the case management authorities may wish to re-evaluate the following species: *Blackfordia virginica*, *Balanus eburneus*, *Charybdis japonica*, *Dinophysis norvegica*, *Eriocheir sinensis*, *Neogobius melanostomus*, *Perna perna*, *Petricolaria pholadiformis*, *Potamocorbula amurensis*, *Pseudodiaptomus marinus* and *Pseudo-nitzschia seriata*.

Figure 13 Next pest hazard analysis (see Table 12 for species codes)



5 DISCUSSION AND CONCLUSIONS

The hazard analysis described here develops and extends the analysis completed in the first priority pest project in two ways. In the first instance this analysis has consolidated a number of domestic target lists, integrated these with international lists of invasive marine species and standardised the impact, vector, establishment and invasion status information of the resultant list. This standardised and consolidated list of invasive marine species enables domestic and international target species to be identified in a consistent and systematic fashion. Secondly the hazard analysis performed here includes a simple environmental similarity analysis based on latitudinal difference. Interestingly, however, this has only a small effect on the overall invasion potential of international species, and very little effect on invasion potential of domestic species, because of the highly skewed trading patterns of international and domestic vessels. It is important to note that the effect of environmental similarity on the international and domestic hazard analysis performed here will be similar for any monotonic similarity function based on latitude or any other environmental variable that is strongly correlated with latitude (e.g. sea surface temperature).

The potential domestic and international target species identified in this analysis were selected because they are species with a documented ship-mediated invasion history, and associated impacts, that are known to be non-native in Australia (domestic target species) or are not currently established in Australian waters (international target species). The analysis has also identified cryptogenic species that may, at the discretion of the relevant regulatory authority, be considered as potential domestic target species. Eradication is not considered a feasible option for any of these species given current control technology.

A species invasion history is an important, but not infallible, guide to its behaviour in a new region. Hence the species identified in the international and domestic lists may have little if any impact if they were successfully introduced into, or translocated within, Australian waters. Alternatively species that are not identified in these lists may have significant impacts if they were introduced to new localities on Australia’s coast. Considerable uncertainty surrounds the significance of the impacts associated with many of the species identified in this report. In this instance we have used interval arithmetic to capture the uncertainty surrounding impact estimates because it is simple, intuitive and sufficiently robust in data poor situations. Other uncertainty calculi, such as fuzzy arithmetic or Monte Carlo methods, may prove more instructive so long as there is sufficient data to warrant their use. This analysis attempts to eliminate linguistic uncertainty by carefully defining the impact categories and by forcing assessors to score impacts on a scale of 0 to 1. Nonetheless linguistic uncertainty and epistemic uncertainty may still be present in the impact scores allocated to the species, as evidenced by large impact intervals. It may be possible to improve on this analysis through Delphi-like elicitation techniques. These techniques, however, are time consuming and beyond the resources of this project.

In contrast to the impact potential, relatively accurate information exists on the number and types of commercial ship movements into and around Australian waters. Furthermore the world-wide IUCN bioregion distribution, and Australian IMCRA distribution, of marine pests is also reasonably well defined. These data sources allow a more robust estimate of invasion potential (sufficient for hazard ranking purposes) given simple assumptions about the condition of species over the duration of the journey. The particular nature of Australian trading patterns and ship routes suggest that the next ballast or hull fouling mediated invasion is most likely to come from only 10 of the 208 IUCN bioregions around the world. The incidence of new pest-like species in these regions should therefore be carefully monitored.

The results of the international analysis presented in the previous chapter are robust hazard estimates. They do not represent accurate absolute measure of risk but rather accurate relative (to each other) measures of hazard. The international analysis captures the vast majority of international vessel visits to Australia including all commercial vessels over 250 GRT and all international yachts. It is important to recognise, however, that this is not the case for the domestic analysis. We currently do not hold data on the movement of recreational yachts and commercial fishing vessels around the Australian coastline, and are unable therefore to include these vessel types in the domestic invasion potential analysis. This lack of data introduces an important bias into the results of the domestic analysis. The domestic analysis captures the vast majority of domestic ballast water discharges but does not capture anywhere near the total number of ship visits. Hence, whilst the ballast water contribution to the overall domestic invasion potential score is relatively robust, the hull fouling component is not. The effect of this is to (significantly) underestimate the domestic invasion potential of hull fouling species relative to ballast water species. The effect of this bias is clearly evident in Figures 7 and 8 – the tight cluster of species whose invasion potential is (apparently) zero are all hull fouling species that are not transported by ballast water. The invasion potential of these species is not zero rather it is underestimated and incorrectly normalised.

The selection of actual domestic target species from the potential target list identified here, can also be informed by the date of introduction, current distribution and significance of impacts. Species which have recently been introduced (at least post-1950), with relatively restricted range and highly significant impacts should be considered as priority candidates for domestic vector control. This analysis has deliberately avoided being overly prescriptive in identifying domestic target species, largely because the significance of the impacts associated with each species is a value-laden, socio-economic decision that should properly be taken in consultation with affected industry groups and stake-holders. The utility of this analysis lies in the sub-set of potential targets selected from the total set of non-native and cryptogenic species known to be established in Australian waters. In this context it is encouraging to note that many of the species identified in previous target lists, by a variety of often ad-hoc measures, satisfied the systematic selection criteria developed in this analysis. This is perhaps unsurprising since pest-like species have, by definition, a relatively high profile. Nonetheless, the introduction of domestic vector control (e.g. domestic ballast-water control) warrants the transparent and systematic re-evaluation of domestic target species completed here. Important to this process is the clear, auditable, decision process, supported by peer review scientific literature, provided in this report.

Information on the distribution and identity of non-native species in Australian waters detected in the ports surveys completed around Australia is yet to be collated in a central database. Nonetheless the consolidated species list developed in this analysis has been cross referenced against each of the port survey reports that were available to the project team during the course of this analysis. Ultimately we envisage that once the port survey data has been electronically collated and vetted for quality assurance it will be added to this consolidated list developed here and made available to a wider audience through the National Introduced Marine Pest Information System (NIMPIS).

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Appendix A Acknowledgments

Domestic list

The following people provided valuable assistance with the taxonomy, invasion status and/or date of first record/introduction of introduced and cryptogenic species in Australia. They also provided thoughtful discussion during the development and completion of the project. We are indebted to Pat Hutchings who helped us start dialogues with other taxonomists in the Australian Museum Invertebrate Taxonomists (AMIT) group.

Name	Organisation	Taxonomic group
Alan Webb	James Cook University	Freshwater fish
Angela Arthington	Griffith University	Freshwater fish
Christopher Bolch	University of Tasmania	Microalgae
Diana Jones	WA Museum	Barnacles
Gary Poore	Museum Victoria	Isopods
George (Buz) Wilson	Australian Museum	Isopods
Jan Watson	Hydrozoan Research Laboratory	Hydroids
Jane Fromont	WA Museum	Sponges
Jim Lowry	Australian Museum	Amphipods
John Hooper	Queensland Museum	Sponges
John Lewis	DSTO	Algae, Polychaetes
Liz Turner	Tasmanian Museum	General
Martin Gomon	Museum Victoria	Fish
Matthew Lockett	University of Technology, Sydney	Fish
Pat Hutchings	Australian Museum	Polychaetes
Patricia Mather	Queensland Museum	Ascidians
Peter Arnold	Queensland Museum	Bryozoans
Phil Bock	RMIT	Bryozoans
Richard Willan	NT Museum	Molluscs
Robin Wilson	Museum Victoria	Polychaetes
Tim O’Hara	Museum Victoria	Echinoderms

Domestic list questionnaire responses.

The following people kindly assisted us by completing the questionnaire for the potential domestic target list species.

Name	Organisation	Species
Caroline Sutton	CSIRO	Asterias amurensis
Craig Proctor	CSIRO	Carcinus maenas
John Hooper	Queensland Museum	Halisarca dujardini
Matt Lockett	University of Technology, Sydney	Tridentiger trigonocephalus
Rob Gurney	CSIRO	Carcinus maenas
Ron Thresher	CSIRO	Carcinus maenas
Sonia Talman	MAFRI	Varicorbula gibba
Craig Sanderson	Scottish Association for Marine Science	Undaria pinnatifida
Niel Bruce	NIWA	Sphaeroma walkeri
Kerstin Wasson	Elkhorn Slough National Estuarine Research Reserve Research Program	Barentsia benedeni
Helen Larson	Museum and Art Gallery of the Northern Territory	Tridentiger trigonocephalus
Laurie Cookson	CSIRO	Teredo navalis
Jane Fromont	Western Australian Museum	Halisarca dujardini
Chris Bolch	University of Tasmania	Alexandrium minutum, Gymnodinium catenatum
Naomi Parker	DAFF	Alexandrium minutum, Gymnodinium catenatum
Pat Mather	Queensland Museum	Ciona intestinalis, Styela clava
Jeff Ross	University of Melbourne	Asterias amurensis, Sabella spallanzanii, Styela clava
Robin Wilson	Museum Victoria	Polydora websteri, Pseudopolydora paucibranchiata, Sabella spallanzanii
Jan Watson	Marine Science and Ecology, Victoria	Bougainvillia muscus, Cordylophora caspia, Ectopleura crocea
Alice Morris	DPIWE, Tasmania	Asterias amurensis, Carcinus maenas, Crassostrea gigas, Gymnodinium catenatum
Jim Blake	ENSR Marine and Coastal Center	Boccardia proboscidea, Polydora cornuta, Polydora websteri, Pseudopolydora paucibranchiata
Toshiyuki Yamaguchi	Marine Biosystems Research Center, Chiba University, Japan	Balanus □eticulates, Megabalanus rosa, Megabalanus tintinnabulum, Notomegabalanus algicola

Name	Organisation	Species
Robert Van Syoc	California Academy of Sciences	Balanus reticulatus, Megabalanus rosa, Megabalanus tintinnabulum, Notomegabalanus algicola
Gerry Kraft	University of Melbourne	Antithamnionella spirographidis, Cladophora prolifera, Gymnogongrus crenulatus, Polysiphonia brodiaei, Schottera nicaeensis
Britta Schaffelke	James Cook University	Cladophora prolifera, Codium fragile tomentosoides, Polysiphonia brodiaei, Schottera nicaeensis, Undaria pinnatifida
John Lewis	Maritime Platforms Division, DSTO Australia	Antithamnionella spirographidis, Cladophora prolifera, Codium fragile tomentosoides, Gymnogongrus crenulatus, Schottera nicaeensis, Undaria pinnatifida
Liz Turner	Tasmanian Museum and Art Gallery	Asterias amurensis, Carcinus maenas, Chiton glaucus, Crassostrea gigas, Musculista senhousia, Theora lubrica, Undaria pinnatifida, Varicorbula gibba
Pat Hutchings	Australian Museum	Boccardia proboscidea, Euchone limnicola, Hydroides diramphus, Hydroides ezoensis, Hydroides sanctaecrucis, Polydora cornuta, Polydora websteri, Pseudopolydora paucibranchiata, Sabella spallanzanii
Phil Bock	Royal Melbourne Institute of Technology	Bugula flabellata, Bugula neritina, Cryptosula pallasiana, Schizoporella errata, Schizoporella unicornis, Scrupocellaria bertholetti, Tricellaria occidentalis, Watersipora arcuata, Watersipora subtorquata, Zoobotryon verticillatum
Emma Johnston	University of New South Wales	Asterias amurensis, Bugula flabellata, Bugula neritina, Ciona intestinalis, Hydroides ezoensis, Hydroides sanctaecrucis, Sabella spallanzanii, Schizoporella errata, Styela clava, Tricellaria occidentalis, Watersipora subtorquata
Chad Hewitt	Ministry of Fisheries, New Zealand	Alexandrium minutum, Apocorophium acutum, Asterias amurensis, Barentsia benedeni, Ciona intestinalis, Crassostrea gigas, Ectopleura crocea, Monocorophium acherusicum, Teredo navalis, Undaria pinnatifida, Watersipora arcuata, Watersipora subtorquata, Zoobotryon verticillatum

Name	Organisation	Species
Tim Glasby	NSW Fisheries	Bugula flabellata, Bugula neritina, Cladophora prolifera, Codium fragile tomentosoides, Crassostrea gigas, Cryptosula pallasiana, Hydroides ezoensis, Hydroides sanctaecrucis, Sabella spallanzanii, Schizoporella errata, Schizoporella unicornis, Styela clava, Tricellaria occidentalis, Watersipora arcuata, Watersipora subtorquata, Zoobotryon verticillatum

International List

The following people kindly assisted us by contributing information or by completing the questionnaire for the "nest pest" list species.

Name	Organisation	Species
Andrea Junqueira	Universidade Federal do Rio de Janeiro	Balanus eburneus; Limnoperna fortunei; Perna perna
Andrew M. Lohrer	University of South Carolina	Hemigrapsus sanguineus
Ann Kuhn-Hines	United States Environment Protection Authority	Ampelisca abdita
Anthony B.Wilson	University of Konstanz, Germany	Dreissena bugensis
Bryan Womersley	State Herbarium of South Australia	Womersleyella setacea
Charles E. Epifanio	University of Delaware	Callinectes sapidus
Chris Hopkins		Petricolaria pholadiformis
Flavio da Costa Fernandes	Instituto de Estudos do Mar Alm, Brazil	Limnoperna fortunei; Perna perna
Gonzalo Castillo	Hatfield Marine Science Centre, Oregon State University	Nippoleucon hinumensis
Graeme Inglis	NIWA, New Zealand	Charybdis japonica
Heather Peterson	USGS	Potamocorbula amurensis
Helmut Zibrowius	Centre d'oceanologie de Marseille	Hydroides dianthus
Jan J. Beukema	Netherlands Institute of Sea Research	Ensis directus
Jennifer Smith	University of Hawaii	Grateloupia doryphora
Jim Orsi	California Department of Fish and Game	Pseudodiaptomus forbesi; P. marinus; Sinocalanus doerri; Tortanus dextrilobatus
Jonne Kotta	Estonian Marine Institute, University of Tartu	Marenzelleria cf. viridis
Larry G. Harris	University of New Hampshire	Hemigrapsus sanguineus
Laurie Cookson	CSIRO Division of Forestry and Forest Products	Limnoria pfefferi
Marilyn M. Harlin	University of Rhode Island	Grateloupia doryphora
Mark L. Botton	Dept. Natural Sciences, Fordham College, NY	Limulus polyphemus
Martin Berg	Department of Biology, Loyola University Chicago,	Dreissena polymorpha; Neogobius melanostomus
Melek Ýþinibilir	Istanbul University	Beroe ovata; Mnemiopsis leidyi
Philip Rainbow	Natural History Museum, London	Eriocheir sinensis
Risto Väinölä	Finnish Museum of Natural History	Maeotias marginata; Marenzelleria cf. viridis; Mya arenaria

Name	Organisation	Species
Susan M. Bower	Department of Fisheries and Oceans, Canada	Mytilicola orientalis
Wim J. Wolff	University of Groningen	Mya arenaria

Appendix B – Calculating ballast water discharge

Data used to estimate ballast comes from two sources, Client Place Move (CPM) data from Lloyds Maritime Information Unity (LMIU) from 1998 to 2002 and Vessel Management System (VMS), data from the Australian Quarantine and Inspection Service, from 1999 to 2000.

Information from VMS was used to estimate relationships between discharge (m^3) and ship deadweight (DWT; tonnes). The ships are separated into eight classes; bulk carriers, container vessels, general cargo, roll-on/roll-off (ro/ro), woodchip carriers, crude tankers, product tankers and all other tankers. The most appropriate functional relationship varied between the classes. For bulk carriers, general cargo, woodchip carriers, crude tankers, product tankers and all other tankers the relationship was:

$$D = m \times DWT^2 + c \times DWT \quad ,$$

where *D* is the ballast water discharged (m^3) and *m* and *c* are parameters to be estimated from the data. For container vessels and ro/ro the relationship was:

$$D = (m \times DWT + c)^2$$

In ports with high number of ship visits for a particular ship class, estimates of *m* and *c* could be estimated for that particular port.

The CPM data provided information on the number of ships visiting each port, the ship class and the DWT of each ship. The relationships estimated from the VMS data were applied to the CPM data set, estimating ballast for each arriving ship by using the DWT and the estimated relationship. However, application of the VMS relationships directly to CPM data assumes that all ships arriving at a port discharge ballast at the average rate for the DWT of the ship. To adjust for the cases where ships were importing goods and consequently were carrying no ballast, discharge at the recipient port was adjusted according to the ratio of goods imported and exported at the recipient port, calculated from the gross tonnage imported and gross tonnage exported (Table B1).

For internaiotnal ships entering Australia this was applied at the first port of call. Ships operating within Australia have slightly different behaviours. Ships travelling between ports may partially load at a port and consequently carry no ballast to the next port (*pers. com.* Teresa Hatch, Australian ShipOwners Association). To adjust for this behaviour, the ballast carried by ships moving between domestic ports is modified by the import/export ratio of the port of departure.

For example, Abbot Point is a 100% export, 0% import port (Table B1). Ships arriving at Abbot Point will be only loading cargo. Consequently, ships coming from international ports will be carrying ballast and will discharge the ballast at Abbot Point. If ships are moving from Abbot Point to another domestic port it is assumed that the ships will have partially loaded at Abbot Point and will not be carrying any ballast water sourced from Abbot Point. Thus, any domestic port that receives ships from Abbot Point will receive no ballast water from Abbot Point.

In contrast, Fremantle receives 53% export and 47% import (Table B1). In this case, 53% of boats arriving at Fremantle from international ports will be carrying ballast and will discharge ballast at Fremantle. Likewise, 53% of boats leaving Fremantle for other domestic ports will be carrying cargo, perhaps partially loaded. These boats will have no ballast. However, 47% will be carrying ballast and will discharge this ballast at the next domestic port visited.

Figure B1 shows the 30 highest ranked ports in terms of domestic ballast discharge for Australia and Figure B2 shows the 30 highest ranked ports in terms of international ballast discharge based on the above calculations over a period of five years (1998-2002 inclusive).

Table B1 Import/Export proportions for selected Australian ports

Port Name	Import	Export
Abbot Point	0	1
Adelaide	0.399894	0.600106
Botany Bay	0.781815	0.218185
Brisbane	0.561106	0.438894
Bunbury	0.095374	0.904626
Cape Flattery	0	1
Dalrymple Bay	0	1
Dampier	0.003364	0.996636
Esperance	0.07176	0.92824
Fremantle	0.472429	0.527571
Geelong	0.46393	0.53607
Geraldton	0.13433	0.86567
Gladstone	0.197131	0.802869
Karumba	0.016301	0.983699
Klein Point	0	1
Launceston	0.286697	0.713303
Lucinda	0	1
Melbourne	0.589986	0.410014
Mourilyan	0	1
Newcastle	0.039574	0.960426
Port Giles	0	1
Port Hedland	0.004479	0.995521
Port Kembla	0.422907	0.577093
Port Lincoln	0.048357	0.951643
Port Pirie	0.352294	0.647706
Port Walcott	0	1
Sydney	0.781815	0.218185
Thevenard	0	1
Thursday Island	1	0
Townsville	0.560152	0.439848
Wallaroo	0.114599	0.885401
Weipa	0.000929	0.999071

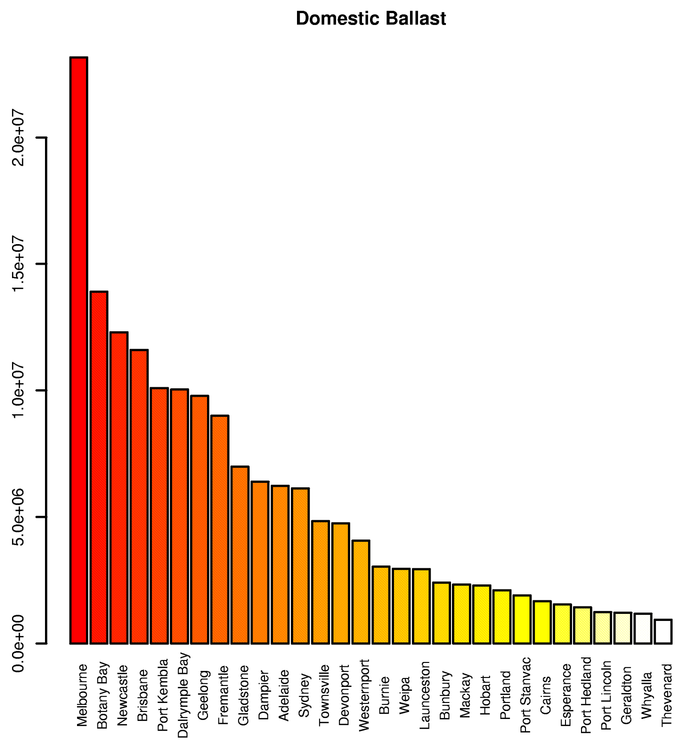

Figure B1 Domestic discharge for the 30 highest ranked domestic ports.

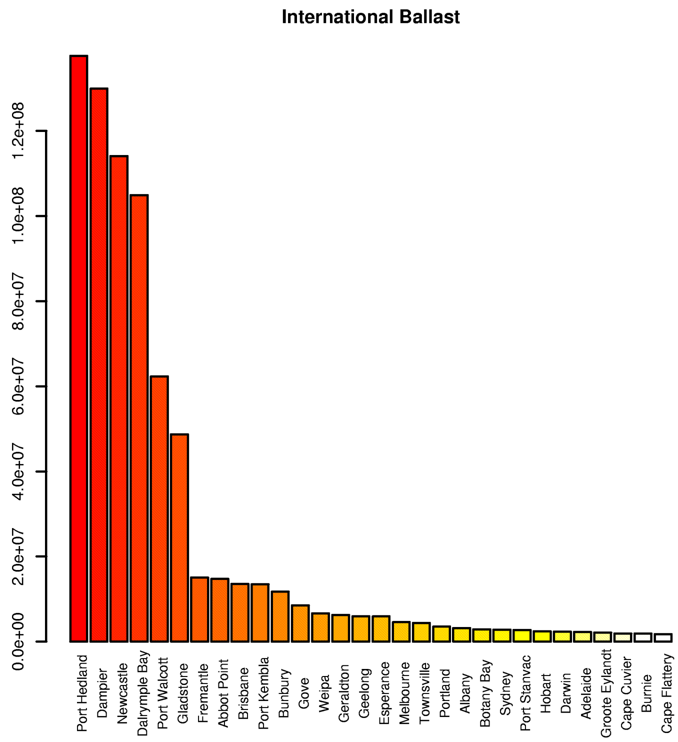

Figure B2 International discharge for the 30 highest ranked domestic ports.

The CPM data contained some instances where ships returned to the port of origin without a record of moving to another port. This pattern was determined to only be a problem for ships that returned repeatedly to Weipa. The vessels showing this pattern were identified as ships moving from Weipa to Gladstone and returning (*pers. com.* Teresa Hatch, Australian ShipOwners Association). Weipa is a 100% export port (Table B1), hence any vessel coming from Weipa was deemed to be carrying no ballast, despite the vessels involved in the loop actually coming from Gladstone and therefore carrying ballast. The last ports of vessels that fit this description was changed to indicate they were coming from Gladstone.

Domestic ballast to Dalrymple Bay appeared to be high. However, upon examination of the source ports for Dalrymple Bay (Table B2), it is apparent that the number of domestic source ports was high, and that, based on current assumptions, many of the ships arriving at Dalrymple Bay would be carrying ballast.

Table B2 Source ports for Dalrymple Bay

Source Port	Number of Ships	Import/Export
Gladstone	136	20/80
Newcastle	112	04/96
Port Kembla	92	44/58
Townsville	46	56/44
Brisbane	13	56/44

Appendix C – Impact questionnaire

NEXT PEST HAZARD ASSESSMENT

Instructions on completing this questionnaire
You are being asked to use your knowledge of the biology and/or invasion history of a species to score its potential or actual impacts on human health, economic values and environmental values. Please complete and submit a new questionnaire for each species assessed.
This questionnaire requires you to place a score alongside 14 impact categories by shading boxes on a scale from 0 to 1. The location of the shaded boxes describes the level of impact from no impact to high impact. The number of shaded boxes (ie the overall length of shading) reflects your uncertainty about the level of impact. The more boxes you shade, the more uncertain you are about the level of impact.

Example 1: The assessor thinks the level of impact on human health is somewhere between low and medium.

H1: Lethal/non-lethal impact on human health

☐	☑	☑	☑	☑	☐	☐	☐	☐	☐
No Impact									High Impact

Example 2: The assessor is certain there is no impact.

H1: Lethal/non-lethal impact on human health

☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

A comment box is provided below each scale – add any qualifying or explanatory comments that you think are necessary or appropriate. A comment box is also provided at the end of the questionnaire for any other additional comments that you may have.
Once you have completed the questionnaire please press the submit button. Please make a separate submission for each species – fill in the species scientific name on each occasion.
If you are unsure about how to complete the questionnaire you can contact any one from the project team:

Keith Hayes: keith.hayes@csiro.au; Tel +61 3 6232 5260
Cath Sliwa: cath.sliwa@csiro.au; Tel +61 3 6232 5023
Felicity McEnnulty: felicity.mcennulty@csiro.au; Tel +61 3 6232 5150

If you experience difficulty with your web browser please contact us – we can email an electronic copy of the questionnaire in MS Word – you can complete this and email it back to us

---

Assessors Name:

Email Address:

Species Scientific Name:

Clear the form for a new species

HUMAN

H1: Lethal/non-lethal impact on human health

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

ECONOMIC

M1: Obstructing/damaging aquatic waterways

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

M2: Water abstraction/nuisance fouling (eg clogging cooling water pipes, fouling turbines)

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

M3: Loss of aquaculture or commercial or recreational fisheries harvest

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

M4: Loss of public/tourist amenity or aesthetic values (eg spoiling beaches, restricting access to water)

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

M5: Damage to marine structures or marine archaeology

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

ENVIRONMENTAL

E1: Detrimental modification of physical habitat

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

E2: Alters trophic interactions or food-webs

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

E3: Dominates/out competes and limits the resources of native species

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

E4: Predates native species (incl. herbivory)

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

E5: Introduces/facilitates diseases or pathogens

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

E6: Alters bio-geochemical cycles (eg chemical/nutrient composition of sediment)

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

E7: Induces novel behavioural or eco-physiological responses in native species

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

E8: Genetic impacts (eg introgression and hybridisation)

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Impact									High Impact

Comments:

Any additional comments:

Submit to CSIRO

Appendix D – Other vectors

Table D1 lists the number of non-native and cryptogenic species which satisfy the selection criteria for each of the standardised vector codes developed in this project. Species that have been possibly introduced into Australia via vectors other than hull fouling or ballast water are listed by vector in the table that follow. Note that many of these species are also capable of being transported by shipping (S1 and S3). Those without a record of hull fouling or ballast water vector are denoted by *

Table D1 Number of species which satisfy selection criteria listed by vector

Code	Description	# non-native spp	# crypto spp
B1	Biocontrol: deliberate translocation as a biocontrol agent	0	0
B2	Biocontrol: accidental translocation with deliberate biocontrol release	0	0
C	Canals: natural range expansion through man-made canals	0	0
D	Debris: transport of species on human generated debris	0	0
F1	Fisheries: deliberate translocations of fish or shellfish	6	0
F2	Fisheries: accidental with deliberate translocations of fish or shellfish	24	12
F3	Fisheries: accidental with fishery products, packing or substrate	0	0
F4	Fisheries: accidental as bait	0	0
IR1	Individual release: deliberate release by individuals	0	0
IR2	Individual release: accidental release by individuals (e.g. aquariums)	2	0
P1	Plant introductions: deliberate translocation of plant species	0	0
P2	Plant introductions: accidental with deliberate plant translocations	0	0
RE	Recreational equipment: accidental with recreational equipment	0	0
S1	Ships: accidental as attached or free-living fouling organisms	48	17
S2	Ships: accidental with solid ballast (e.g. rocks, sand, etc)	6	0
S3	Ships: accidental with ballast water, sea water systems, live wells, etc.	23	5
S4	Ships: accidental associated with cargo	0	0
SP	Seaplanes: accidental as attached or free-living fouling organisms	0	0
SR1	Scientific research: deliberate release with research activities	0	0
SR2	Scientific research: accidental release with research activities	0	0
O	Other	2	0
U	Unknown	4	0

Vector: F1 - Fisheries: deliberate translocations of fish or shellfish to establish or support fishery - non native species

Scientific name	Common name	Control in AUS	ID in AUS	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Crassostrea gigas	Pacific oyster	Yes	1947			1		1	1	1		1						
Oncorhynchus mykiss*	Rainbow trout	No	1894									1	1					
Poecilia latipinna*	Sailfin molly	No	1968									1						
Salmo trutta trutta*	Brown trout	No	1864									1	1					
Salvelinus fontinalis*	Brook trout	No	1900									1	1					
Spartina anglica*	Rice grass	Yes	1930		1			1		1	1				1			

Vector: F2 - Fisheries: accidental with deliberate translocations of fish or shellfish – non native species

Scientific name	Common name	Control in AUS	ID in AUS	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Alitta succinea	Pile worm	No	1930												1			
Apocorophium acutum	Amphipod	No	1937			1									1			
Barentsia benedeni	Nodding head	No	1952			1												
Bougainvillia muscus	Sea anemone	No	1918			1												
Cancer novaezealandiae*	Pie-crust crab	No	1880				1					1	1					
Chiton glaucus	Chiton	No	1910									1						
Ciona intestinalis	Sea Vase	No	1899			1	1											
Cordylophora caspia	Hydroid	No	1931			1						1						
Cryptosula pallasiana	Bryozoan	No	1880			1						1						
Ectopleura crocea	Athecate hydroid	No	1885			1												
Hydroides ezoensis	Serpulid tubeworm	No	1996		1	1	1					1						
Maoricolpus roseus*	New Zealand screw shell	No	1965				1	1		1	1	1			1			
Monocorophium acherusicum	Amphipod	No	1921			1									1			
Monocorophium insidiosum	Amphipod	No	1973			1						1			1			
Musculista senhousia	Asian bag mussel	Yes	1982							1	1	1						
Ostrea edulis*	Edible oyster	No	No data				1	1						1				
Patiriella regularis*	New Zealand sea star	No	1930									1						
Petrolisthes elongatus*	New Zealand half-crab	No	1912									1						
Polydora websteri	Spionid polychaete	No	1885				1											
Pseudopolydora paucibranchiata	Spionid polychaete	No	1971							1		1						
Ruditapes largillierti*	Clam	No	1930									1						
Schizoporella unicornis	Bryozoan	No	1925									1						
Styela clava	Sea squirt	No	1972	1		1	1					1						
Undaria pinnatifida	Brown macroalgae	Yes	1988			1	1					1			1			

Vector: F2 - Fisheries: accidental with deliberate translocations of fish or shellfish - cryptogenic species

Scientific name	Common name	Control in AUS	ID in AUS	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Ascidiella aspersa	Solitary ascidian	No	No data			1						1						
Botrylloides leachi	Colonial ascidian	No	No data			1						1						
Botryllus aurantius	Colonial ascidian	No	No data			1				1								
Botryllus schlosseri	Colonial ascidian	No	No data			1				1		1						
Dipolydora armarta	Spionid polychaete	No	1978				1											
Dipolydora flava	Spionid polychaete	No	1978				1											
Dipolydora giardi*	Spionid polychaete	No	1968			1	1											
Dipolydora socialis	Spionid polychaete	No	1978			1	1											
Hydroides elegans	Serpulid tubeworm	No	No data			1												
Obelia longissima	Hydroid	No	No data									1						
Polydora hoplura*	Spionid polychaete	No	1975			1												
Styela plicata	Sea squirt	No	No data			1	1					1						

Vector: IR2 - Individual release: accidental release by individuals (e.g. aquarium discards) – non native species

Scientific name	Common name	Control in AUS	ID in AUS	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Gambusia holbrooki*	Mosquitofish	No	1920									1	1					
Poecilia latipinna*	Sailfin molly	No	1968									1						

Vector: S2 - Ships: accidental with solid ballast (e.g.rocks, sand, etc) - non native species

Scientific name	Common name	Control in AUS	ID in AUS	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Apocorophium acutum	Amphipod	No	1937			1									1			
Chiton glaucus	Chiton	No	1910									1						
Euchone limnicola	Sabellid polychaete	No	1984							1	1	1			1			
Monocorophium acherusicum	Amphipod	No	1921			1									1			
Monocorophium insidiosum	Amphipod	No	1973			1						1			1			
Theora lubrica	Asian semelid bivalve	No	1958									1			1			

Vector: U – Unknown – non native species

Scientific name	Common name	Control in AUS	ID in AUS	H1	M1	M2	M3	M4	M5	E1	E2	E3	E4	E5	E6	E7	E8	E9
Asperococcus compressus*	Brown macroalgae	No	1976									1						
Elachista orbicularis*	Brown macroalgae	No	1976									1						
Gymnogongrus crenulatus	Red macroalgae	No	1969											1				
Sphacella subtilissima*	Brown macroalgae	No	1969			1					1							