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## Assessing the port to port risk of vessel movements vectoring non-indigenous marine species within and across domestic Australian borders

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Biofouling of vessels is implicated as a high risk transfer mechanism of non-indigenous marine species (NIMS). Biofouling on international vessels is managed through stringent border control policies, however, domestic biofouling transfers are managed under different policies and legislative arrangements as they cross internal borders. As comprehensive guidelines are developed and increased compliance of international vessels with 'clean hull' expectations increase, vessel movements from port to port will become the focus of biosecurity management. A semi-quantitative port to port biofouling risk assessment is presented that evaluates the presence of known NIMS in the source port and determines the likelihood of transfer based on the NIMS association with biofouling and environmental match between source and receiving ports. This risk assessment method was used to assess the risk profile of a single dredge vessel during three anticipated voyages within Australia, resulting in negligible to low risk outcomes. This finding is contrasted with expectations in the literature, specifically those that suggest slow moving vessels pose a high to extreme risk of transferring NIMS species.

**Keywords:** risk assessment; introduced marine species; non-indigenous marine species; biofouling; marine biosecurity; domestic borders

### Introduction

Large numbers of species have been unintentionally introduced to a variety of global regions in association with several mechanisms of human-mediated transport including ballast water and sediment, hull biofouling, and transfers of mariculture species and gear (eg Carlton 1996; Hewitt 2002, 2003; Hewitt et al. 2004). Alterations to coastal waters are increasing, including higher nutrient levels, habitat alteration, ecosystem degradation and community replacement as forms of disturbance (Halpern et al. 2008). These changes are coincident with large shifts to patterns of international and coastal shipping (see Campbell and Hewitt 1999). A concomitant increase in the number of non-indigenous marine species (NIMS) has been observed globally (eg Carlton 2001; Hewitt 2003), with pest species (those causing recognised harm) becoming widespread and problematic, particularly in Australia (Pollard and Hutchings 1990a, 1990b; Hewitt et al. 1999a, 2004; Hewitt 2002). The demonstrated significance of these pest species is the recognised impact upon economic, health and environmental values (eg Asian kelp, *Undaria pinnatifida*; northern Pacific seastar, *Asterias amurensis*; Hewitt et al. 1999a).

Although numerous transport mechanisms (vectors) exist for NIMS, it has been suggested that hull biofouling is responsible for a large proportion of introductions (eg Hewitt et al. 1999a), with more recent research supporting this suggestion (Hewitt 2002; Hewitt et al. 2004, 2009; Otani et al. 2007; Davidson et al. 2008). Hull biofouling has been a prevalent vector since historical times, with wooden sailing vessels and their associated dry ballast most likely being responsible for introductions since vessels first plied the seas (Carlton and Hodder 1995; Campbell and Hewitt 1999). The hulls of modern vessels and their associated sea chests have received increasing attention as a vector of concern (Coutts et al. 2003; Coutts and Dodgshun 2007) specifically with the phasing out of TBT as a key antifouling substance (Lewis et al. 2004; Dafforn et al. 2008). This increased focus on hull biofouling, with the realised threat that it poses, has seen an increased awareness by decision-makers at both national and international scales (Hewitt et al. 2009; <http://www.marinepests.gov.au/>).

The establishment of NIMS has potential negative ecological flow-on effects such as altering food webs, displacing native species and causing local extinctions, which in turn have ecological impacts (eg Vermeij

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1993; Grosholz and Ruiz 1996; Ruiz et al. 1999). Management of unintentionally introduced species is typically regulated at both the national and state levels (Hewitt and Campbell 2007; Hewitt et al. 2009). Within Australia, a species cannot be intentionally imported unless an Import Risk Assessment (IRA) for the importation of that species exists, or an exemption from an IRA is requested and granted. Applications for exemptions occur on a case-by-case basis. Intentional importation is covered by policies and legislation set by the Australian Department of Agriculture, Fisheries and Forestry (DAFF) and managed by the Australian Quarantine and Inspection Service (AQIS) and Biosecurity Australia.

The unintentional importation of species is more problematic to manage and control, due to the unknown species, pathways and vectors that interact synergistically. A number of guidelines have now been established to manage the unintentional importation of marine species in waters under Australian state jurisdiction (eg Australian Intergovernmental Agreement on a national system for the prevention and management of marine pest incursions; <http://www.environment.gov.au/coasts/imps/publications/pubs/intergovernmental-agreement.pdf>). Of concern is that the domestic movement of vessels has the potential to transfer species from one port or region to another (eg hub and spoke model; Carlton 1996).

Management has a number of intervention options that have varying costs, certainty and time requirements (Figure 1), viz. (1) undertake a risk based process that would inform the decision to increase the

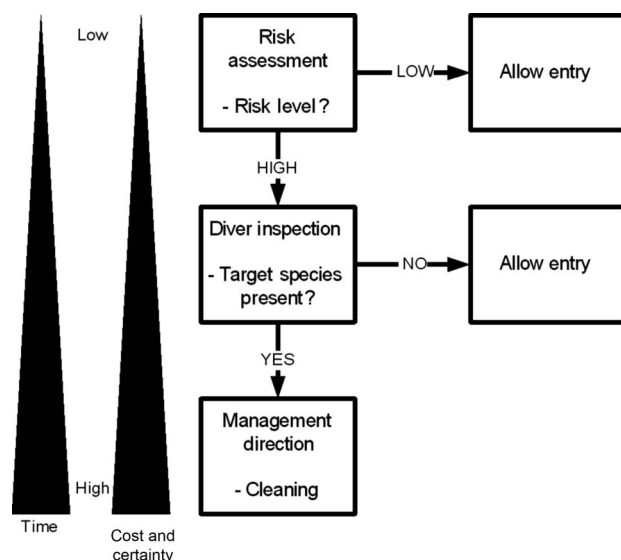


Figure 1. Staged management approach demonstrating the relative roles of risk assessment, inspection and regulatory direction.

level of management to diver inspection, diver sampling, and ultimately cleaning, (2) diver inspection and sampling where appropriate (including delay costs associated with identification of species), or (3) a direction to clean requiring a dry docking at the nearest appropriately sized facility. This suite of management options can be assembled as a cascade with increasing levels of intervention based on certainty, but incurring increasing costs in time and resources (including human resources). While no movement is likely to be free of risk, the use of an appropriate and transparent risk management process is key to the minimisation of species transfer in a pragmatic fashion (Campbell 2008, 2009). Thus, risk assessment may prove an invaluable tool to assess the threat posed by both international and domestic vessel transfers of species during domestic movements.

The assessment of risks associated with international arrivals is a standard procedure for quarantine agencies across the world. The evaluation of commodities (eg cattle, horses, birds, aquarium fish, frozen seafood) to determine the associated risks of introducing NIMS typically results in the establishment of Import Health Standards (IHSs) that inform quarantine regulation and border inspection. It is only recently that formalised risk assessment has been applied to vessel arrivals for ballast water (Hayes and Hewitt 1998) and biofouling (Hewitt et al. 2009). These assessments focus on international arrivals, but rarely evaluate domestic transfers (but see Hayes 2002).

In this article, a domestic biofouling risk assessment is undertaken to assess the port to port voyage risks of transferring NIMS from one location to another, using the anticipated operational movements of a self-propelled cutter suction dredger (MV Leonardo da Vinci) that undertook dredging activities associated with port expansion and port maintenance at a number of ports in the austral summer, December 2008 to February 2009. This vessel is used as an example where the movement of the vessel between ports was thought to pose a risk of NIMS transfer due to a previous inspection identifying a species of concern (*Perna viridis*; Wells et al. 2009) associated with biofouling and its entry and subsequent movements required management by the State jurisdiction.

Originally the MV Leonardo da Vinci arrived in Geraldton, Western Australia, from the Caribbean (Wells et al. 2009) and following detection of the NIMS *Perna viridis*, subsequently left Australian waters to be cleaned and dry docked in Singapore before returning to Port Hedland, Western Australia (unpublished data), where it subsequently passed marine biosecurity inspection by the Western Australian Department of Fisheries (State based agency that deals with marine biosecurity regulations, compliance

and enforcement). Because the vessel was in-water and had passed entry inspection but remained in Port Hedland for a period of time, it was likely that biofouling organisms originating in Port Hedland would be present on the vessel hull, making a simplistic diver inspection (eg looking for the presence of a specified 'level of biofouling') redundant and the absence of a target suite of NIMS making comprehensive diver sampling inefficient due to the need for subsequent taxonomic evaluation. Similarly, because the MV Leonardo da Vinci is a dredge vessel, it was likely that marine sediments would have been resuspended leading to the possibility of entrainment for NIMS associated with sediments in the biofouling matrix or in the biofouling organisms themselves. Hence, it was deemed that a risk analysis of biofouling was a more pragmatic method to determine the risk this vessel posed to the receiving marine environments in order to inform biosecurity management conditions.

This article assesses the port to port pathway (voyages) risks for three planned domestic voyages in Australia, viz. voyage 1) Port Hedland, Western Australia (WA) to Cockburn Sound, WA, voyage 2) Port Hedland, WA, to Botany Bay, New South Wales (NSW), and voyage 3) Botany Bay, NSW, to Port Hedland, WA (Figure 2). This assessment was undertaken for each planned voyage using a semi-quantitative risk assessment approach that is relatively simple and informed management agencies as to the need for additional measures (Figure 1). The assessment is restricted to the individual planned voyage and the risk is restricted to species transfers from the port of origin to the receiving port and does not evaluate the accumulation of biofouling associated with multiple voyages. The assessment has an impact endpoint, and determines hazard NIMS likely to be present (species present in the donor region and absent in the recipient

region), the likelihood of each hazard NIMS transfer, the consequence of that transfer and the derived risk associated with each hazard NIMS.

## Method

### Risk process

A four-step risk analysis process was used based upon standard risk management guidelines (Standards Australia 2000, 2004) that has been previously applied in a marine biosecurity context (eg Kluza et al. 2006; Campbell 2008) and resource risk assessment (eg Crawford 2003; Fletcher 2005; Campbell and Gallagher 2007). The first of these steps was hazard identification, which determined what species represent potential hazards (eg NIMS) associated with the transfer of the vessel during three separate planned voyages (Table 1).

The second step in the process examined each voyage to determine the likelihood that a hazard NIMS would be transferred (*via* hull biofouling and translocated sediments associated with the dredge hopper and suction equipment). In this risk assessment, likelihood was assessed using a combination of the NIMS association with hull biofouling or sediments as a proxy for exposure and environmental matching (based at the level of the province) between the source and receiving port conditions. Likelihood was then obtained using a standardised likelihood matrix (Table 2). In the absence of a comprehensive evaluation of vessel movements (ie a vessel risk assessment), a single voyage can only be evaluated on the basis of source and recipient regions, voyage characteristics (where known), and the assumed husbandry (cleaning and antifouling treatment) of the vessel.

The use of environmental matching (or similarity) is contentious as it often neglects to fully account for species-traits, yet it represents a good starting point for many risk assessments. This method has been used for a number of marine biosecurity assessments (eg Gollasch and Leppakoski 2007; Gollasch et al. 2007; Otani et al. 2007). This approach was supported by combining environmental matching with expert opinion. Methods such as traits-based analysis and propagule pressure, although useful quantitative tools for risk assessment, are less relevant for single voyage assessments that must occur rapidly. To undertake traits-based and propagule pressure analyses in this instance would require the use of divers and collection of samples, which would require an added time component of up to 12 months (for taxonomic analysis and verification; Hayes et al. 2005; Campbell et al. 2007). This added time component is unacceptable for the immediate needs of ship-owners or operators and

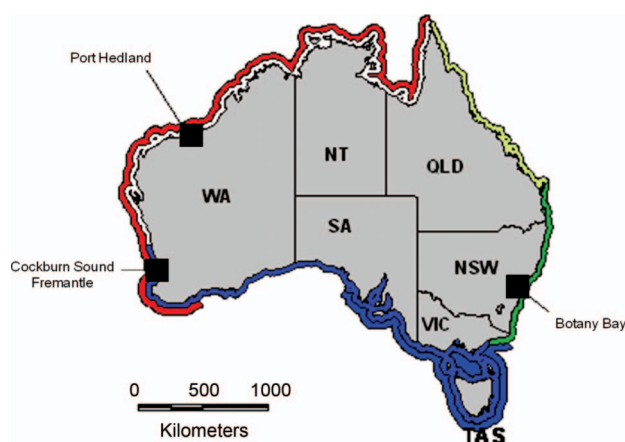


Figure 2. Australian biological provinces (modified from Poore 1995).

Table 1. Introduced species found in Port Hedland, WA, their recorded presence/absence in Cockburn Sound, WA, and Botany Bay, NSW, and their association with hull fouling.

Taxa	Port Hedland	Cockburn Sound	Botany Bay	Association with	
				Hull fouling	Sediments
Dinoflagellates					
<i>Cochlodinium polykrikoides</i>	+	—	—	—	+
<i>Gymnodinium catenatum</i>	+	—	—	—	+
Rhodophyta					
<i>Polysiphonia blandii</i>	—	—	+	+	—
<i>Solieria filiformis</i>	—	—	+	+	—
Ascidia					
<i>Botrylloides leachii</i>	—	—	+	+	—
<i>Diplosoma listerianum</i>	—	—	+	+	—
Barnacles					
<i>Megabalanus rosa</i>	—	—	+	+	—
<i>Megabalanus zebra</i>	—	—	+	+	—
Bryozoa					
<i>Acanthodesia savartii</i>	—	—	+	+	—
<i>Amathia distans</i>	+	—	+	+	—
<i>Bowerbankia gracilis</i>	+	—	—	+	—
<i>Bugula flabellata</i>	—	—	+	+	—
<i>Bugula neritina</i>	+	+	—	+	—
<i>Bugula stolonifera</i>	+	+	—	+	—
<i>Cryptosula pallasiana</i>	—	—	+	+	—
<i>Schizoporella unicornis</i>	—	—	+	+	—
<i>Tricellaria occidentalis</i>	—	—	+	+	—
<i>Watersipora subtorquata</i>	—	—	+	+	—
Cnidaria					
<i>Antenella secundaria</i>	+	—	+	+	—
<i>Obelia dichotoma</i>	—	—	+	+	—
<i>Obelia longissima</i>	+	+	—	+	—
<i>Phialella quadrata</i>	—	—	+	+	—

Note: + = presence or association; — = absence or lack of association.

Table 2. Likelihood matrix.

Descriptor	Description	Probability of event occurring
Rare	Event will only occur in exception circumstances	< 5%
Unlikely	Event could occur but not expected	5–25%
Possible	Event could occur	26–50%
Likely	Event will probably occur in most circumstances	51–75%
Almost certain	Event is expected to occur in most circumstances	76–> 95%

biosecurity managers dictating the type of risk assessment required in this context.

The third step assessed the potential degree of impact (consequence) that the hazard NIMS would have on marine fauna and flora, industries and human health, either singularly or synergistically in the receiving environment (Table 3). Impact information was drawn from the authors' database of recognised or assumed impacts, based on published and grey

Table 3. Consequence matrix.

Descriptor	Impact
Insignificant	Species that have no discernible impact to biology, economics or human health
Minor	Species cause limited impact to biology, economics or human health; restricted in space or time
Moderate	Species cause short term or spatially restricted impacts to biology, economics or human health
Major	Species cause long term or widespread impacts to biology, economics or human health; species diversity loss, industry disruption, human morbidity
Significant	Species cause long term and widespread impacts to biology, economics or human health; species diversity loss, industry collapse, human mortality

literature. In the final step, risk was derived by multiplying likelihood by consequence (Table 4).

This risk assessment focuses on known NIMS and NIMS listed on the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE)



Table 4. Risk ranking.

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Significant
Rare	N	L	L	M	M
Unlikely	N	L	M	H	H
Possible	N	L	H	H	E
Likely	N	M	H	E	E
Almost certain	N	M	E	E	E

Note: Risk is denoted as N = negligible; L = low, M = moderate; H = high; E = extreme.

trigger list (pest species considered high risk to Australia; [http://www.marinepests.gov.au/national\\_system/how-it-works/emergency\\_management/trigger\\_list](http://www.marinepests.gov.au/national_system/how-it-works/emergency_management/trigger_list)). It did not assess the risk posed by domestically translocated native species (although these also pose an introduction risk, especially in light of climate change). An assessment of native species risk requires comprehensive baseline data that were not available in both donor and receiving regions. To undertake such an evaluation would require significant further field research and resources.

The data used within this article are based upon the official baseline NIMS biological information derived from the national port surveys (Commonwealth Scientific Industrial Research Organisation's [CSIRO] Centre for Research on Introduced Marine Pests [CRIMP] undertaken between 1995 and 2001; Campbell et al. 2007), the authors' own reference collections, published literature, and the research data of colleagues. Species were assessed against the modified Chapman and Carlton (1991, 1994) 10-point criteria to determine which species were likely to be introduced, native, or cryptogenic (unknown origin). Evaluation of species does not rely solely on taxonomic input but uses ecological, biogeographical, genetic, and trophodynamic information in a multi-disciplinary approach. Because of this multidisciplinary approach the use of expert opinion was integral to the determination of a species status. The benefit of using the national port survey data is that they are still the best available data for native and introduced species in the ports being examined, although in some instances these data are more than 10-years old. The attractiveness of using baseline data is that when further surveys, resurveys and monitoring for introduced species occur in these regions, available data can be updated and hence the risk assessment can be revised and uncertainty can potentially be reduced. By creating a premium on current data, it encourages regulatory and port authorities to maintain an accurate representation of the diversity of their NIMS and does not overburden industry.

### *Provincial biogeography approach*

Bioregions were delineated based on established biogeographic provinces (Poore 1995; modified in Figure 2). Provinces were used because they deal with regional species assemblages. The provinces used herein concatenate a number of different systems and are supported by port survey data that shows overlaps between native species within these provinces (Hewitt unpublished data). There are a vast number of different biogeographic provinces that have been suggested by taxonomists (Morgan and Wells 1991; Wells et al. 2009), yet few of these have been developed based on a holistic approach for all benthic species; typically they are focussed on single phyla or single class (Veron and Marsh 1989; Ponder and Wells 1998; Jones 2003). Bioregionalisations typically are generated based on a limited set of species (eg Integrated Marine and Coastal Regionalisation of Australia [IMCRA]), on a limited set of physical parameters (eg IMCRA), or a combination that includes political boundaries (eg IUCN bioregions).

On analysis, a species, especially a NIMS that shows the ability to fully utilise their fundamental niche, can typically exist across wide ranging environmental conditions (eg salinities and water temperatures) and hence their range can extend over many biogeographic regions (Hewitt et al. 2009). The physiological tolerances (maxima and minima) of many species are related to their native bioprovinces (Figure 3a), suggesting that their realised and fundamental niches are environmentally constrained. The biogeographical overlaps of different provinces therefore may indicate the likelihood of species survival in various regions. For example, significant provincial overlap occurs from the Arctic to the Antarctic along the eastern Pacific basin (Figure 3b).

Thus, it can be seen that biogeographies differ widely between who is using them and whether they are approaching the bioregionalisation from a purely taxonomic perspective (which is based on realised niche alone), or from the perspective of an introduced

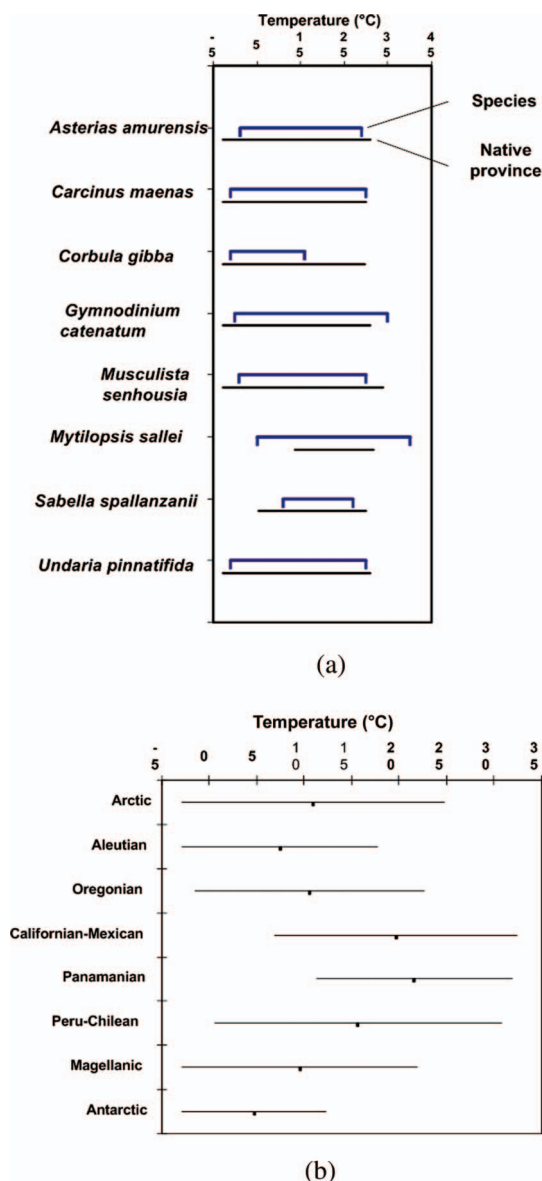


Figure 3. (a) = Comparison of the physiological tolerances of species (top line) vs native province sea surface temperature range (bottom line); (b) = comparison of sea surface temperature for the eastern Pacific provinces.

species (which is based on realised and fundamental niche). Therefore, the province system was used that is recognised for Australia rather than the more recent bioregionalisations (eg IMCRA) which were created for a different (ie conservation) use.

## Results and discussion

### Identified hazard species

Given the vessel cleaning immediately prior to entry to Port Hedland, for this risk analysis it was assumed that the dredge vessel had only been colonised by species following arrival in Port Hedland. Port Hedland was

surveyed for introduced marine pests by CSIRO-CRIMP as part of the Australian National Port Baseline Program in 1998 (Hewitt et al. 1999b) providing an indication of the NIMS present at that time.

The vessel was contracted to undertake additional work in other locations around Australia (Fremantle, WA and Botany Bay, NSW) and consideration of the biosecurity risks was considered essential to plan the vessel activity and the biosecurity management interventions necessary to meet state obligations. The port of Fremantle, which includes Cockburn Sound was surveyed by CSIRO-CRIMP in 1999 (Hewitt et al. 2000). The port of Botany Bay was surveyed by CSIRO-CRIMP and New South Wales Fisheries in 1998 (Pollard and Pethebridge 2002). To the authors' knowledge, no further similar surveys have occurred in Port Hedland, Fremantle, or Botany Bay, thus it was assumed that these surveys represent the present NIMS lists for the target ports, despite lag times.

Cockburn Sound and Port Hedland are both found within the same biological province (Figure 2) suggesting that the native species are similar between regions and that species transfer and survival between regions is possible. The port survey species data were used (see Hewitt et al. 1999b, 2000) to assess potential NIMS hazards associated with a vessel transfer between these regions. Consequently, the NIMS found in Port Hedland, but not found in Cockburn Sound are identified as hazard species.

Botany Bay and Port Hedland are found within different biological provinces that are non-contiguous but have an environmental overlap based on latitudinal gradients (Figure 2). This suggests that the native species are not likely to be similar between regions and that natural transfer of species is thus unlikely. However, due to similarity in the environmental conditions, survival between regions is probable. Again, the port survey species data (see Hewitt et al. 1999b; Pollard and Pethebridge 2002) were used to determine potential NIMS hazards. The same port survey species data were also assessed to determine the potential NIMS hazards for voyage 3, the return route, Botany Bay to Port Hedland. The native hazards were not assessed in this evaluation.

From the analysed data, seven NIMS exist in Port Hedland (Hewitt et al. 1999b), 53 introduced species exist in Cockburn Sound (Hewitt et al. 2000) and 19 NIMS are found in Botany Bay (Pollard and Pethebridge 2002). Of these, five NIMS were considered hazards for voyage 1 (ie found in Port Hedland only; Table 1); and 6 and 14 species are considered to be hazards for voyages 2 and 3, respectively (Tables 1 and 5).

For all three voyages, none of the identified hazard species are listed on the CCIMPE trigger list (see

Table 5. Identified hazards for three voyages undertaken by the MV Leonardo da Vinci and identified values that are impacted upon by the hazards.

Hazard species	Values impacted upon			Supporting references
	Environmental	Economic	Social	
Voyage 1				
<i>Cochlodinium polykrikoides</i>	+	—	—	Kim et al. 1999; Kim et al. 2002
<i>Gymnodinium catenatum</i>	+	+	+	Anderson et al. 1989; Oshima et al. 1993; Corrales and Maclean 1995; Hallegraeff 1998; Mendez et al. 2001; Gomez 2003
<i>Amathia distans</i>	—	—	—	NA
<i>Bowerbankia gracilis</i>	—	+	—	Ryland 1965
<i>Antenella secundaria</i>	—	—	—	Watson 1999
Voyage 2				
<i>Cochlodinium polykrikoides</i>	+	—	—	Kim et al. 1999
<i>Gymnodinium catenatum</i>	+	+	+	Kim et al. 2002
<i>Bowerbankia gracilis</i>	—	—	—	Ryland 1965
<i>Bugula neritina</i>	—	—	—	NA
<i>Bugula stolonifera</i>	—	—	—	NA
<i>Obelia longissima</i>	—	—	—	NA
Voyage 3				
<i>Polysiphonia blandii</i>	—	—	—	NA
<i>Solieria filiformis</i>	—	—	—	NA
<i>Botrylloides leachii</i>	—	—	—	NA
<i>Diplosoma listerianum</i>	—	—	—	NA
<i>Megabalanus rosa</i>	—	—	—	NA
<i>Megabalanus zebra</i>	—	—	—	NA
<i>Acanthodesia savartii</i>	—	—	—	NA
<i>Bugula flabellata</i>	—	—	—	NA
<i>Cryptosula pallasiana</i>	—	—	—	NA
<i>Schizoporella unicornis</i>	—	—	—	NA
<i>Tricellaria occidentalis</i>	—	—	—	NA
<i>Watersipora subtorquata</i>	—	—	—	NA
<i>Obelia dichotoma</i>	—	—	—	NA
<i>Phialella quadrata</i>	—	—	—	NA

Note: NA = no impact.

Supplementary material [Supplementary material is available via a multimedia link on the online article webpage]. Five identified hazard NIMS have the potential to impact on environmental, economic and/or social values (Table 5). The remaining hazard NIMS are not known to have any demonstrated impacts on native species, human health, or economic impacts. *Bowerbankia gracilis* is listed by Ryland (1965) in the OECD catalogue of main marine biofouling organisms and as such may pose a threat to economic values related to infrastructure cleaning and maintenance.

Of the remaining two species that have a demonstrated impact, the dinoflagellate *Cochlodinium polykrikoides* produces a range of ichthyotoxic effects on wild and caged fin fish (Kim et al. 1999, 2002). Similarly, the dinoflagellate *Gymnodinium catenatum* is responsible for producing neurotoxins that can cause outbreaks of paralytic shellfish poisoning (Anderson et al. 1989; Oshima et al. 1993; Mendez et al. 2001), have impacts upon aquaculture practices (Corrales and Maclean 1995; Hallegraeff 1998) and pelagic communities (Gomez 2003).

Within Australia, *G. catenatum* is known from the southern coast of Victoria from Portland to Port Welshpool, and on the southeast coast of Tasmania from Recherche Bay to Georges Bay, including the Derwent and Huon estuaries and was detected in Port Hedland, Western Australia. It is presumed that the introduction occurred via ballast tank sediments from either Japan or Spain probably in the early 1980s. Sediment cores have dated the introduction in the Huon River, Tasmania, to 1973 (Bolch and Hallegraeff 1990). This species can form extensive blooms which appear to be correlated with highly stratified sea conditions (such as calm weather following significant rainfall).

#### Assessment of likelihood of transfer

The probability that a species can move from one region to another based on the voyage profiles was assessed using a likelihood matrix (Table 2). Data deficiencies were classified as 'highly likely' events (following the precautionary principle applied from a



biodiversity conservation context), which results in a conservative assessment of likelihood.

#### *Voyage 1 – Port Hedland to Cockburn Sound*

Given the similar environmental conditions between these two ports (same biological province; Figure 2), all five-identified hazard species were 'likely' to survive transfer from Port Hedland to Cockburn Sound. However, the likelihood of transferring the two hazard dinoflagellate NIMS (*C. polukrikoides* and *G. catenatum*) was 'rare' given that they are indirectly associated with hull biofouling. These NIMS can be found in sediments of sea chest areas and when in bloom forming phase can be detected as cysts in the gut contents of benthic biofouling species. *B. gracilis* is associated with hull biofouling and as such it was 'likely' that this species would be transferred. The remaining two hazard NIMS (the bryozoan *Amathia distans* and the cnidarian *Antenella secundaria*) were 'almost certain' to be transferred as hull biofouling species between these two ports.

#### *Voyage 2 – Port Hedland to Botany Bay*

Again, there is an environmental overlap between these two ports, and hence all six-identified hazard NIMS were 'likely' to survive transfer from Port Hedland to the Port of Botany Bay. The likelihood of transferring the two hazard dinoflagellate NIMS (*C. polykrikoides* and *G. catenatum*) was 'rare'. The remaining four hazard NIMS (the bryozoans *B. gracilis*, *Bugula neritina* and *Bugula stolonifera* and the cnidarian *Obelia longissima*) were 'likely' to be transferred as hull biofouling species between these two ports.

#### *Voyage 3 – Botany Bay to Port Hedland*

Given the environmental overlap between these two ports, a number of the hazard NIMS were 'likely' to survive the transfer from the Port of Botany Bay to Port Hedland. The two macroalgal species, *Polysiphonia blandii* and *Solieria filiformis* are also associated with hull biofouling (Lewis 1999; Table 1) and have been detected in temperate Australian ports (four and two ports respectively), suggesting a 'possible' likelihood of transfer from Botany Bay to Port Hedland.

Two identified barnacle hazard NIMS (*Megabalanus rosa* and *Megabalanus zebra*) are associated with biofouling and ballast water and are distributed in temperate waters. *M. rosa* and *M. zebra* have been detected previously in Port Kembla and Botany Bay, NSW (Pollard and Pethebridge 2002). Thus, the likelihood of transferring the two barnacle species was 'possible'.

The ascidians *Botrylloides leachii* and *Diplosoma listerianum* are both associated with hull biofouling and aquaculture. *B. leachii* has been detected in temperate ports, including Hobart and Lady Baron (Flinders Island), Tasmania; Eden and Newcastle, NSW; Melbourne and the greater Port Phillip Bay, Victoria; Esperance, Western Australia and the Queensland tropical ports of Gladstone, Mackay, and Townsville. Thus, the likelihood of *B. leachii* being transferred was 'almost certain' given the port environmental match, the presence of the species in both temperate and tropical waters, and the association with hull biofouling. *D. listerianum* has been detected in temperate water ports such as Burnie, Devonport, Launceston, and Hobart, Tasmania. Thus, the likelihood of *D. listerianum* being transferred to Port Hedland from the Port of Botany Bay was 'possible'.

Six bryozoans were identified as hazard NIMS (Table 6). The bryozoan NIMS were 'almost certain' to be transferred between the two ports as hull biofouling species; however, this likelihood is reduced because of environmental matching. Thus, *Acanthodesia savartii* is typically located in temperate waters, having only been detected in the Australian temperate ports of Launceston, Tasmania; Adelaide, South Australia; and Port Phillip Bay, Victoria and hence the likelihood of transfer was 'possible'. Similarly, *Bugula flabellata*, *Cryptosula pallasiana*, *Schizoporella unicornis*, *Tricellaria occidentalis* and *Watersipora subtorquata* have been detected in 12, 13, eight, six and 15 different Australian temperate ports, respectively, but no tropical ports thus deriving a 'possible' likelihood. The cnidarians *Obelia dichotoma* and *Phialella quadrata* are associated with hull biofouling and ballast water (Watson 1999) and have been only detected in temperate Australia ports (11 and seven, respectively; Watson 1994). Thus the likelihood of transferring the two cnidarian species was also 'possible'.

#### *Assessment of consequence*

Consequently, in this analysis there was the probability that the NIMS would have an impact on biological, economic or human health issues either singularly or synergistically, and was assessed using a consequence matrix (Table 3). Following a precautionary approach, data deficiencies were treated as 'almost certain' consequences.

#### *Voyage 1 – Port Hedland to Cockburn Sound*

Two of the five hazard NIMS (the bryozoan *A. distans*; and the cnidarian *A. secundaria*) were considered to have no discernable impacts on environmental, economic or human health, resulting in an 'insignificant'

Table 6. Risk analysis outcomes for voyage 1: Port Hedland to Cockburn Sound; voyage 2: Port Hedland to the Port of Botany Bay; voyage 3: the Port of Botany Bay to Port Hedland.

Hazard taxa	Likelihood	Consequence	Risk ranking
Voyage 1			
Dinoflagellates			
<i>Coccolodinium polukrikoides</i>	Rare	Moderate	Low
<i>Gymnodinium catenatum</i>	Rare	Moderate	Low
Bryozoa			
<i>Amathia distans</i>	Almost certain	Insignificant	Negligible
<i>Bowerbankia gracilis</i>	Likely	Minor	Moderate
Cnidaria			
<i>Antenella secundaria</i>	Almost certain	Insignificant	Negligible
Voyage 2			
Dinoflagellates			
<i>Coccolodinium polukrikoides</i>	Rare	Moderate	Low
<i>Gymnodinium catenatum</i>	Rare	Moderate	Low
Bryozoa			
<i>Bowerbankia gracilis</i>	Likely	Minor	Moderate
<i>Bugula neritina</i>	Likely	Insignificant	Negligible
<i>Bugula stolonifera</i>	Likely	Insignificant	Negligible
Cnidaria			
<i>Obelia longissima</i>	Likely	Insignificant	Negligible
Voyage 3			
Algae			
<i>Polysiphonia blandii</i>	Possible	Insignificant	Negligible
<i>Solieria filiformis</i>	Possible	Insignificant	Negligible
Ascidians			
<i>Botrylloides leachii</i>	Almost certain	Insignificant	Negligible
<i>Diplosoma listerianum</i>	Possible	Insignificant	Negligible
Arthropods			
<i>Megabalanus rosa</i>	Possible	Insignificant	Negligible
<i>Megabalanus zebra</i>	Possible	Insignificant	Negligible
Bryozoans			
<i>Acanthodesia savartii</i>	Possible	Insignificant	Negligible
<i>Bugula flabellata</i>	Possible	Insignificant	Negligible
<i>Cryptosula pallasiana</i>	Possible	Insignificant	Negligible
<i>Schizoporella unicornis</i>	Possible	Insignificant	Negligible
<i>Tricellaria occidentalis</i>	Possible	Insignificant	Negligible
<i>Watersipora subtorquata</i>	Possible	Insignificant	Negligible
Cnidarians			
<i>Obelia dichotoma</i>	Possible	Insignificant	Negligible
<i>Phialella quadrata</i>	Possible	Insignificant	Negligible

consequence rating (Tables 3 and 5). The bryozoan *B. gracilis* had no discernable impacts on environmental, economic or human health in Australia (Keough and Ross 1999). However, because it has been listed in the OECD catalogue of marine biofouling organisms (Ryland 1965) and is noted as a widespread biofouling species (eg Aliani and Molcard 2003; Koçak 2007), the consequence was categorised as 'minor' (Table 3).

Both species of dinoflagellates (*C. polukrikoides* and *G. catenatum*) produce toxic chemicals when in bloom densities (Kim et al. 1999, 2002; Van Dolah 2000). Dinoflagellate species have been associated with a number of human health illnesses such as diarrhetic shellfish poisoning (DSP), neurotoxic shellfish poisoning

(NSP), paralytic shellfish poisoning (PSP), and ciguatera fish poisoning (Gosselin et al. 1989; Backer et al. 2001). As such, the consequence of the two dinoflagellate species (*C. polukrikoides* and *G. catenatum*) was 'moderate' due to the limited impact in space and time (blooms generally last for less than 2-weeks). It should be noted that in some circumstances where poor medical treatment or lack of public reporting of outbreaks, dinoflagellate toxins can cause human mortality and loss of consumer confidence in the aquaculture industry. In these circumstances, the consequence will be considered significant. Cockburn Sound does not meet these circumstances and hence the consequence for these species is considered to be moderate.

*Voyage 2 – Port Hedland to Botany Bay*

As discussed above, *B. gracilis* represented a ‘minor’ consequence (Tables 3 and 5). The cnidarian, *O. dichotoma*, and the bryozoans *B. neritina* and *B. stolonifera*, are considered to have no discernable impacts on environmental, economic or human health resulting in an ‘insignificant’ consequence rating (Tables 3 and 5).

The impacts that the two dinoflagellates species (*C. polykrikoides* and *G. catenatum*) were discussed above, and for this voyage, these two NIMS were considered to represent a ‘moderate’ consequence. The Port of Botany Bay has excellent medical facilities and hence the consequence for these species remains as ‘moderate’.

*Voyage 3 – Botany Bay to Port Hedland*

All of the 14 identified hazard species are considered to have had no discernable impacts on environmental, economic or human health, resulting in an ‘insignificant’ consequence rating (Table 3).

**Derived risk**

A categorical measure of risk was derived by multiplying likelihood by consequence (Table 4) and used a matrix based on those from the Australian Standards (Standards Australia 2000, 2004). The results for each voyage are summarised in Table 6. The derived risk for voyage 1 was ‘negligible’ for the hazard species *A. secundaria* and *A. distans*. Whereas both *C. polykrikoides* and *G. catenatum* had a ‘low’ derived risk ranking. *B. gracilis* had a ‘moderate’ risk ranking.

For the second voyage, *O. dichotoma*, *B. neritina* and *B. stolonifera* all posed a ‘negligible’ risk (Table 6). The two dinoflagellates (*C. polykrikoides* and *G. catenatum*) had a ‘low’ derived risk ranking. *B. gracilis* had a ‘moderate’ derived risk ranking. Each of the 14 hazard species in Voyage 3 posed a ‘negligible’ risk (Table 6).

**Risk assessment implications**

A semi-quantitative risk assessment was used to determine whether a number of planned voyages within and across state borders in Australian waters by a dredge posed a risk of transporting known NIMS from a proposed port of origin into identified receiving environments. The risk assessment examined movement risk but did not assess the issues associated with transit (ie voyage) survival, the ability of the species to establish within the receiving environment, or the accumulation of biofouling species across multiple voyages. The process is transparent and repeatable but relies on knowledge of NIMS in both the donor and

receiving environments (such as information derived from baseline port surveys or other methods; see Campbell et al. 2007).

Biofouling (and its associated sub-vectors) is a recognised vector of introduced marine and freshwater species (Hewitt et al. 1999a, 2004; Hewitt 2002; Godwin 2003; Lee and Chown 2009). As hull husbandry requirements become prevalent, particularly for international vessel entries, the likelihood of vessels arriving in clean condition or being subject to inspection upon arrival will increase. Ship-owners and operators and biosecurity managers will turn attention to voyage planning and fit for purpose management interventions. These decisions will increasingly be predicated by risk evaluations at the port to port basis.

The implications of risk perception need to be considered. Is biofouling considered a major threat because there is often focus on events such as the F/V Yefim Gorbenko, where the level of biofouling was extreme, yet in most instances biofouling of non-trading vessels may be relatively low? A tendency to ‘arm wave’ (or ‘cry wolf’) when a problem occurs to highlight a threat may result in a number of false positives, which from an environmentally conservative approach is preferable (‘better to be safe than sorry’). However, from a trade precautionary approach (eg Campbell 2009), this may be detrimental to trade and add an extra burden to ship owners.

A special case has been made in relation to the biofouling risk associated with slow moving vessels; within the literature, slow moving vessels, such as barges and dredges, are often portrayed as a vector of concern (see Godwin and Eldredge 2001; Coutts 2004; Godwin et al. 2004; Davidson et al. 2009; Hopkins and Forrest 2010), because they are slow moving (placing little stress on the biofouling community), they have long residence times (Godwin 2003; DAFF 2009; Davidson et al. 2009), and consequently biofouling communities can become well established across large portions of the hull, become large in size (and assumed diversity), and have the ability to remain relatively undamaged during a voyage. The slow pace with which the vessels transit from one region to another also provides species with the opportunity to adapt to the changing water temperatures and salinities. As such, these vessels often arrive in a region heavily fouled (eg Coutts 2004) leading to significant statements of risk both within the peer reviewed literature (Farrapeira et al. 2007; Otani et al. 2007; Davidson et al. 2009; Hopkins and Forrest 2008; Lee and Chown 2009) and the management grey literature (Savarese 2005; Biosecurity New Zealand 2008; <http://www.biosecurity.govt.nz/enter/ships/yachts>; <http://www.marinepests.gov.au/recreational-boating/managing-biofouling>). A result of this concern is the development of biosecurity

management plans to control the movement and the hull husbandry explicitly for these vessels (DAFF 2009).

Consequently, industry within Australia have reacted by implementing mobilisation plans that include haul-out or multiple in-water inspections of vessels prior to arrival in Australian waters, or prior to interstate movement of vessels (eg <http://www.woodside.com.au/NR/rdonlyres/9E1D4BE6-2F00-4F42-BC1B-AC265732202D/0/NIMSMP.pdf>). With increasing levels of hull husbandry of slow moving vessels, the reduction of accumulations of species on hulls is likely to result in a concomitant reduction in risks. The results presented here indicate that the risks of transferring introduced species on a port to port domestic scale was generally negligible to low (Table 6). One exception existed; the non-indigenous bryozoan, *B. gracilis*, had a moderate risk rating. However, it needs to be recognised that each voyage represents a new risk event, with differing locales and potentially different known species being moved. Thus, the results for these three voyages are not spatially or temporally transferable to other port to port voyages. Additionally, the composition of introduced species within a port will change through time with additional invasion events. Example extrapolations by Cohen and Carlton (1995) and Hewitt et al. (2004) suggest that new NIMS arrive every 32 weeks in San Francisco Bay (USA) and every 41.5 weeks in Port Phillip Bay (Australia).

There also needs to be an awareness that the occurrence of vessels with high biofouling tends to be a low frequency event (rare occurrence), but often the level of biofouling is so high that these events are perceived as a greater risk than they may really represent. A case in point, is the F/V Yefim Gorbenko that had >90 tonnes (wet weight) of biological material removed while in dry dock in NZ in 1995 (Hay and Dodgshun 1997). Reports of such heavy biofouling are rarely found in the literature (published or grey).

Currently, further risk assessments are being undertaken by Hewitt et al. (2009) and Azmi (2010) to assess species, vector and sub-vector (eg vessel types) risk profiles. This information, coupled with fine scale port to port risk assessments (or point to point, such as the one presented here) will provide a greater understanding of the synergistic potential of NIMS, vectors and pathways within a domestic marine biosecurity incursion context. The patterns seen in this domestic pathway risk assessment differ from recent international biofouling risk assessments (eg Hewitt et al. 2009) that assess the accumulation of species throughout a vessel's history since the last dry-docking which indicate biofouling is an issue that needs to be dealt with. Thus, the present findings suggest that, not unexpectedly, the risk profile is diminished when

moving from an unmanaged context to one in which international vessels operating domestically have undergone cleaning regimes prior to arrival in Australia.

## Conclusions

This risk assessment found that the risk profiles of individual voyages between source and receiving ports differed, with risk generally ranging from 'negligible' to 'low'. These findings are contrary to the published literature, which has typically focussed on international patterns not domestic patterns, and on the accumulation of risk during the interval between hull cleanings. The attractiveness of this risk assessment approach is the speed with which the analyses can occur, the reduced costs associated with the assessment and the pragmatic approach that it takes. A vessel is not laid-up in port while divers collect samples and the samples are taxonomically analysed and verified, thus reducing the burden on ship owners and operators, while still maintaining a scientifically robust biosecurity risk assessment. The data requirements are not onerous if the ports in question have undertaken baseline port surveys for NIMS. The risk assessment can be used to inform subsequent decisions, including requiring diver inspection and collection of samples for analysis, or a direction to clean or be dry-docked.

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