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A likelihood analysis of the introduction of marine pests to Western Australian ports via commercial vessels

S. Bridgwood and J. McDonald

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

Fisheries Research Division
Western Australian Fisheries and Marine Research Laboratories
PO Box 20 NORTH BEACH, Western Australia 6920

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Enquiries:

WA Fisheries and Marine Research Laboratories, PO Box 20, North Beach, WA 6920
Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: www.fish.wa.gov.au
ABN: 55 689 794 771

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Contents

List of Figures

List of Tables

Executive summary

The following document is an analysis of the likelihood of an introduced marine pest (IMP) being translocated by commercial vessels into Western Australian (WA) state waters. This analysis is presented at the bioregional level (North Coast, Gascoyne Coast, West Coast and South Coast bioregions) and at the port level. The ports include: Albany, Broome, Bunbury, Dampier, Esperance, Fremantle, Geraldton, Port Hedland, Useless Loop and Wyndham. The analyses are based on vessel data supplied by the ports for the period of 2011. As such, all outputs and assumptions are based on data from that period and while the likelihood may change over time, the basic risk principles apply.

From a biosecurity perspective the overall likelihood of the introduction of a marine pest to any region is based on three key factors: the likelihood of inoculation, the likelihood of infection and the likelihood of establishment. In addition, the sociopolitical risk of a vessels profile was also investigated and this was included as a component of the likelihood of inoculation. The assumption underpinning the likelihood of inoculation is that the greater the number of vessel visits from a source with IMPs the greater the risk of IMPs being brought into the recipient port. To assess the likelihood of inoculation of a recipient bioregion and port with an IMP the port data was interrogated for the frequency of visits, types and risk rating of vessels.

The sociopolitical risk considers the flag of registry under which the vessel operates and whether that country of registry has signed the International Maritime Organisation International Convention for the Control and Management of Ships' Ballast Water and Sediments Ballast Water Management (IMO BWM). The assumption is that if it's a flag of convenience (FOC), the overall vessel management standards may be lower, thus these vessels may have a greater likelihood of translocating a marine pest.

The assumption underpinning the likelihood of infection and establishment is that in order for a WA port to be infected with an IMP, there needs to be a viable source of IMPs at the last port of call (LPOC), and those IMPs have to be compatible (in terms of salinity and temperature tolerances) with the recipient WA port.

To assess the likelihood of infection and establishment of 42 IMPs listed on the *Department of Fisheries (DoF) IMP list* (as of 22/8/2012, see Appendix 1), a three-step process was used. Firstly, using the locations listed as LPOCs from all 10 ports, a database was generated of the distribution of these species. Secondly, if a vessel's LPOC was from a location that contained an IMP then it was assumed the vessel would be inoculated with the IMP. Thirdly, salinity and temperature tolerances of that species were compared to the environmental salinity and temperature values of the WA port to determine compatibility.

The greatest inoculation risk (described as the vessel origin that poses the greatest risk) to the North Coast bioregion was from vessels that travelled within state waters (intrastate), whereas for the other bioregions the greatest risk was from international vessels (Table 1). There was a very high compatibility between the potential incoming marine pests and the environments of the North Coast, West Coast and South Coast bioregions, but compatibility was only moderate for the Gascoyne Coast bioregion (Table 1). The greatest infection and establishment risk to the North Coast and South Coast bioregions was from China. Japan was the LPOC that represented the greatest infection and establishment risk to the Gascoyne Coast bioregion and Singapore was the LPOC that represented the greatest infection and establishment risk to the West Coast bioregion (Table 1).

Overall results for the individual ports were varied, with the likelihood of inoculation varying from low to high (Table 1). The inoculation risk for the ports it is described as the overall inoculation risk which takes into account the vessel risk types, the frequency of visits and the duration of stay. The likelihood of infection and establishment is a measure of the compatibility between the potentially incoming IMP and the recipient port. The IMP compatibility varied from low to very high. The international LPOCs which posed the greatest infection and establishment risk were all within Asia and the most common domestic LPOCs which posed the greatest risk were Port Adelaide and intrastate sources (Table 1).

Table 1 The inoculation risk and the infection and establishment risk for the bioregions and ports. The values for the IMP compatibility are: very high (85–100%), high (70–84%), moderate (50–69%) and low (<50%)

	Inoculation risk	Infection and establishment risk		
		IMP compatibility	LPOCs	
Bioregion	**Greatest inoculation risk**		**Overall**	
North Coast	intrastate vessels	very high	China	
Gascoyne Coast	international vessels	moderate	Japan	
West Coast	international vessels	very high	Singapore	
South Coast	international vessels	very high	China	
Port	**Overall inoculation risk**		**International**	**Domestic**
Wyndham	low	high	Indonesia	Broome
Broome	moderate	n/a	n/a	n/a
Port Hedland	low	low	China	Dampier
Dampier	high	high	China and Japan	Geelong
Useless Loop	low	moderate	Japan	Port Adelaide
Geraldton	low	high	China	Kwinana and Fremantle
Fremantle	high	high	Singapore and Indonesia	Port Adelaide
Bunbury	low	high	Japan	Port Adelaide
Albany	low	very high	Japan	Port Adelaide
Esperance	low	very high	China	Port Adelaide, Portland Port and Kwinana

n/a indicates no data was available for analysis

This analysis provided an increased understanding of the risks posed to recipient ports from vessel and donor ports by highlighting where (LPOC) the greatest risk to a WA port comes from and the pest species most likely to infect a recipient port.

1.0 Introduction

Introduced marine pests (IMPs) can have negative impacts on the environment, the sociocultural value of a location, can compromise human health standards and be costly to the economy. Typically the goal of biosecurity is to prevent IMP incursions, as once established they are known to be difficult and expensive to eradicate. For example, the outbreak of the black striped mussel (*Mytilopsis sallei*) in Darwin cost more than $2 million to eradicate (Bax *et al.* 2002).

There are two key vectors for IMP translocation: ballast water and hull fouling. Being an ocean-bound nation, Australia is particularly reliant on shipping, both as a means of transporting goods in, out and around the country, and to support other primary industries such as commercial fishing and oil and gas production. For example, over 95% of Australia's current imports and exports are transported by sea. Western Australia's (WA's) export value contributed 44% of the total Australian export value in 2013 (Department of Transport 2013). As such, WA is particularly susceptible to IMPs from shipping vectors.

This project examined commercial shipping data consisting of 11 882 vessel visits to 10 WA ports during 2011. Data was analysed in two ways. The first used the Department of Fisheries' (DoF), WA aquatic resources bioregions which consists of the North Coast, Gascoyne Coast, West Coast and South Coast. For this analysis, ports that occurred in the same bioregion were grouped together i.e. data was pooled across the ports. The second analysed the data at the individual port level. A total of 15 WA ports were initially approached for vessel data, however five of these ports either did not provide the vessel data or the vessel data which they routinely recorded was not sufficient for us to undertake the analysis. The 10 ports that were analysed were Albany, Bunbury, Broome, Dampier, Esperance, Fremantle, Geraldton, Port Hedland, Useless Loop and Wyndham.

1.1 Aims and objectives

From a biosecurity perspective the introduction of a marine pest to any region is based on multiple factors. For the purpose of this analysis, these factors were grouped into two themes; the likelihood of inoculation and the likelihood of infection and establishment.

It is acknowledged that using a particular list of IMP could be perceived as a limiting factor in the analysis. However a list was used because it provides managers, port authorities and other stakeholders a watch list of species which they are then able to use for pre-border protection and for post incursion surveillance. The DoF IMP list (Appendix 1), comprised of 89 marine species of concern was used for the analysis. The 89 species were categorised into high, medium and low risk based on their impact ranking following the methodology of Hewitt *et al.* (2010), and taking into account the WA perspective. Only the moderate and high risk species were used in the analysis (n = 42).

There were two aims of the analysis. The first was to examine the likelihood of inoculation of an IMP to each port and bioregion. The assumption was that the greater the number of vessel visits from a source with an IMP, the greater the risk that an IMP would be brought into the recipient port (i.e. a positive linear relationship). An additional assumption was that if the vessel was registered under a flag of convenience (FOC) then the vessel management standards may be lower, thus the vessel would have a greater likelihood of translocating an IMP (i.e. sociopolitical risk).

The second aim was to provide each port and bioregion with a description of the likelihood of infection and establishment of compatible IMPs. The assumption being that in order for a WA port or bioregion to be infected with IMP there needs to be a viable source of IMPs, and those species have to be compatible (in terms of salinity and temperature tolerances) with the recipient port.

The specific objectives were to:

1. assess and characterise the vessel types and the individual and overall risk rating profiles of vessels visiting the bioregions and the ports
2. provide each bioregion and port with an analysis of the potential risk posed by FOC vessels or those perceived as having lower vessel maintenance and thus lower environmental standards
3. identify and characterise the last ports of call (LPOCs) that pose the greatest risk to each bioregion and port as a function of the number of vessel visits from and the number of species from, a particular source
4. identify and characterise the potential moderate and high risk IMPs that may pose a threat of introduction to the bioregions and the ports
5. identify any information gaps that limited the ability to undertake the above and provide recommendations to address these gaps and to improve future analyses

2.0 Methods

This likelihood analysis examined vessel data from 10 WA ports, including Albany, Bunbury, Broome, Dampier, Esperance, Fremantle, Geraldton, Port Hedland, Useless Loop and Wyndham.

Data was analysed in two ways. The first used DoF's, WA aquatic resources bioregions which consist of the North Coast, Gascoyne Coast, West Coast and South Coast (Figure 1). For this analysis, ports that occurred in the same bioregion were grouped together i.e. data was pooled across the ports.

The second analysed the data at the individual port level. For the majority of the ports, the analysis was based on data provided by the port authorities and ports from 2011. However, the Dampier Port data provided did not include all the required information for analysis, so as an alternative, 2011 data from Lloyd's (i.e. Lloyd's List Intelligence database) was used. Broome Port data also did not include all of the required information (no information regarding LPOC) however as the Broome Port data consisted of 947 recorded vessel visits and the Lloyd's data only consisted of 231 recorded vessel visits it was decided to utilise the port data. Data outputs and graphs were generated using Excel 2010 and R version 3.0.2 (R Core Team 2013). The world maps were generated using the R package 'maps'.

From a biosecurity perspective the overall likelihood of the introduction of a marine pest to any region is based on multiple factors. For the purpose of this analysis, these factors were grouped into two categories; the likelihood of inoculation and the likelihood of infection and establishment. Often, components of the same data were used across and between these two likelihoods.

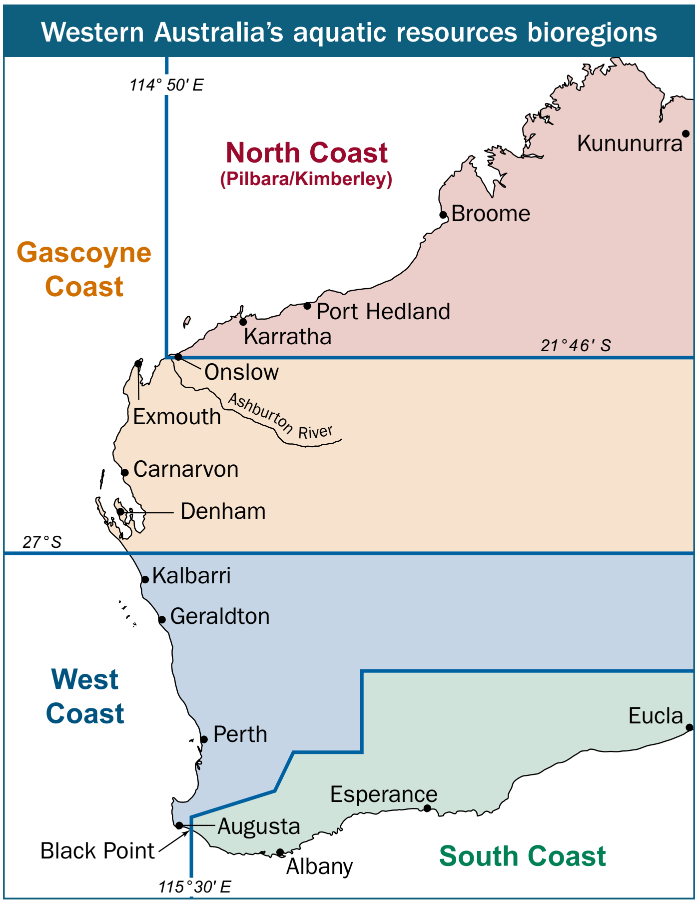


Figure 1 Map of the DoF WA aquatic resources bioregions

2.1 Inoculation likelihood

Inoculation likelihood assumes that the greater the number of vessel visits from a source with IMPs the greater the risk of IMPs being brought into the recipient port i.e. a positive linear relationship.

The aim was to analyse the vessel types, their risk rating and movements for a particular WA port. The process used and the outputs generated are shown schematically in Figure 2 and include:

1. total number of commercial vessels visiting a port in one year (i.e. 2011)
2. repeat visits: frequency of same vessel visiting same port
3. types of vessels (n = 13) and their risk rating (low/moderate/high)
4. Number and percentage of visits by source
5. average duration of stay (in days mean ± SE)
6. frequency (%) from different sources i.e. international/interstate/intrastate.

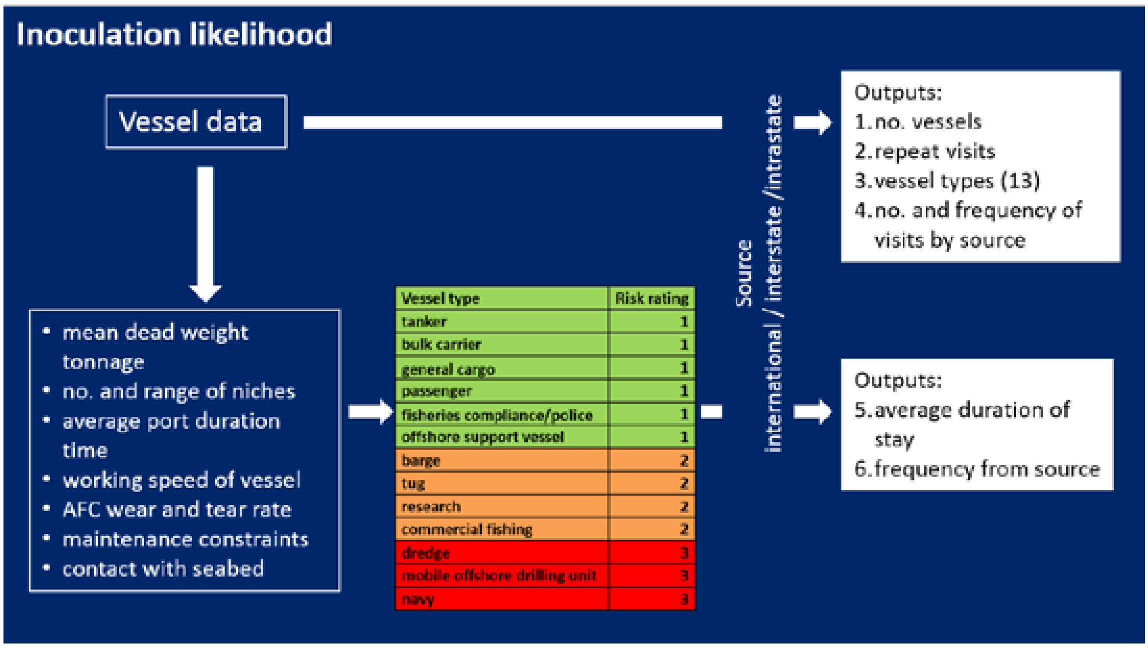


Figure 2 Schematic diagram for the process behind the analysis of the inoculation likelihood

Data used included the vessel name, the LPOC and the duration of stay within the WA port of interest. Additional information was developed including whether the LPOC was international, interstate or intrastate. For international LPOCs the data was grouped into countries, and for domestic LPOCs they were referred to by the port name. Vessels were grouped into one of 13 different vessel types using a number of arbitrary characteristics, including the type of cargo and the vessels activity and function. Vessels were assigned to the different types based directly on the port data provided or following interrogation of the online database MarineTraffic.com using the available port data.

Initial analysis determined the total number of vessel visits for the one-year period per WA port and summarised the contribution (as a percentage) of the different vessel types visiting the WA port. In addition, the frequency of vessel visits to a WA port was quantified by interrogating the data by vessel name. The assumption was that although a vessel may only stay a short while, if its frequency of visits is high then the risk of inoculation is increased i.e. there is greater opportunity for inoculation. Vessel names were allocated one of four categories based on the number of times that vessel's name was repeated in the port data. It is acknowledged that from time-to-time vessels change their names; however it was beyond the scope of this analysis to account for those changes. The frequencies for the four categories were:

1. single visits
2. 2–5 visits
3. 6–10 visits
4. >10 visits

Vessel types may not consistently reflect a vessel's size or activity (Ruiz *et al.* 2000), thus it is a widely recognised practice to further categorise them based on established risk determination methods. Risk determination methods reflect the inherent differences in vessels, including management regimes, voyage characteristics and activity types (see Lewis *et al.* 2004; McGee *et al.* 2006; McDonald *et al.* 2008; Hulme 2009; Hewitt *et al.* 2011). Using established risk determination methods, the vessel types were categorised into: (1) low risk, (2) moderate risk, and (3) high risk. This categorisation included consideration of the following factors:

1. **Mean dead weight tonnage (DWT)**: a proxy for biofouling potential
   Assumption: the bigger the vessel the greater the surface area for biofouling.
2. **Number and range of niche areas** e.g. sea chests, anodes and stabilisers
   Assumption: the more niche areas the greater the potential for retaining biofouling.
3. **Port duration time**
   Assumption: the longer the duration of stay the greater the likelihood of inoculation of the recipient port.
4. **Working speed of the vessel**
   Assumption: the slower the vessel the greater the likelihood that an IMP can settle on the hull.
5. **Antifouling coating (AFC) wear and tear rate**
   Assumption: vessels that have an operating profile that causes increased wear and tear on the AFC will have an increased likelihood of IMP settlement on the hull.
6. **Maintenance constraints**
   Assumption: vessels that have structural profiles that inhibit effective maintenance of AFC application will have an increased likelihood of IMP settlement on the hull.
7. **Contact with seabed**
   Assumption: vessels that have an operating profile that causes contact with the seabed have a greater likelihood of IMP settling directly on the hull or being entrained along with sediment.

For each factor a value of 0, 1, 2 or 3 was assigned to a vessel type. The values were then averaged across the factors and rounded to the nearest whole number. This provided the overall level of risk for each type i.e. the risk rating (Table 2). A low risk rating of 1 is represented by the colour green, a moderate risk rating of 2 is represented the colour orange and a high risk rating of 3 is represented by the colour red (Table 2). Navy vessels were initially assessed as a moderate risk using the above process. However, the authors considered that due to their unusual operating profiles e.g. engagement of suspected illegal entry vessels (SIEVs) and inability to provide LPOC data, a moderate risk score did not truly reflect their inherent risk. As such, navy vessels were assigned a risk rating of high.

Table 2 The factors and their assigned values used to determine the overall risk rating for each vessel type

Vessel types	Factors mean DWT	no. and range of niches	port duration time	working speed	AFC* wear and tear rate	maintenance constraints	contact with seabed	Overall risk rating
TANK: tankers	3	1	1	1	1	2	0	**1**
BULK: bulk carriers	3	1	1	1	1	2	0	**1**
CARGO: general cargo	3	1	1	1	1	2	0	**1**
PASS: passenger	1	2	1	1	1	2	0	**1**
FISH: fisheries compliance/water police	1	1	3	1	1	1	0	**1**
OFSV: offshore support vessel	1	1	2	1	2	1	0	**1**
BARGE: barge	1	1	2	3	3	1	0	**2**
TUG: tug	1	2	2	3	3	2	0	**2**
RESE: research	1	2	2	2	2	2	2	**2**
COMF: commercial fishing	1	3	2	3	2	2	2	**2**
DREDGE: dredge	1	3	3	3	3	3	3	**3**
MODU: mobile offshore drilling unit/floating production storage offshore vessel	3	3	2	3	3	3	3	**3**
NAVY: navy	NA	NA	NA	NA	NA	NA	NA	**3**

**AFC: antifouling coating*

In order for an IMP to inoculate a port, the organism either needs to undergo a reproductive process or be dislodged from the vessel while in that port. Intuitively, this implies that the longer a vessel stays in a port the greater the chances that either of these will happen and the port will become inoculated with an IMP from that vessel (Hewitt *et al.* 2011). The number of days a vessel type was in the port was determined by using the arrival and departure dates and times provided in the port data. The duration of stay (mean ± SE of days) was then calculated by source location (LPOC: international/interstate/intrastate) for the different vessel types and their risk. The contribution of the different vessel types and their risk rating (expressed as a percentage) were also examined by their source location (LPOC: international / interstate / intrastate).

2.1.1 Sociopolitcal risk

The authors considered that the sociopolitical risk of a vessel's profile was another component worthy of investigation. This was based on the premise that the flag of registry under which the vessel operates (i.e. standards) and the willingness of that flag state to sign up to international conventions (e.g. IMO BWM), could affect the propensity of a vessel to translocate IMPs. The assumption is that if it's a FOC, the overall standards to which the vessel adheres may be compromised, including environmental standards, hence they will have a greater propensity to harbour marine pests.

A commercial vessel has to be registered; however its operators can choose which country the vessel is registered with i.e. flag state. Standards that a vessel needs to meet for registration vary greatly between countries and not all countries have ratified and enforce international standards. Therefore the choice of flag state can represent a behavioural risk from operators (Knudsen & Hassler 2011). The reasons for choosing a FOC state are varied but could include tax avoidance, the ability to avoid national labour and environmental regulations and the ability to hire crews from lower-wage countries. National or closed registries typically require a ship be owned and constructed by national interests, and be at least partially crewed by its citizens (International Transport Workers' Federation (ITF) 2012).

The ITF believes there should be a 'genuine link' between the real owner of a vessel and the flag the vessel flies, in accordance with the United Nations Convention on the Law of the Sea (UNCLOS). There is no such genuine link in the case of FOC registries. The following 34 countries have been declared FOCs by the ITF's Fair Practices Committee, a joint committee of ITF seafarers' and dockers' unions (ITF website):

Antigua and Barbuda	Honduras
Bahamas	Jamaica
Barbados	Lebanon
Belize	Liberia
Bermuda (UK)	Malta
Bolivia	Marshall Islands (USA)
Burma	Mauritius
Cambodia	Moldova
Cayman Islands	Mongolia
Comoros	Netherlands Antilles
Cyprus	North Korea
Equatorial Guinea	Panama
Faroe Islands	São Tomé and Príncipe
French International Ship Register (FIS)	Saint Vincent
German International Ship Register (GIS)	Sri Lanka
Georgia	Tonga
Gibraltar (UK)	Vanuatu

Currently there is no convention for biofouling, thus consideration was only given as to whether or not a country was a signatory to the IMO BWM as of 31 July 2013. The IMO BWM was adopted in 2004 and as of July 2013 the convention has been ratified by 37 countries (i.e. 30.32% of world tonnage). Although the required number of countries ratifying the convention has been met (i.e. 30) it will not come into force until the percentage of world tonnage carried by signatories to the convention reaches 35% (Pughiuc 2010).

The aim was to provide each port with a detailed analysis of the potential risk posed by vessels with perceived low standards. The process used and outputs generated are shown schematically in Figure 3 and included the:

1. proportion of all flag states coming into the port that have signed the IMO BWM
2. proportion of flag states coming into the port that fly a FOC
3. proportion of FOCs that have signed the IMO BWM.

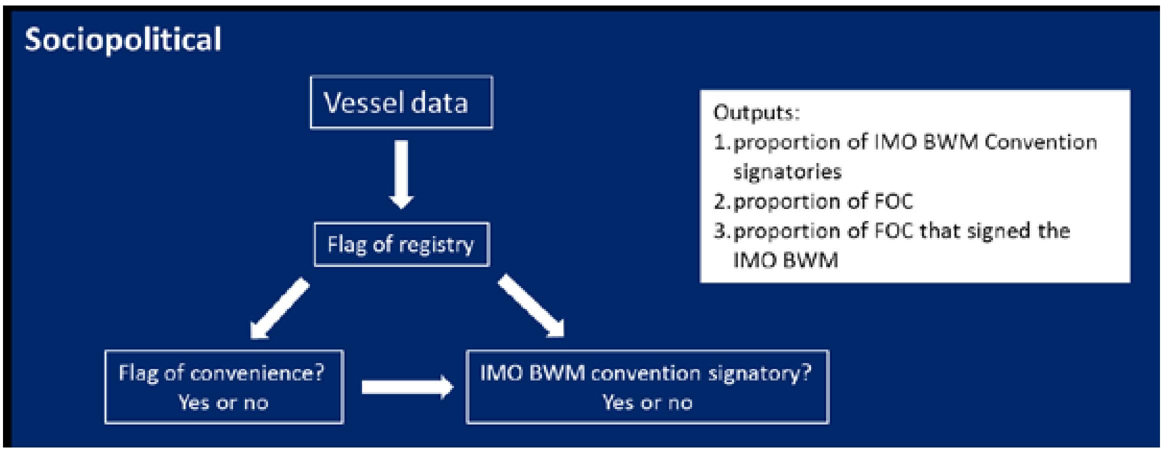


Figure 3 Schematic of the process and outputs used to analyse the sociopolitical risk of vessels

The analyses of the above data provided a measure (low, moderate, high) of the likelihood of inoculation for a particular port.

2.2 Infection and establishment likelihood

In order for a WA port to be infected with an IMP there needs to be a viable source of species, and those species have to be compatible (in terms of salinity and temperature tolerances) with the recipient port.

The aim was to provide each port with a description of the likelihood of infection and establishment of compatible IMPs. The process used and the outputs generated are shown schematically in Figure 4 and included the:

1. impact rank (high, medium or low) of the marine IMPs on the *DoF IMP list* (Appendix 1)
2. IMP status for the vessel's source (international and domestic)
3. number of compatible IMPs for each port
4. LPOC with the greatest infection and establishment risk to each port.

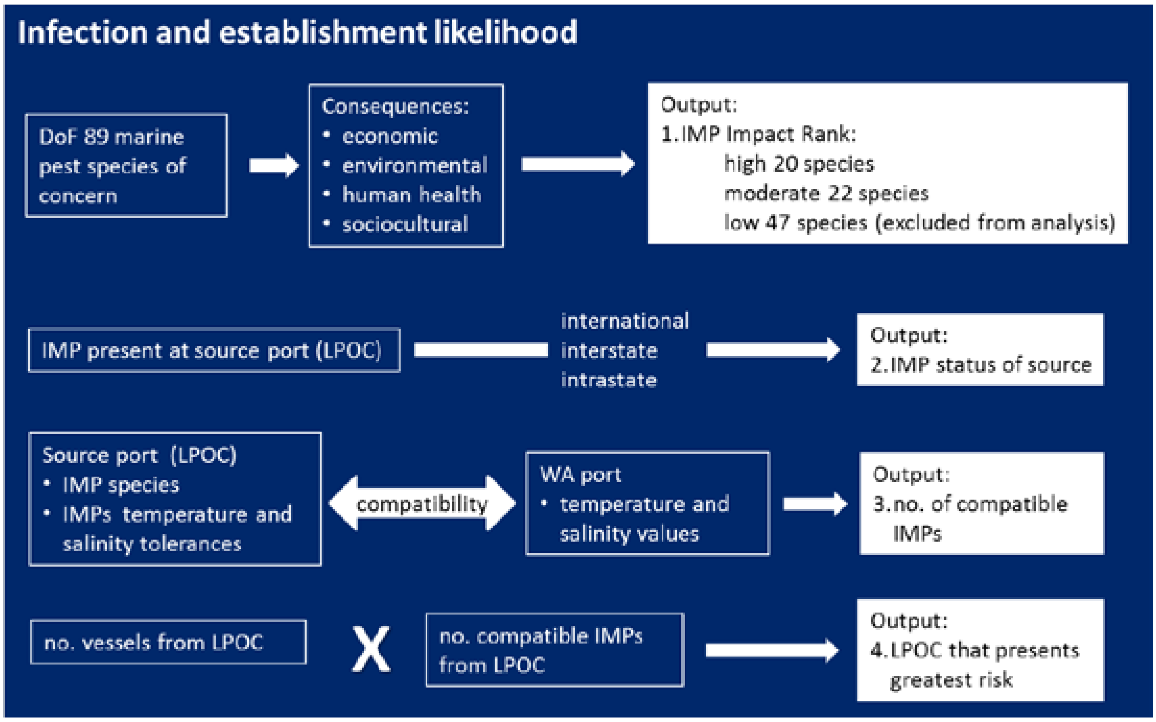


Figure 4 Schematic diagram of the process behind the analysis of the infection and establishment likelihood

The *DoF IMP list*, comprised of 89 marine species of concern, was used for the analysis. The 89 species were categorised into high, medium and low risk based on their impact rank following the methodology of Hewitt *et al.* (2011), with consideration given from a WA perspective. The impact rank of each species was assessed against four core consequences: environmental; economic; sociocultural; and human health (see Hewitt *et al.* (2011) for a detailed description of the methodology).

Environmental consequence encompasses the 'biological and physical characteristics of an ecosystem being assessed, excluding extractive use and aesthetic value' (Hewitt *et al.* 2011 p 7). Economic consequence encompasses the 'components within an ecosystem that provide a current or potential economic gain or loss' (Hewitt et al 2011 p 7). Sociocultural consequence encompasses the 'values placed on a location in relation to human use for pleasure, aesthetic and generational values' (Hewitt *et al.* 2011 p 7). Human health consequence encompasses ‘the value of a safe and healthy society shared equally across generations and socioeconomic groups’ (Hewitt *et al.* 2011 p 7).

Hewitt *et al.* (2011) assigned a value of 1, 3 or 5 for each consequence to each species based on current knowledge of that species. For each species, the values across the four consequences were summed to give an overall rating value. For the most part, the authors used the values as allocated by Hewitt *et al.* (2011) however the analysis was approached from a WA perspective. Thus, adjustments were made where necessary and species that were not considered in Hewitt *et al.* (2011) were incorporated.

To derive the impact rank for the *DoF IMP list* the authors devised a ranking scheme. A low impact rank was assigned to those species with an overall ranking value of ≤3, a moderate impact rank to those species with an overall ranking value of 3 – 5 and a high impact rank to those species with an overall ranking value of >5. This resulted in 21 high risk species, 22 medium risk species and 47 low risk species. Only the IMPs with a high and moderate risk (42) were used for the analysis (see Appendix 1).

For the 42 IMPs being considered, invasive species databases were interrogated for location data (country name) and temperature and salinity tolerance values. These databases included:

1. National Introduced Marine Pest Information System (NIMPIS)
2. Delivering Alien Invasive Species Inventories for Europe (DAISIE)
3. Invasive Species Compendium (ISC)
4. Global Invasive Species Database (GISD)
5. National Exotic Marine and Estuarine Species Information System (NEMESIS)
6. World Register of Marine Species (WoRMS)
7. European Network on Invasive Alien Species (NOBANIS)

To ensure consistency with other similar analyses (see Hayes & Sliwa 2003; Barry *et al.* 2008; Hewitt *et al.* 2011) it was assumed that if a pest species was present in an international source country, then the pest species was present in all ports of that country. The authors acknowledge that available pest species distribution information is most likely limited, as some locations may not monitor for or record marine pest species. As there was no way to account for this, it was assumed that if a species was not recorded for a location then the species did not inhabit that location.

Based on the LPOC vessel data, source locations for IMPs for each WA port were identified. International LPOC locations were assigned to their country, and following the above rationale, were assumed to be infected if the IMP was present in that country. Domestic sources were left as the actual port name but grouped into interstate and intrastate. It is acknowledged that there are many contributing factors that need to be met for a vessel to become infected with a marine pest species. However, for the purpose of this analysis the authors assumed that every vessel that was in the presence of an IMP was infected.

Next, the species that posed a threat to a specific recipient port were identified. To do this, the authors used what is referred to as a ‘species-specific environmental matching approach’ (based on temperature and salinity). That is, the number of potential incoming species was reduced to those with temperature and salinity tolerances that were compatible with the temperature and salinity values of the recipient WA port.

This method is different to other environmental matching methods because it uses species-specific temperature and salinity tolerances, rather than 'surrogate' values. For example, 'port to port' environmental matching for marine pest compatibility compares the environmental characteristics of 'Port A' to 'Port B' (see Clarke *et al.* 2004). However, direct comparison of one port's temperature and salinity values to another may actually exclude potentially viable pest species. For example, Portland Port (United States of America (USA)) has a water temperature range of –2 °C to 14 °C and Port Hedland Port (Australian) has a water temperature range of 20 °C to 32 °C. A direct comparison between these ports would conclude that they are dissimilar and hence species from one would not be able to survive in the other (Figure 5). However, the species-specific environmental matching method that the authors used showed that a marine pest such as *Balanus improvisus* (with a water temperature tolerance of 0 °C to 35 °C), known to exist in Portland Port, would also be able to exist in Port Hedland Port as its temperature tolerances are compatible (Figure 5). Thus, there is a translocation risk for this species.

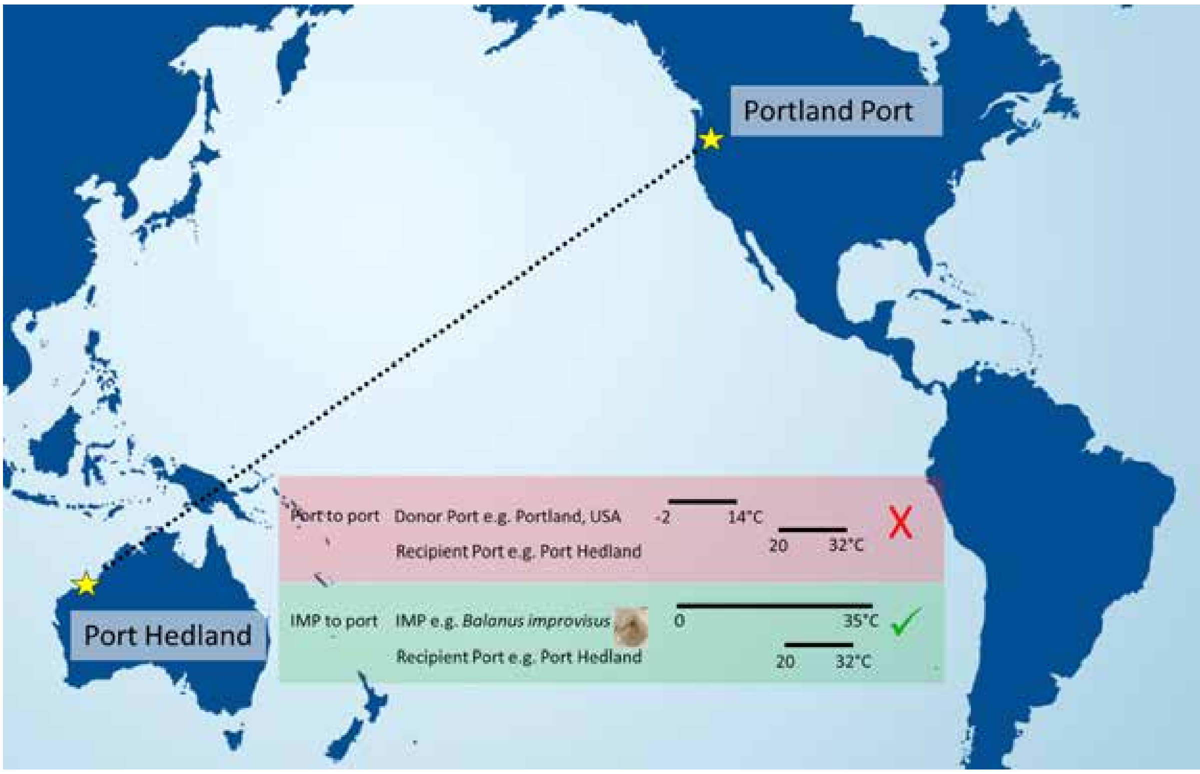


Figure 5 Example of the different results that can arise when 'port to port' and 'species-specific' comparisons are used

Another method is to match the environmental characteristics of a donor region (where a pest is known to exist) to the recipient region of interest (see Hewitt *et al.* 2011). This is a very broadscale, bioregional approach that was considered inappropriate for this finer-scale analysis targeted to inform individual WA ports.

As previously stated, temperature and salinity tolerance values for the 42 pest species were sourced from various databases. If tolerance values for a species differed between the databases, the most extreme values were used for the analysis. However, it is possible that a species may be able to tolerate a wider range in temperature and salinity values than is currently known or reported. For this reason, a precautionary buffer was also added to the temperature and salinity values. The buffers used were ± 3 °C for temperature and ± 3 ppt for salinity. For pest species where temperature and salinity data was lacking, it was assumed they could survive in the recipient WA port (i.e. a precautionary principal was applied). Temperature and salinity data for the WA ports was acquired from one of two sources: the ports themselves or from Appendix 6 in Clarke *et al.* (2004). It was assumed that if a species' tolerances were compatible with the temperature and salinity values of the recipient WA port, then the pest would be able to survive in that WA port. It was also assumed that the recipient WA port offered suitable, available habitat for the pest species to colonise.

Compatible pest species and their frequency of occurrence were quantified internationally by country and domestically by port location. The compatible pests were also separated into high or moderate risk based on the impact rank determined previously.

The LPOCs that posed the greatest infection and establishment risk for each WA port were identified. The risk value was obtained for each LPOC by multiplying the number of vessels visits from each LPOC by the number of compatible IMP present at the same LPOC, accounting for the cumulative effect of these two factors. The risk values of each LPOC were expressed as a relative percentage of the largest value identified for that port, and ranked from largest to smallest. The LPOC with the highest percentage value was determined as the LPOC that posed the greatest risk to the WA port.

3.0 Bioregional analysis

The DoF uses a bioregional approach to managing the state's fisheries and aquatic resources (Fletcher & Santoro 2013). Consistent with this approach, the authors grouped ports that occur within the same bioregion, thus providing an overall analysis of the likelihood of inoculation, infection and establishment of IMPs to a bioregion. The following bioregions were analysed:

1. North Coast bioregion, incorporating data from Wyndham, Broome, Port Hedland and Dampier ports
2. Gascoyne Coast bioregion, incorporating data from Useless Loop port
3. West Coast bioregion, incorporated data from Geraldton, Fremantle and Bunbury ports
4. South Coast bioregion, incorporating data from Albany and Esperance ports.

Due to the lack of LPOC data from Broome Port, the Broome Port data was not included in the infection and establishment likelihood analysis for the North Coast bioregion. Please note that data was only available for one port in the Gascoyne Coast bioregion—Useless Loop. Hence, summary statistics from this port are presented here and a more detailed analysis is presented later in the document (see Useless Loop Port).

3.1 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include the inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. Refer to the Methods section for a full explanation of these factors.

3.1.1 North Coast bioregion

3.1.1.1 Inoculation likelihood and sociopolitical risk

The North Coast bioregion recorded 8195 vessel visits in 2011 and just over half of these were rated as low risk vessels (4858 or 59.3%, Table 3). Visits from vessels with a moderate risk rating accounted for 3221 visits (39.3%) and vessels with a high risk rating accounted for 116 visits (1.4%).

The greatest inoculation risk to the North Coast bioregion was from vessels that travelled within state waters i.e. intrastate movements (4491 or 54.8%, Table 3). These vessels were mostly rated as moderate risk vessels (2766 or 61.6%). This result has implications for the management of vessel movements within the state in that if an IMP was introduced to a port in the North Coast bioregion, there is a significant risk that the IMP could be translocated to other ports within the bioregion. International visits made up about a third of visits (2641 or 32.2%). The remaining visits (87 or 13%) were from interstate locations.

Vessels visiting the North Coast bioregion were registered from 55 different flag states, 15 (27.3%) of which were listed as having a FOC. The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 29.8% of all visits to the North Coast bioregion. Of the 55 flag states only 17 (15.6% of total visits) have ratified the IMO BWM. Further analysis revealed that 3 of these 17 were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to only 8.1% of total visits to the North Coast bioregion. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

Table 3 The number of vessel visits for each bioregion (North Coast, West Coast and South Coast), examined by the LPOC (international, interstate, intrastate and unknown) and the vessel risk rating, high, moderate or low.

LPOC	Vessel risk rating	Bioregion			
		North Coast	Gascoyne	West Coast	South Coast
International	high	3	0	5	0
	moderate	53	0	51	0
	low	2585	45	1585	188
Total		**2641**	**45**	**1641**	**188**
Interstate	high	0	0	8	0
	moderate	12	0	12	1
	low	75	0	605	33
Total		**87**	**0**	**625**	**34**
Intrastate	high	30	0	4	0
	moderate	2766	0	215	1
	low	1695	4	622	75
Total		**4491**	**4**	**841**	**76**
Unknown	high	83*	0	13	2
	moderate	390*	0	6	0
	low	503*	0	9	2
Total		**976***	**0**	**28**	**4**
Total number of vessel visits per bioregion		**8195**	**49**	**3135**	**302**

*includes vessel data from Broome Port.

3.1.1.2 *Infection and establishment likelihood*

There were 41 IMP species present at LPOC locations and of these, 37 (90%) had temperature and salinity tolerances compatible with the North Coast bioregion (Table 4). These 37 were comprised of 18 species with a high impact ranking and 19 species with a moderate impact ranking. Every compatible IMP was present at international LPOC locations. In terms of domestic presence, six compatible IMPs were present interstate and two were present intrastate.

There were 23 international LPOCs that contained an IMP with either a high and/or moderate risk rating that was compatible with the North Coast bioregion's environment (Figure 6). USA had the greatest number of IMPs with 29 species, 16 of which were high impact ranked species. Japan had the next greatest with a total of 20 species (13 with a high rating), followed by Thailand with 16 species (11 with a high rating) and China, also with 16 species (10 with a high rating). Compatible IMPs were also recorded at 14 domestic LPOCs, 7 each for interstate and intrastate, with only the interstate LPOCs containing high risk IMPs.

When the cumulative effect of the number of vessel visits from a LPOC and number of IMPs present at that LPOC is considered, the greatest infection and establishment risk to the North Coast bioregion was from China (Figure 7). LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 7.

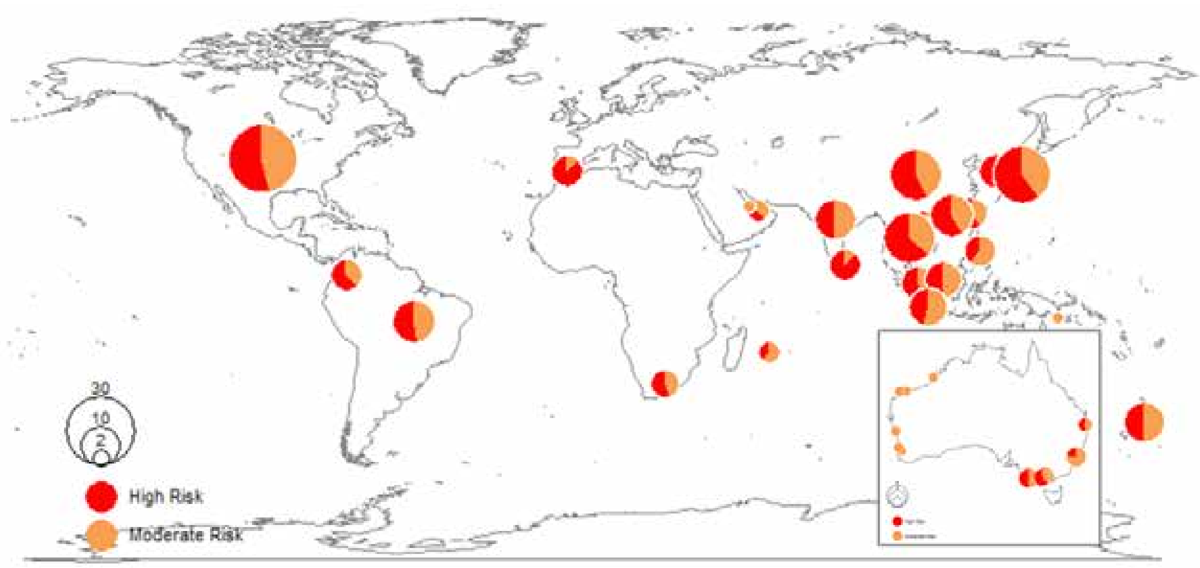


Figure 6 LPOC locations (international and domestic (inset)) of compatible high and moderate risk IMPs for the North Coast bioregion

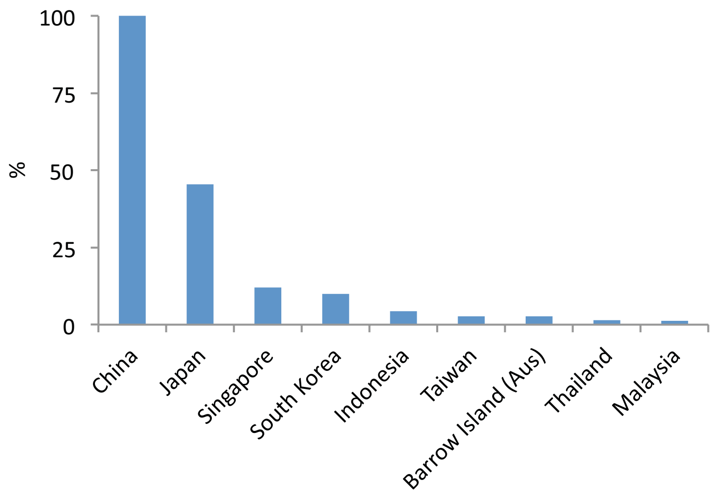


Figure 7 Ranking of the infection and establishment risk posed to the North Coast bioregion by international and domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. China 100%)

3.1.2 Gascoyne bioregion

3.1.2.1 Inoculation likelihood and sociopolitical risk

The Gascoyne Coast bioregion recorded 189 vessel visits in 2011 and all were from vessels with a low risk rating (Table 3). Analysis of the LPOCs showed that most of the vessel visits to the Gascoyne Coast bioregion (45 or 91.8%) were from international LPOCs. The remainder were from intrastate locations (4 or 8.2%). Therefore, vessels travelling from international LPOCs pose the greatest inoculation risk to the Gascoyne Coast bioregion.

Vessels visiting the Gascoyne Coast bioregion were registered from 8 different flag states and of these, 5 (62.5%) were listed as having a FOC. The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 63.3% of all visits to the Gascoyne Coast bioregion. Of the 8 flag states only 4 (22.4% of total visits) have ratified the IMO BWM. Further analysis revealed that all four were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 0% of total visits to the Gascoyne Coast bioregion. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

3.1.2.2 Infection and establishment likelihood

There were 28 IMP species present at LPOC locations, 19 (68%) of which had temperature and salinity tolerances compatible with the Gascoyne Coast bioregion (Table 4). These 19 were comprised of 12 species with a high impact ranking and 7 species with a moderate impact ranking. Every compatible IMP was present at international LPOCs, however there was only one IMP present domestically (i.e. intrastate LPOC.

There were 11 international LPOCs that contained an IMP with either a high and/or moderate risk rating that was compatible with the Gascoyne bioregion's environment (Figure 8). Japan had the greatest number of IMPs with 14 species, 10 of which were classed as high risk. Thailand had the next greatest total of 12 species (9 with a high rating) followed by India with 8 species (5 with a high rating). Compatible IMPs were only recorded at two domestic intrastate LPOCs—Dampier and Kwinana.

When the cumulative effect of the number of vessel visits from a LPOC and number of IMPs present at that LPOC is considered, the greatest infection and establishment risk to the Gascoyne Coast bioregion was from Japan, closely followed by Malaysia (Figure 9). LPOCs that had negligible relative infection and establishment risks (i. e. <1%) are not shown in Figure 9.

Figure 8 LPOC locations (international and domestic (inset)) of compatible high and moderate risk IMPs for the Gascoyne Coast bioregion

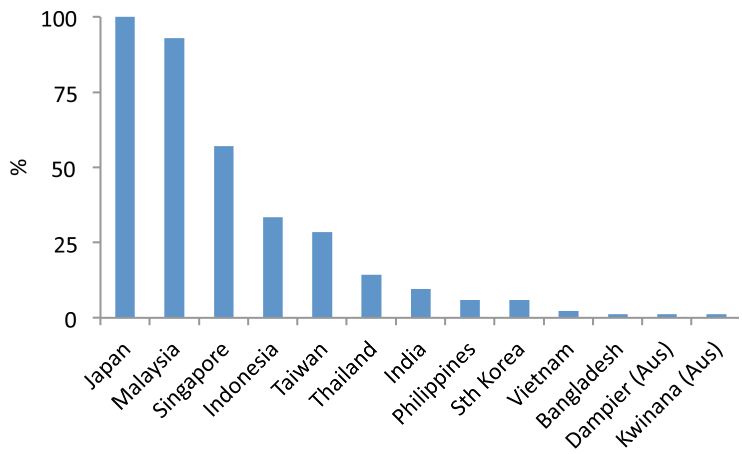


Figure 9 Ranking of the infection and establishment risk posed to the Gascoyne Coast bioregion by international and domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Japan 100%)

3.1.3 West Coast bioregion

3.1.3.1 Inoculation likelihood and sociopolitical risk

The West Coast bioregion recorded 3135 vessel visits in 2011, the majority of which were from vessels with a low risk rating (2821 or 90.0%, Table 3). Vessels with a moderate risk rating accounted for 9.1% (284) of total vessel visits to the West Coast bioregion, and vessels with a high risk rating accounted for only 1.0% (30). Over half of the vessels visits to the West Coast bioregion (1641 or 52.3%) were from an international LPOC.

The greatest inoculation risk to the West Coast bioregion was from vessels travelling from international LPOCs (1641 or 52.3% Table 3). The vast majority of these were visits from vessels with a low risk rating (1585 or 96.6%). However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Vessel visits from intrastate LPOCs accounted for just over a quarter of the visits (841 or 26.8%), while the remainder (625 or 19.9%) were from interstate LPOCs.

Vessels visiting the West Coast bioregion were registered from 56 different flag states, 15 (26.8%) of which were listed as having a FOC. The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 46.1% of all visits to the West Coast bioregion. Of the 56 flag states, only 18 (28.5% of total visits) have ratified the IMO BWM. Further analysis revealed that 4 of these 18 were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to only 10.7% of total visits to the West Coast bioregion. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

3.1.3.2 Infection and establishment likelihood

There were 42 IMP species present at LPOC locations of which 37 (88%) had temperature and salinity tolerances compatible with the West Coast bioregion (Table 4). These 37 were comprised of 18 species with a high impact ranking and 19 species with a moderate impact ranking. Every compatible IMP was present at international LPOCs. In terms of domestic presence, 7 compatible IMPs were present interstate and 2 were present intrastate. It should be noted that a species may occur at multiple LPOCs.

There were 40 international LPOCs that contained an IMP with either a high and/or moderate risk rating that was compatible with the West Coast bioregion's environment (Figure 10). USA had the greatest number of IMPs with 29 species, 16 of which were classed as high risk. Japan had the next greatest with a total of 20 species (13 with a high rating), followed by Thailand with 17 species (12 with a high rating) and China also with 17 (11 with a high rating). Compatible IMPs were also recorded at 15 domestic LPOCs, 10 from interstate and 5 from intrastate (Figure 10), with only the interstate LPOCs containing high risk IMPs.

When the cumulative effect of the number of vessel visits from a LPOC and number of IMPs present at that LPOC is considered, the greatest infection and establishment risk to the West Coast bioregion was from Singapore (Figure 11). China and Indonesia also present a significant risk to the West Coast bioregion. LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 11.

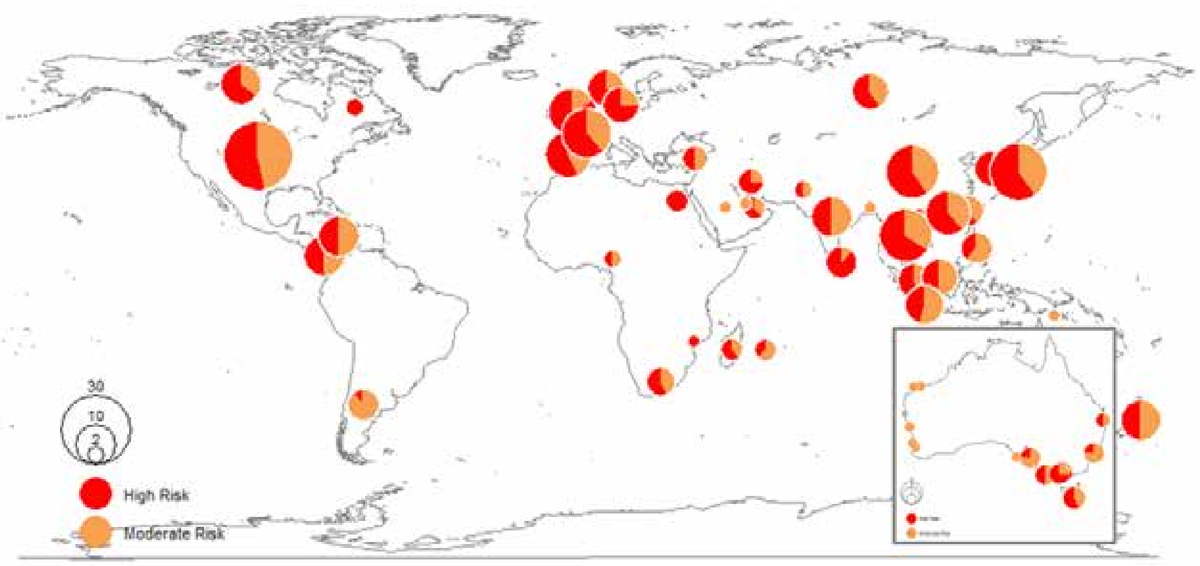


Figure 10 LPOC locations (international and domestic (inset)) of compatible high and moderate risk IMPs for the West Coast bioregion

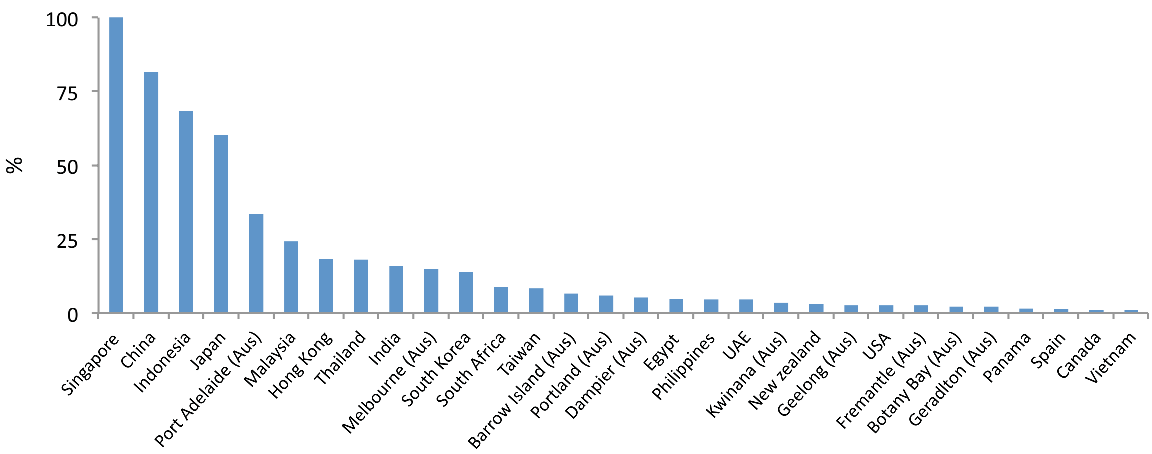


Figure 11 Ranking of the infection and establishment risk posed to the West Coast bioregion by international and domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Singapore 100%)

3.1.4 South Coast bioregion

3.1.4.1 Inoculation likelihood and sociopolitical risk

The South Coast bioregion recorded 302 vessel visits in 2011, 98.7% (298) of which were from vessels with a low risk rating (Table 3). Almost two-thirds (188 or 62.3%) of the vessel visits to the South Coast bioregion were from an international LPOC.

The greatest inoculation risk to the South Coast bioregion was from vessels with an international LPOC (188 or 62.2%) and all of these vessels had a low risk rating (Table 3). However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Intrastate visits made up a quarter of visits (75 or 25.2%) and the remainder were from interstate LPOCs (34 or 11.3%) or from unknown LPOCs (4 or 1.3%).

Vessels visiting the South Coast bioregion were registered from 34 different flag states and of these, 9 (26.5%) were listed as having a FOC. The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 54.0% of all visits to the South Coast bioregion. Of the 34 flag states, only 7 (16.8% of total visits) have ratified the IMO BWM. Further analysis revealed that 2 of these 7 were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 11.0% of total visits to the South Coast bioregion. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

3.1.4.2 Infection and establishment likelihood

There were 39 IMP species present at LPOC locations, 37 (95%) of which had temperature and salinity tolerances compatible with the South Coast bioregion (Table 4). These 37 were comprised of 18 species with high impact ranking and 19 species with a moderate impact ranking. Every compatible IMP was present at international LPOCs. In terms of domestic presence, 7 compatible IMPs were present interstate and 2 were present intrastate. It should be noted that a species may occur at multiple LPOCs.

There were 19 international LPOCs that contained an IMP with either a high and/or moderate risk rating that was compatible with the South Coast bioregion's environment (Figure 12). Eastern USA had the greatest number of IMPs with 23 species, 12 of which were classed as high risk. Japan had the next greatest with a total of 21 species (14 with a high rating), then China with 18 species (11 with a high rating). Compatible IMPs were also recorded at 11 domestic LPOCs, 8 interstate and 3 intrastate, with only the interstate LPOCs contained high risk IMPs.

When the cumulative effect of the number of vessel visits from a LPOC and number of IMPs present at that LPOC is considered, the greatest infection and establishment risk to the South Coast bioregion was from China, followed closely by Japan (Figure 13). LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 13.

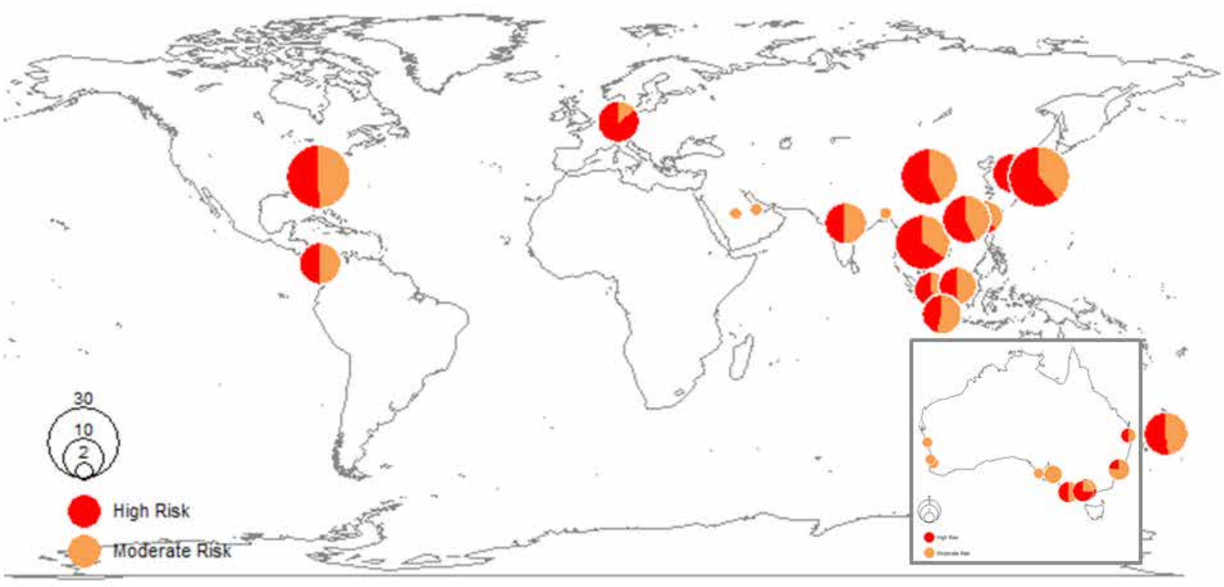


Figure 12 LPOC locations (international and domestic (inset)) of compatible high and moderate risk IMPs for the South Coast bioregion

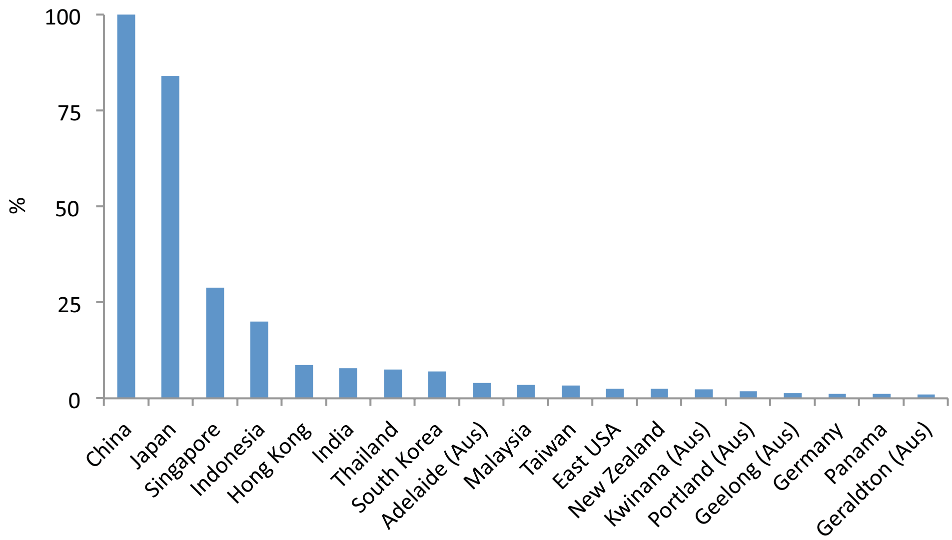


Figure 13 Ranking of the infection and establishment risk posed to the South Coast bioregion by international and domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. China 100%)

Table 4 The compatible IMPs for the North Coast, Gascoyne Coast, West Coast and South Coast bioregions, examined by the source (international, interstate and intrastate LPOCs) and the IMP impact ranking
(H = high; M = medium; X indicates the species is compatible with the bioregion and was documented as being present at the LPOC location)

IMP species	Impact ranking	North Coast			Gascoyne Coast			West Coast			South Coast		
		International LPOC	Interstate LPOC	Intrastate LPOC	International LPOC	Interstate LPOC	Intrastate LPOC	International LPOC	Interstate LPOC	Intrastate LPOC	International LPOC	Interstate LPOC	Intrastate LPOC
Asterias amurensis	H				X			X	X		X	X	
Balanus eburneus	H	X						X			X		
Balanus improvisus	H	X			X			X			X		
Brachidontes pharaonis	H	X			X			X			X		
Carcinus maenas	H	X	X		X			X	X		X	X	
Charybdis japonica	H	X						X			X		
Cliona thoosina	H	X						X					
Crepidula fornicata	H	X			X			X			X		
Didemnum vexillum	H	X						X			X		
Eriocheir sinensis	H	X						X			X		
Hemigrapsus sanguineus	H	X			X			X			X		
Mytilopsis leucophaeata	H	X									X		
Mytilopsis sallei	H	X			X			X			X		
Perna perna	H	X			X			X			X		
Perna viridis	H	X	X		X			X	X		X	X	
Rhithropanopeus harrisii	H	X			X			X			X		
Sargassum muticum	H	X						X			X		
Ulva pertusa	H	X			X			X			X		
Undaria pinnatifida	H	X	X		X			X	X		X	X	

IMP species	Impact ranking	North Coast			Gascoyne Coast			West Coast			South Coast		
		International LPOC	Interstate LPOC	Intrastate LPOC	International LPOC	Interstate LPOC	Intrastate LPOC	International LPOC	Interstate LPOC	Intrastate LPOC	International LPOC	Interstate LPOC	Intrastate LPOC
Anomia nobilis	M	X						X					
Balanus glandula	M	X			X			X			X		
Beroe ovata	M										X		
Blackfordia virginica	M	X			X			X			X		
Briarosaccus callosus	M	X						X			X		
Carcinoscorpius rotundicauda	M	X			X			X			X		
Caulerpa taxifolia	M	X	X	X	X			X	X	X	X	X	X
Chthamalus proteus	M	X						X			X		
Crassostrea ariakensis	M	X						X			X		
Crassostrea gigas	M	X	X		X			X	X		X	X	
Didemnum spp.	M	X		X	X		X	X		X	X		X
Gymnodinium catenatum	M	X	X					X	X		X	X	
Mnemiopsis leidyi	M	X						X			X		
Perna canaliculus	M	X						X			X		
Pfiesteria piscicida	M	X						X			X		
Polydora nuchalis	M	X						X			X		
Pseudo-nitzschia seriata	M	X									X		
Rapana venosa	M	X						X			X		
Solidobalanus fallax	M							X					
Sphaeroma annandalei	M	X						X			X		
Sylon hippolytes	M	X			X			X			X		

4.0 Key Findings from the bioregional analysis

4.1 North Coast bioregion

The greatest inoculation risk to the North Coast bioregion was from vessels that travelled within state waters. This has significant implications for managing vessel movements within this bioregion as there is a greater risk that if an IMP is introduced to one port it will be translocated to others within the bioregion. Based on their operating and structural properties, the majority of these vessels had a moderate risk rating and included barges, commercial fisheries vessels, research vessels and tugs. The flag of registry of the vessel was also identified as a key risk as over a quarter of the vessels visiting the North Coast bioregion came from a FOC state. China was the LPOC that posed the greatest infection and establishment risk to the North Coast bioregion. There was also a very high environmental compatibility (90%) between the potential incoming IMPs and the environment of the North Coast bioregion. IMP species that are of greatest threat to the North Coast bioregion are discussed in detail in the Wyndham, Port Hedland and Dampier ports reports.

4.2 Gascoyne Coast bioregion

The greatest inoculation risk to the Gascoyne Coast bioregion was from vessels travelling from international LPOCs. These vessels had a low risk rating and included bulk carriers, cargo carriers and tankers. The low risk rating does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. The flag of registry of the vessel was identified as a key risk as almost two-thirds of the vessels visiting the Gascoyne bioregion came from a FOC state. Japan and Malaysia were the LPOCs that posted the greatest infection and establishment risk to the Gascoyne Coast bioregion. There was also a moderately high compatibility (68%) between the potential incoming IMPs and the environment of the Gascoyne Coast bioregion. IMP species that are of greatest threat to the Gascoyne Coast bioregion are discussed in detail in the Useless Loop individual port report.

4.3 West Coast bioregion

The greatest inoculation risk to the West Coast bioregion was from vessels travelling from international LPOCs. Based on their operating and structural properties the vast majority of these vessels had a low risk rating and included bulk carriers, cargo carriers, offshore supply vessels, passenger vessels and tankers. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Singapore was the LPOC that posed the greatest infection and establishment risk to the West Coast bioregion. There was also a very high environmental compatibility (88%) between the potential incoming IMPs and the environment of the West Coast bioregion. IMP species that are of greatest threat to the West Coast bioregion are discussed in detail in the following Geraldton, Fremantle and Bunbury ports reports.

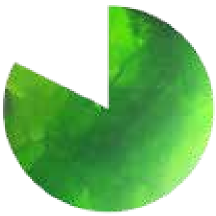
4.4 South Coast bioregion

The greatest inoculation risk to the South Coast bioregion was from vessels with an international LPOC. Based on their operating and structural properties the majority of these vessels had a low risk rating and included bulk carriers, cargo carriers and tankers. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. China was the LPOC that posed the greatest infection and establishment risk to the South Coast bioregion. There was also a very high environmental compatibility (95%) between the potential incoming IMPs and the environment of the South Coast bioregion. IMP species that are of greatest threat to the South Coast bioregion are discussed in detail in the Albany and Esperance individual port reports.

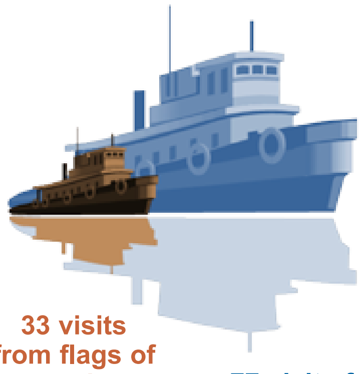
5.0 Wyndham Port

WYNDHAM PORT AT A GLANCE

Asia and North America are the greatest sources of high and moderate risk IMPs to Wyndham

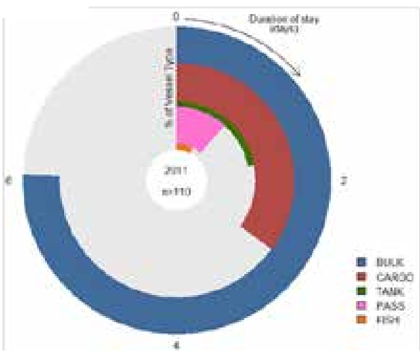


82% of inbound IMPs are compatible with Wyndham Port environs

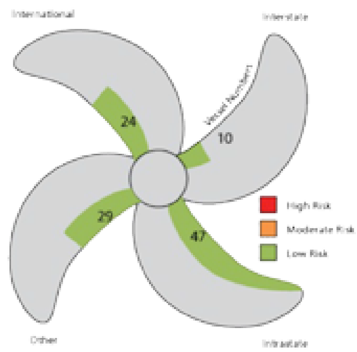


33 visits from flags of convenience

77 visits from recognized flags



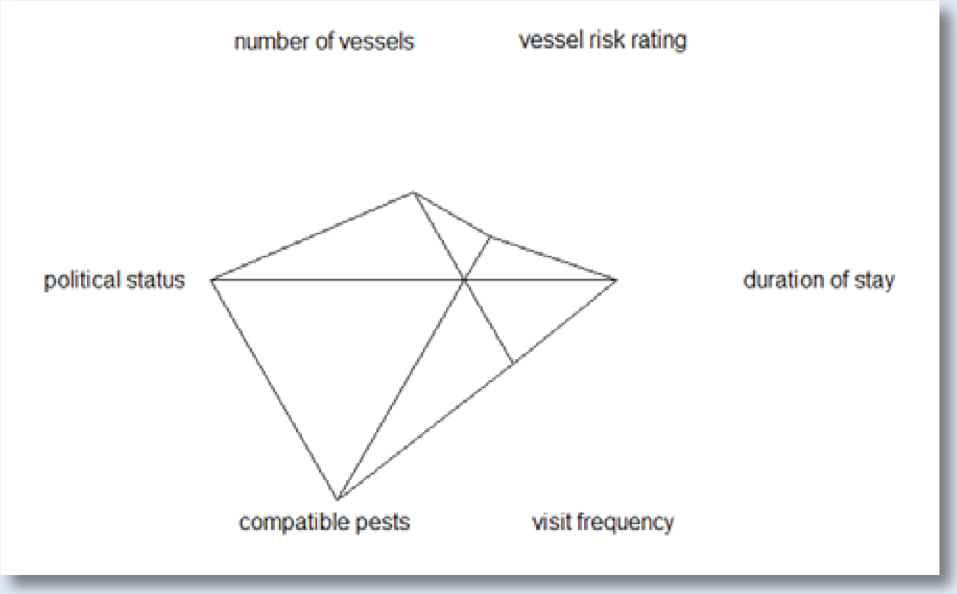
Bulk vessels stay the longest and are the most common along with cargo and passenger (PASS) vessels



Majority of vessels are from intrastate LPOCs and are low risk

Wyndham Port

The drivers for Wyndham Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Wyndham Port. The length of the point in the diagram below indicates the degree to which that factor contributes to the risk.



All vessels entering Wyndham Port were low risk. There was no high risk vessels recorded in the 2011 data. Almost three-quarters of the vessels visiting Wyndham Port were registered from countries considered to be FOCs and only a few of the total number of vessels were from countries that had ratified the IMO BWM convention. There was a very high compatibility (82%) between the potential incoming IMPs and the environment of Wyndham Port. Based on the number of incoming vessels and the number of potentially compatible pests, Indonesia was the LPOC that posed the greatest risk to Wyndham Port. Indonesia has *Caulerpa taxifolia* (an invasive strain of algae), a species listed in the top 100 worst invasive species worldwide. Its temperature and salinity tolerances are compatible with Wyndham Port. Broome Port posed the greatest domestic risk to Wyndham Port, based on the number of vessels arriving from there and the number of potentially compatible pests.

5.1 Wyndham Port description

Wyndham Port is 2200 km north-east of Perth, but only 500 km south-west of the Northern Territory's capital city of Darwin (Figure 14). It services the east Kimberly region of WA and is one of the oldest ports in the north-west. Wyndham was officially recognised as a port in 1886, when it serviced the local stations and cattle industry. It maintains its service to the cattle industry through to the present day. Other exports include nickel and copper concentrates from the local mining industry.

The port is located deep in the Cambridge Gulf and the pilotage passage to reach the port facilities is 45 nautical miles (M). The Cambridge Gulf experiences the large tides typical of the Kimberly region, reaching a maximum of 8.2 m, resulting in significant tidal currents in the area.

The primary port facilities comprise a loop-road causeway running parallel to the shoreline with an approximate berth space of 300 m. The depth at low tide is between 5 m and 8 m.

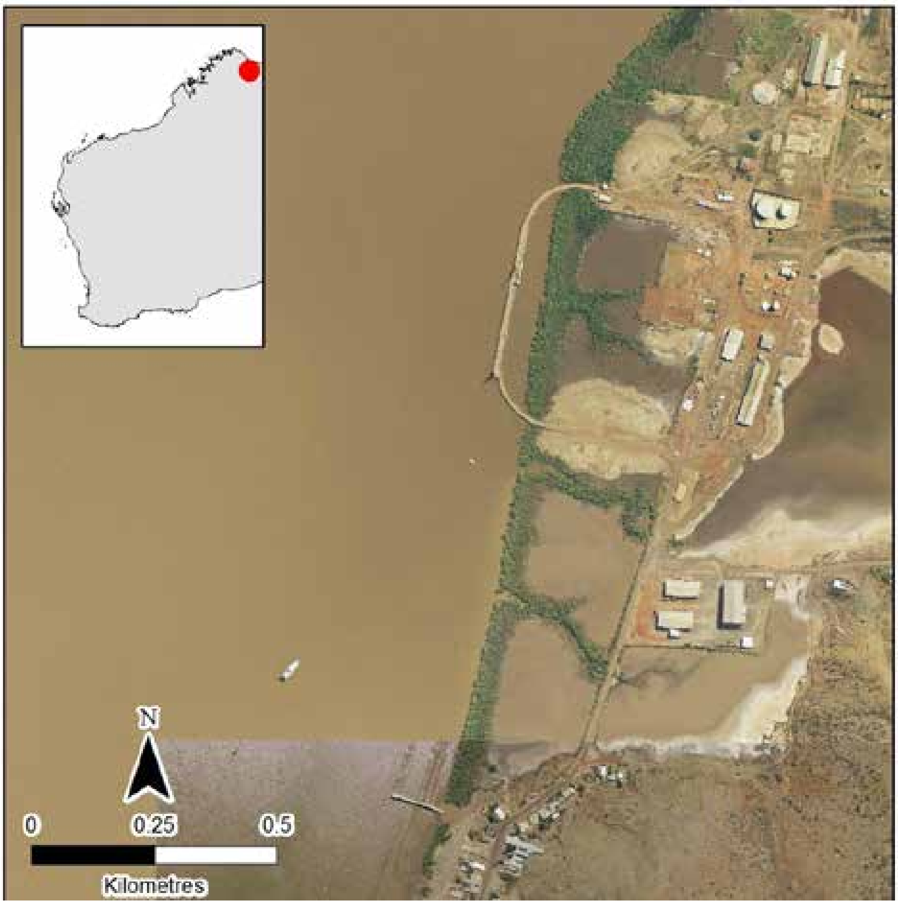


Figure 14 Wyndham Port infrastructure and locality map

5.1.1 Environment

The port waters at Wyndham are very turbid due to the significant riverine input and large tidal currents in the area. The substrates are fine silt, with a dredging program required to maintain the depth at the berth pockets. The actual shoreline is mangrove forest and the primary hard structures in the port are the wharf piles.

Environmental values used for the analysis were a water temperature range of 24.5 °C to 28.9 °C and a salinity range of 30.5 – 35.0 ppt. These values were based on data used in the Global Ballast Water Management Programme (GloBallast).

5.1.2 Current knowledge of introduced marine pests

There have been no marine pest surveys conducted in Wyndham port to date, nor are there any recorded marine species classed as being pests or cryptogenic.

5.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include the inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the Methods section.

5.2.1 Inoculation likelihood

Wyndham Port received a total of 110 vessel visits based on the 2011 data examined. Bulk carriers, general cargo and passenger vessels each accounted for almost a third of the total number of vessel types entering Wyndham Port (31.8%, 33.6% and 31.8% respectively, Figure 15). The majority of vessels visited either once (19 vessels, 48.72%) or 2 – 5 times (15 vessels, 38.46%) during 2011 (Figure 16). Only three vessels (4.69%) visited 6 – 10 times and two (5.13%) visited more than 10 times. All vessels recorded for Wyndham Port in 2011 had a low risk rating and stayed on average 0.5–6 days (Figure 17). Bulk carriers stayed the longest, for an average of 6 days.

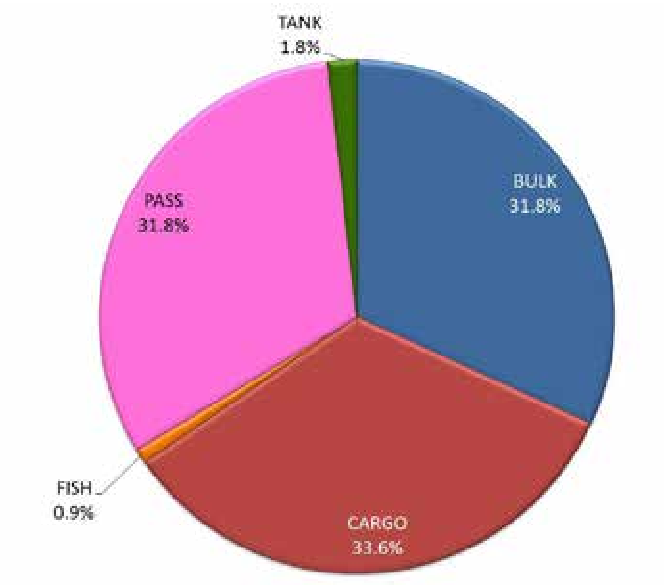


Figure 15 Summary of vessel type entering Wyndham Port in 2011 (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, FISH = fisheries compliance/water police, PASS = passenger vessels, RESE = research vessels, TANK = tankers)

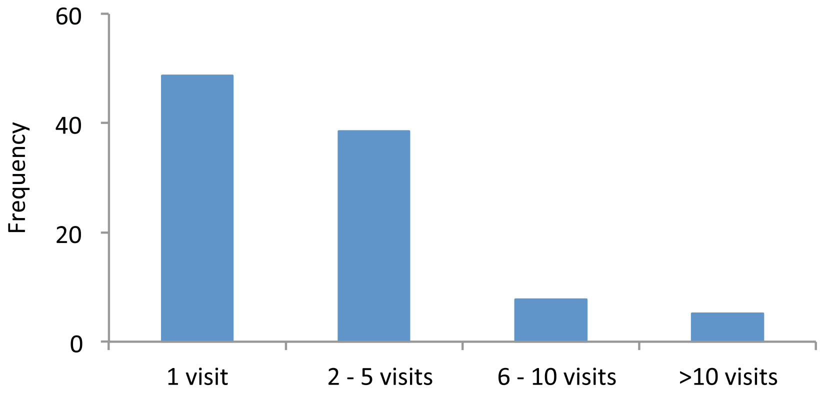


Figure 16 Frequency of repeat vessel visits to Wyndham Port in 2011

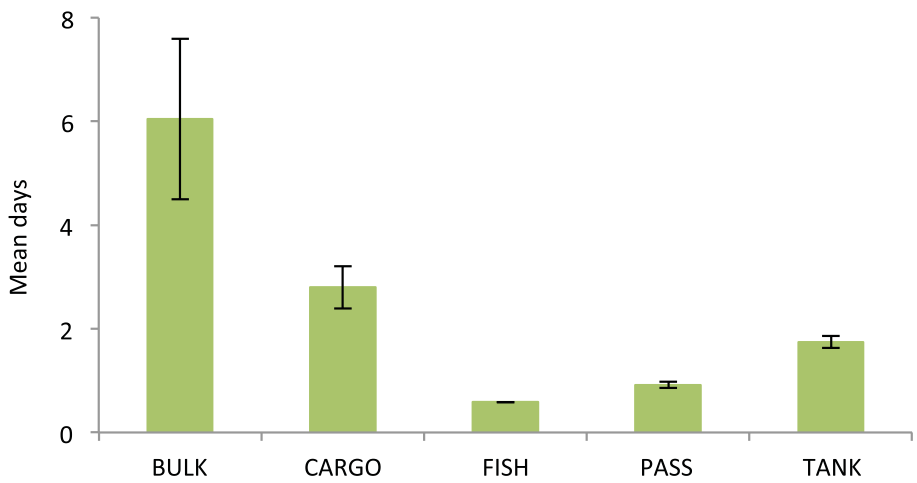


Figure 17 Mean residency time (days ± SE) for the different vessel types visiting Wyndham Port in 2011 and their risk rating (green = low risk) (BULK = bulk carriers, CARGO = general cargo vessels, FISH = fisheries compliance/water police, PASS = passenger vessels, TANK = tankers)

There were only 24 visits from an international source to Wyndham Port (21.8% of total visits, Table 5). These international vessel visits were from seven different countries, of which 11 visits (i.e. 45.8% of the total international visits) were from Indonesia.

Domestic visits (57) accounted for the majority of visits (51.8% of total visits). This included 10 visits from three different interstate locations, Darwin being the most common with 6 visits (Table 5). Intrastate sources were the greatest source of all vessel visits, accounting for over half of all visits (47 out of 81 visits in total). Most of these (40 visits, 81.0% of intrastate visits) were from Broome. There were 29 visits for which no source location was provided.

Table 5 Summary of vessel visits to Wyndham Port from source locations

Source	Number of visits	% of visits
International	**24**	**21.8**
China	3	12.5
East Timor	3	12.5
Indonesia	11	45.8
Japan	1	4.2
Singapore	4	16.7
South Korea	1	4.2
USA	1	4.2
Domestic	**57**	**51.8**
Interstate	**10**	**% of interstate**
Darwin	6	60.0
Newcastle	2	20.0
Port Alma	2	20.0
Intrastate	**47**	**% of intrastate**
Broome	40	85.1
Dampier	2	4.3
Fremantle	3	6.4
Port Hedland	2	4.3
Other	**29**	**26.4**

5.2.2 Sociopolitical risk

Vessels visiting Wyndham Port were registered from 16 different flag states and of these, half were listed as FOC states (Figure 18, see ‘A’). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 70% of all visits to Wyndham (Figure 18, see ‘B’). The greatest proportion of FOC vessels came from the Bahamas (45.5%) (Figure 18, see ‘C’).

Of the 16 flag states, only seven (15.5% of total visits) have ratified the IMO BWM and three of those were FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 7.3% of total visits.

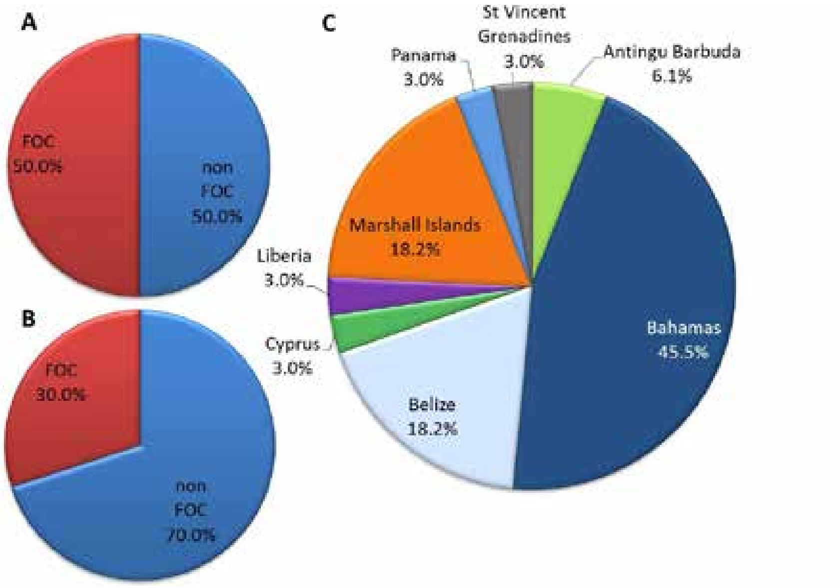


Figure 18 Percentage of FOC and non-FOC states entering Wyndham (A). Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Wyndham (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Wyndham Port based on the 2011 data was low to moderate, as even though all vessels were classed as low risk there were a significant proportion of repeat visits with some vessels staying for a moderate length of time. Additionally, almost three-quarters of the vessels visiting Wyndham Port were registered from countries considered to be FOCs and only a few of the total number of vessels were from flag states that had ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

5.2.3 Infection and establishment likelihood

There were 39 IMP species present at LPOC locations, 33 (85%) of which have temperature and salinity tolerances compatible with Wyndham Port environs. All 33 compatible species were located at one or more of the international sources for vessels (Figure 19). For domestic sources, there were only two species located intrastate. *Balanus improvisus* and *Ulva pertusa* were present in the most sources (7 and 6 respectively: international and domestic combined). The next most common species were *Caulerpa taxifolia*, *Crassostrea gigas*, *Gymnodinium catenatum* and *Perna viridis*, all at five locations each.

B. improvisus (barnacle) is a common biofouler and once introduced into a new range this species can dominate and outcompete native species for available habitat (Qvarfordt *et al.* 2006). *U. pertusa* is a green algae that can be invasive due to its fast growth rate, high reproductive potential and broad environmental tolerances (CAB International 2013b). The macroalgae *C. taxifolia* occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe (Meinesz *et al.* 2001). *C. gigas* (oyster) is a species that could pose a significant threat to native oyster and mussel populations. *G.catenatum* (dinoflagellate) is not regarded as a vessel biofouling species, however it may be transported as a cyst on equipment such as ropes, cages or in sediment present on a vessel. *P.viridis* (mussel) can live in locations that are highly contaminated with industrial and human pollution. It can also potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure (Barber *et al.* 2005; Rajagopal *et al.* 2006).

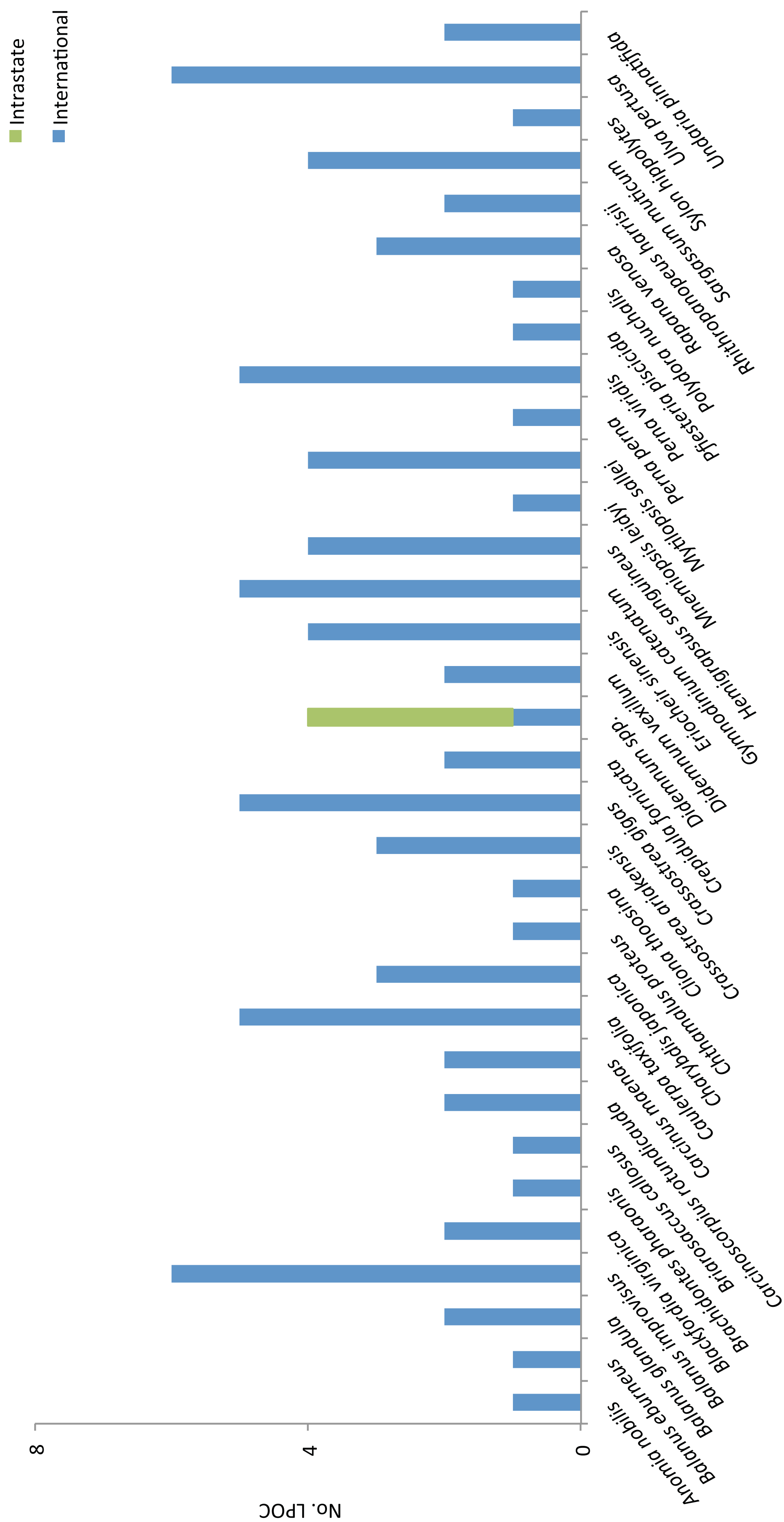


Figure 19 IMP species compatible with Wyndham Port and the number of LPOCs (international and intrastate) at which they occur

Nine LPOCs contained either a high or moderate risk IMP species that was compatible with Wyndham's marine environment. The international source, USA, had the greatest number of IMPs at 27 species, 15 of which were classed as high risk. Japan the next greatest number at 19 species (12 with a high risk rating), followed by China had with 16 species (10 with a high risk rating, Figure 20). There was only one domestic source, Fremantle Port, with a high risk IMP (Figure 20).

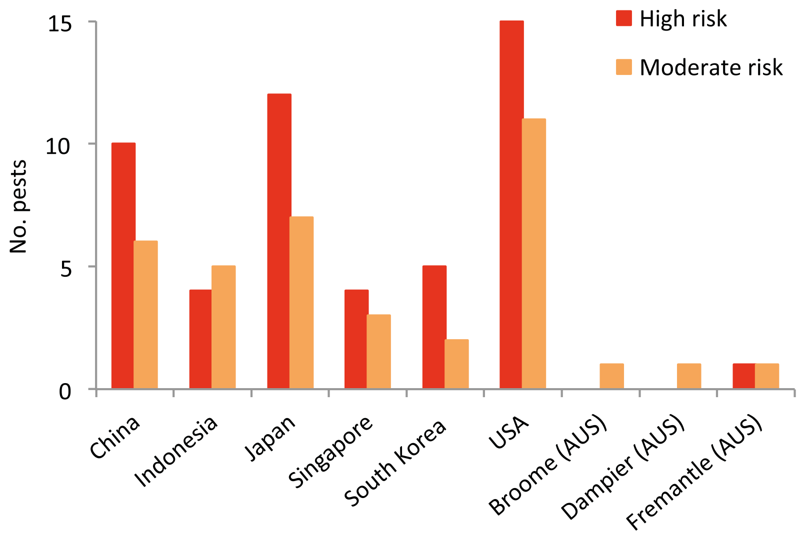


Figure 20 IMP species with a moderate or high risk rating, present at international and domestic LPOCs, that were compatible with Wyndham Port environs

When the cumulative effect of the number of vessel visits from a LPOC and number of IMPs present at that LPOC is considered, the greatest infection and establishment risk to Wyndham Port was from Indonesia (Figure 21). LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 21. Selected IMPs from Indonesia that posed a risk to Wyndham are shown pictorially in Figure 22.

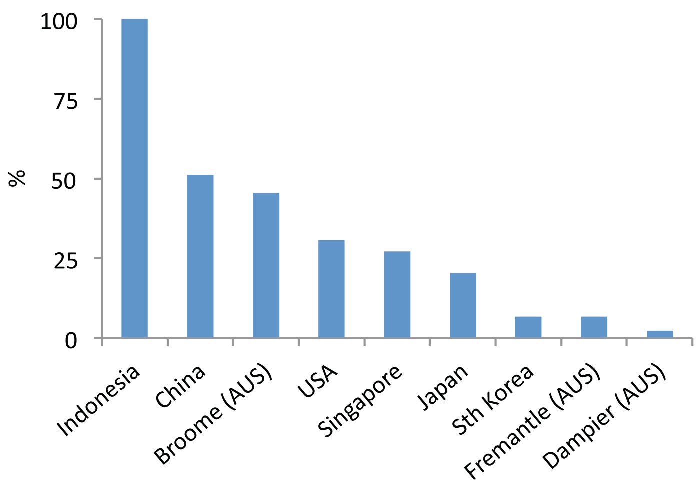


Figure 21 Ranking of the infection and establishment risk posed to Wyndham Port by international and domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Indonesia 100%)

Figure 22 Map showing the proximity of Indonesia (red circle) to Wyndham Port (yellow star) and the selected IMPs that pose the greatest risk to Wyndham Port

There was only one IMP species, *Didemnum perlucidum* (colonial ascidian), recorded at three domestic LPOCs, all of which were intrastate. These ports were Broome, Dampier and Fremantle.

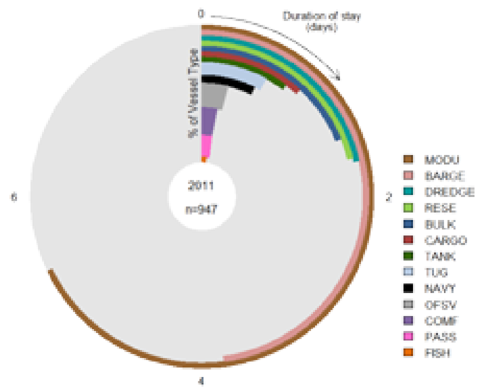
There were nine species from international and domestic LPOCs that presented the greatest likelihood of infection and establishment to Wyndham Port. One of the species, *Caulerpa taxifolia* (clone strain of the macroalgae), is listed in the top 100 worst invasive species worldwide. The remaining eight species, although not listed in the top 100 worst, still pose a significant threat to Wyndham Port for one or more of the following: the environment, sociocultural values, economic values and human health. Brief information on these species is provided in Table 6. For further information, images and references for these species please see Appendix 2.

Table 6 The impact rank and examples of impacts for the nine species which presented the greatest likelihood of infection and establishment to Wyndham Port

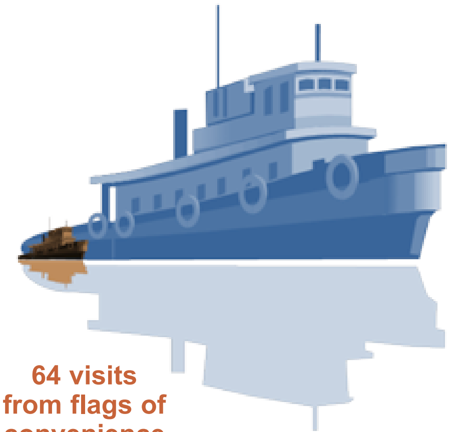
IMP species	Impact rank (M = medium, H = high)	Impacts
Caulerpa taxifolia (algae, clone strain)	M	This is an invasive algae that has the potential to grow rapidly, alter marine habitats and affect biodiversity. It can potentially invade seagrass beds and modify organic and inorganic components of the sediment.
Balanus improvisus (barnacle)	H	This is a fast-growing species that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.
Crassostrea gigas (oyster)	M	This oyster has the potential to smother marine life, exclude species, hybridise with other oyster species, alter ecosystems and destroy habitats, including their social amenity.
Carcinoscorpius rotundicauda (horseshoe crab)	M	While listed by the Australian Government's Department of Agriculture as a species of concern likely to do harm, there is no clear evidence of this species posing a pest risk. The only documented detection of this species as introduced was one instance in New Zealand in 1910. This species is currently listed on the International Union for Conservation of Nature and Natural Resources' (IUCN's) Red List of Threatened Species (IUCN 2013).
Charybdis japonica (crab)	H	This is a highly aggressive crab and opportunistic omnivore, consuming mostly bivalves, crustaceans and polychaetes. This crab can outcompete native species for space and food. It can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication.
Gymnodinium catenatum (dinoflagellate)	M	This microalgae that can form toxic blooms, namely Paralytic Shellfish Poisoning (PSP). PSP can be fatal to humans and in Mexico from 1990 to 2000, there were 32 deaths from 460 recorded poisonings.
Didemnum perlucidum (colonial ascidian)	M	This species can heavily foul artificial substrates including buoys, ropes, pylons, vessels and shellfish farms. This species is already known to occur in Fremantle Port and surrounding waters.

6.0 Broome Port

BROOME PORT AT A GLANCE



Mobile offshore drilling units (MODU) stay the longest but offshore supply vessels (OFSV) and commercial fisheries (COMF) vessels are more common

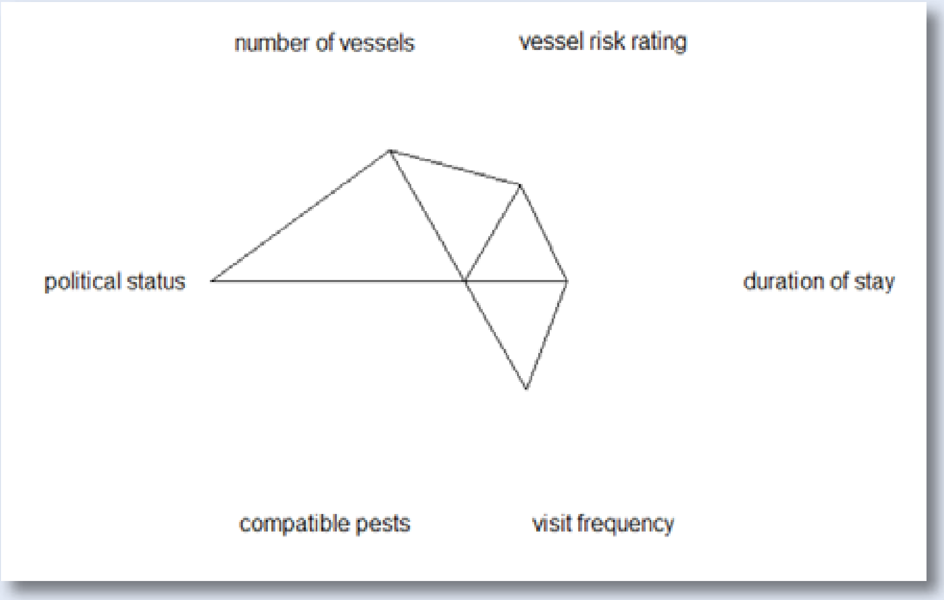


64 visits from flags of convenience

471 visits from recognized flags

Broome Port

The drivers for Broome Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests* and the sociopolitical status (political status) of the vessels arriving at Broome Port. The length of the point in the diagram below indicates the degree to which that factor contributes to the risk.



There were an equal proportion of low and moderate risk vessels entering Broome Port. There were three high risk vessel types visiting Broome Port, the majority of which were navy vessels. The moderate and high risk vessels stayed, on average, the longest in the port. Just over 10% of the vessels visiting Broome were from countries considered FOCs and the majority (89%) of the total vessel visits were from flag states that had not ratified the IMO BWM convention.

*this data was not available to be analysed.

6.1 Broome Port description

Broome is located in WA's Kimberly region, approximately 1600 km north of Perth. Typical of tropical areas, the weather patterns are monsoonal, with mild, dry winters and hot summers with periodic heavy rainfall. Cyclones are common in the Kimberley between November and April.

Broome port is the largest deepwater port in the Kimberly region of WA. The port facilities comprise a single 650 m jetty from the shore to deep water, with a 300 m long 'T' at the end (Figure 23). The end section provides almost 600 m of berth space, which is designated into 12 berths. Aside from the main jetty, there are approximately 160 moorings in the port spread over three separate areas.

The port's trade for the 2011/12 financial year was split almost equally between imports and exports, totalling just under 350 000 tonnes. Imports were primarily fuel, while exports were mostly fuel, water or equipment for the oil and gas sector in the nearby Browse Basin (Broome Port Authority 2012).

Approximately 30 km north of Broome is Willie Creek. This is a tidal inlet which contains substantial amounts of submerged, artificial structures associated with local pearling aquaculture facilities. Additionally, Willie Creek is the location where suspected illegal entry vessels (SIEVs), and in past years, illegal foreign fishing vessels (IFFVs) are hauled ashore for disposal.

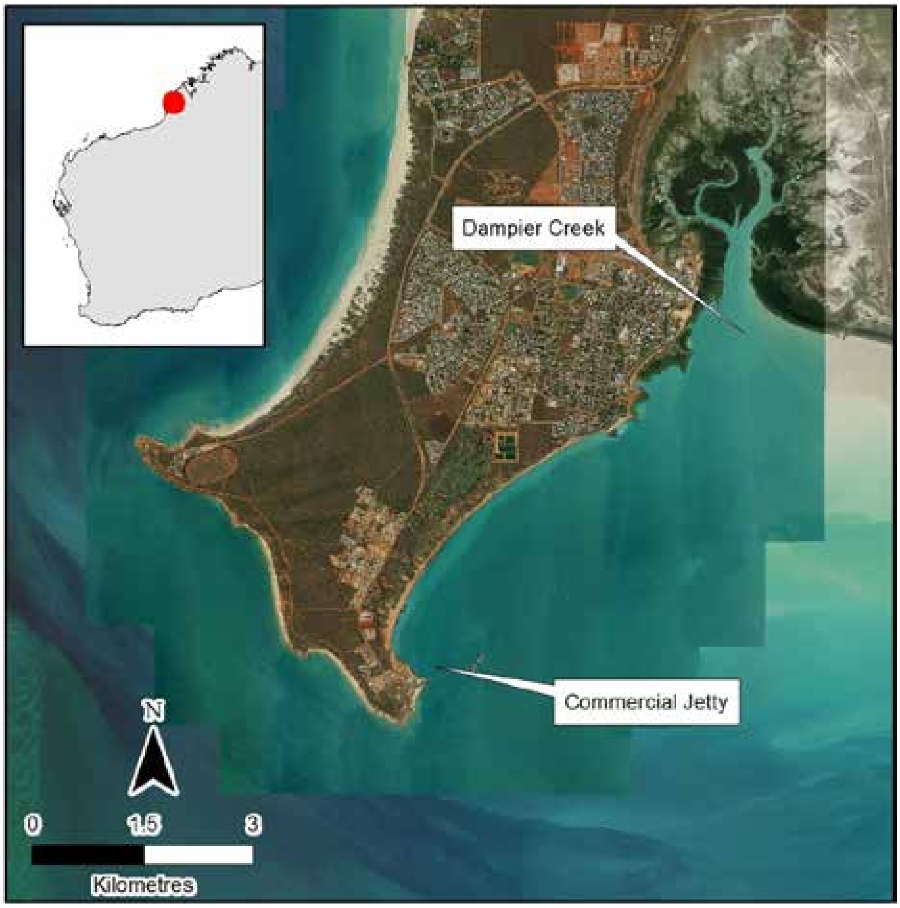


Figure 23 Broome Port infrastructure and locality map

6.1.1 Environment

Broome port waters are dominated by the tidal regime of the region, with spring tidal range in excess of 9.5 m. Tidal currents are common and strong, and large expanses of substrate are exposed at low tide. Substrates within the port are predominantly soft mud tidal flats but some rocky substrates occur around the headlands in the area. Submerged artificial substrates include the steel jetty piles as well as the boat moorings, although most of these are intertidal. Willie Creek also contains submerged structures associated with pearling aquaculture. Areas of mangroves exist within and nearby to the port, particularly in Dampier Creek to the north-east of the port, and in Willie Creek directly to the north.

6.1.2 Current knowledge of introduced marine pests

No dedicated IMP surveys have been conducted in Broome Port. However, Huisman *et al.* (2008) has recorded three species of cryptogenic barnacles from Broome port – *Amphibalanus amphitrite*, *Megabalanus ajax* and *Megabalanus tintinnabulum* – taken from records of museum surveys in the area. A rapid assessment of selected IMPs was undertaken in Willie Creek in 2008 by DoF staff in response to the perceived risk of incursion from IFFVs. This survey targeted only *Mytilopsis sallei* and *Perna viridis* as well as barnacle species, since these were of the greatest concern and considered to have the highest likelihood of establishment. Neither *M. sallei* nor *P. viridis* were detected, and the only barnacles found were native species (Wells 2010).

6.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the *Methods* section.

6.2.1 Inoculation likelihood

There were 947 visits recorded for Broome Port from 172 vessels. The majority of vessels had a low risk rating (50.1%) or a moderate risk rating (41.2%). Commercial fishing (25.6%), passenger vessels (20.1%), and offshore support vessels (22.8%) made up the majority of the vessels with a low or moderate risk rating entering Broome Port (Figure 24). There were three high risk rated vessel contributing to 8.8% of the vessels recorded for 2011, the majority of which were navy vessels (7.3%).

Sixty-three vessels (37%) only visited the port once (Figure 25). Fifty-nine (34%) visited 2 – 5 times, 24 (14%) visited 6 – 10 times and 26 (15%) visited more than 10 times.

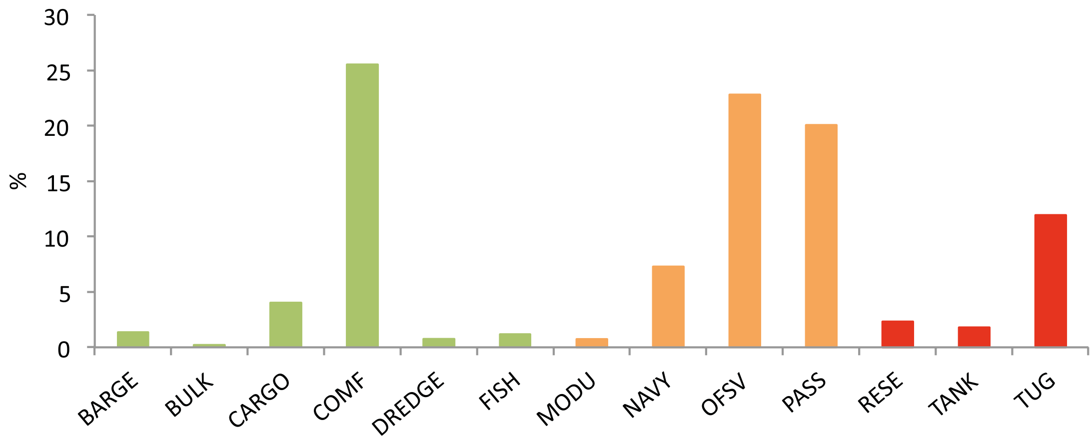


Figure 24 The percentage of vessels arriving into Broome Port by vessel type and risk rating (green = low risk, orange = moderate risk and red high = risk) in 2011 (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, FISH = fisheries compliance/water police, MODU = mobile offshore drilling unit/floating production storage offshore vessels, NAVY = navy vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

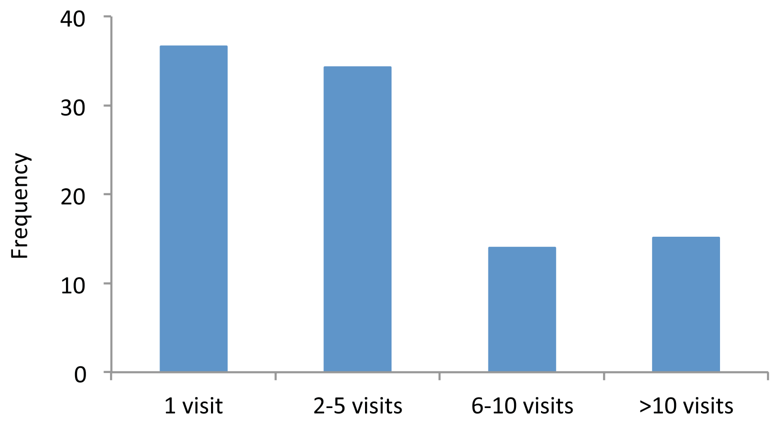


Figure 25 Frequency of repeat vessel visits to Broome Port in 2011

The greatest duration of stay was 24 days from a barge with a moderate risk rating which stayed, on average, for 3.8 days (ranging from <1 to 24 days). The remaining vessels with a moderate risk rating stayed from <1 to 1.7 days (Figure 26).

The second longest duration of stay was 22 days (average 5.4 days) from a mobile offshore drilling unit with a high risk rating. The other vessels with a high risk rating, dredges and navy vessels, stayed an average of 1.7 and 0.6 days respectively (Figure 26).The vessels with a low risk rating stayed from <1 to 1.5 days.

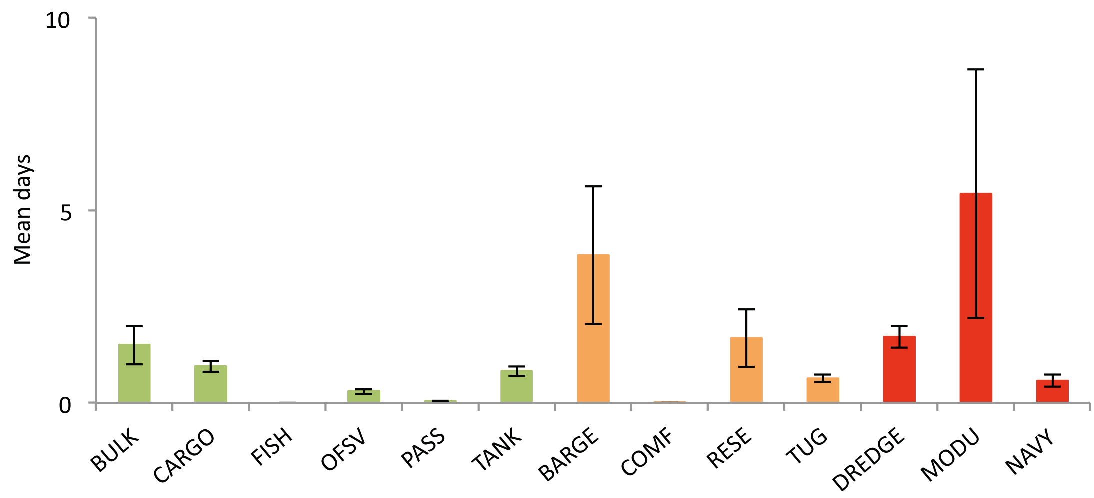


Figure 26 Mean residency time (days ± SE) for vessel types and risk rating (green = low risk, orange = moderate risk and red = high risk) visiting Broome Port in 2011 (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, FISH = fisheries compliance/water police, MODU = mobile offshore drilling unit/floating production storage offshore vessels, NAVY = navy vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

No analysis of LPOCs was possible as the data available did not include this information.

6.2.2 Sociopolitical risk

Vessels visiting Broome Port were registered from 20 different flag states and of these, 7 (35.0%) were listed as FOC states (Figure 27, see ‘A’). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 12.0% of all visits to Broome Port (Figure 27, see ‘B’). The greatest proportion of FOC vessels came from the Bahamas (31.3%), Panama (26.6%) and Belize (20.3%, Figure 27, see ‘C’). Of the 20 flag states, only 4 (10.3% of total visits) have ratified the IMO BWM.

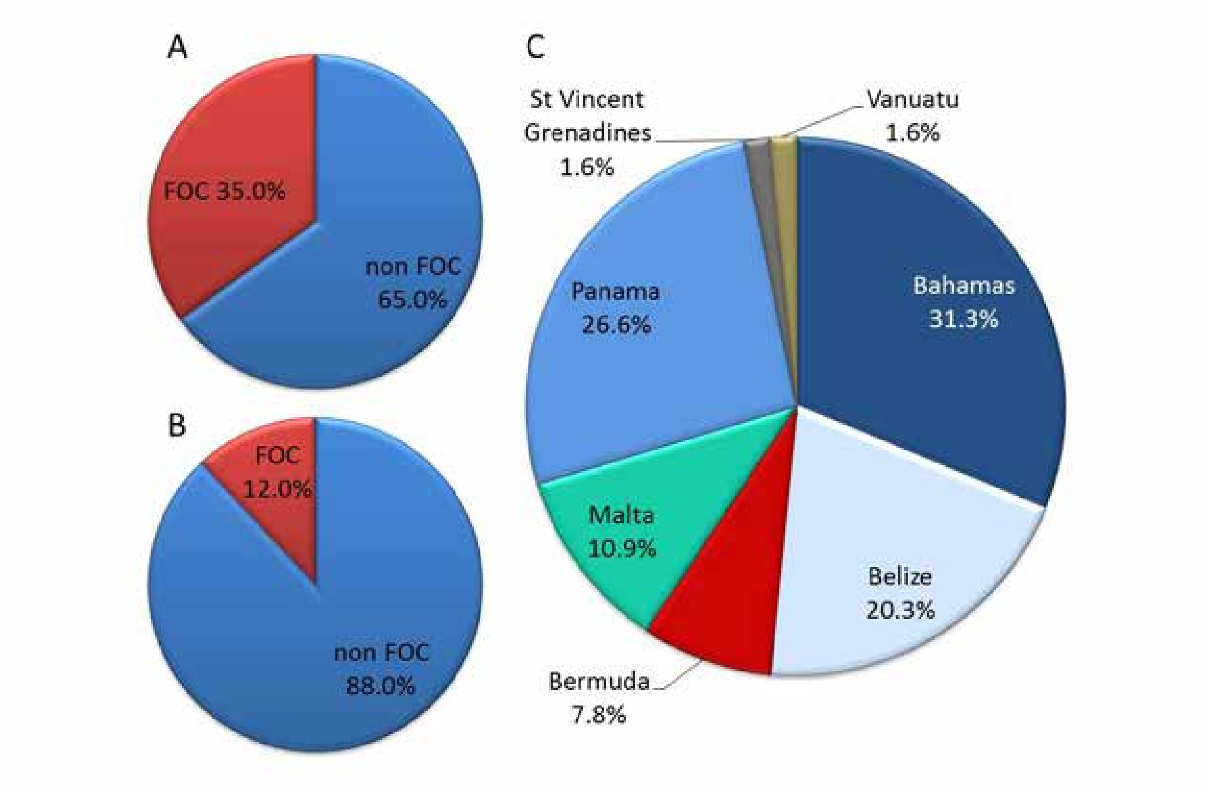


Figure 27 Percentage of FOC and non-FOC states entering Broome Port (A). Percentage of vessel visits by registry of FOC and non-FOC state entering Broome Port (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Broome Port was moderate, as a large percentage of the visiting vessels had a moderate risk rating, they stayed for extended periods and were repeat visitors. A small percentage of the vessels entering Broome Port were registered from countries considered to be FOCs. The greatest inoculation risk to Broome port was from mobile offshore drilling units and barges with a moderate risk rating, staying, on average, for the longest period.

6.2.3 Infection and establishment likelihood

There was no data available on IMPs present at the LPOCs, hence the IMPs compatibility with Broome Port could not be assessed.

7.0 Port Hedland Port

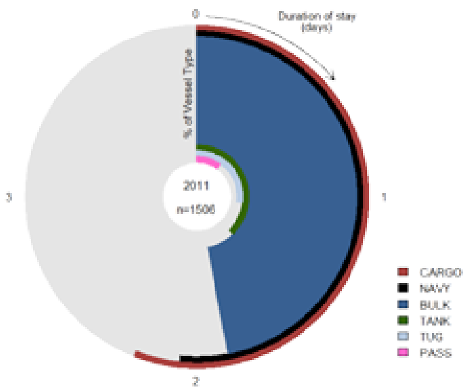
PORT HEDLAND PORT AT A GLANCE

Asia is the greatest source of high and moderate risk IMPs to Port Hedland

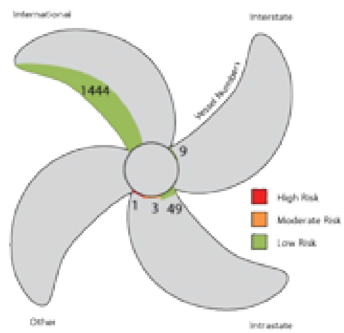
47% of inbound IMPs are compatible with Port Hedland Port environs

598 visits from recognized flags

908 visits from flags of convenience



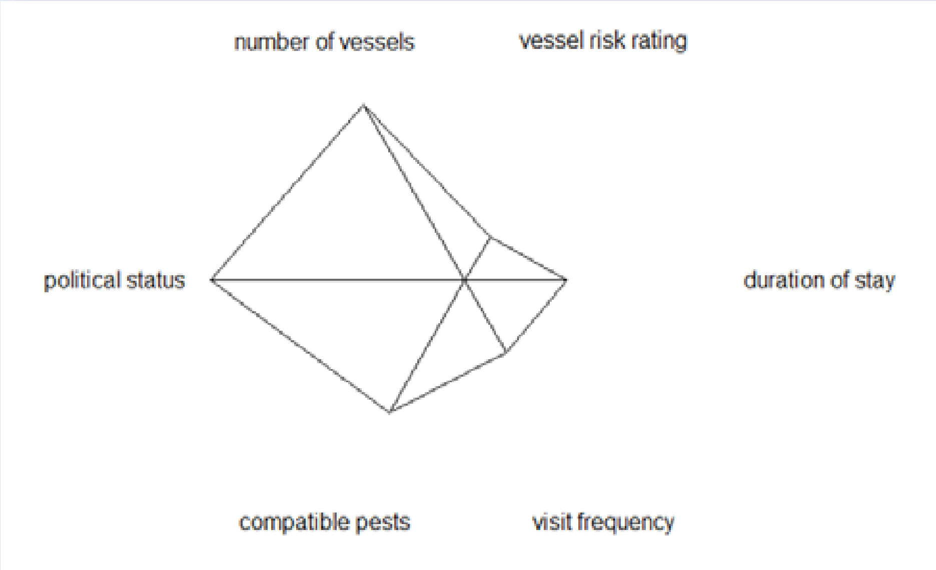
Cargo vessels stay the longest but bulk vessels are more common



Majority of vessels are from international LPOCs and are low risk

Port Hedland Port

The drivers for Port Hedland Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Port Hedland Port. The length of the point indicates the degree to which that factor contributes to the risk.



The majority of vessels entering Port Hedland (from all sources) were low risk. Just under two-thirds of the vessels visiting Port Hedland Port were registered from countries considered to be FOCs and very few of the total number of vessels were from flag states that had ratified the IMO BWM convention. There was a moderate level of compatibility (47%) between the potential incoming marine pests and the environment of Port Hedland port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOC that posed the greatest risk to Port Hedland port was China. Although none of the compatible pests were listed in the 100 worst pest species, there were still 6 that posed a significant threat to Port Hedland Port. These include *Hemigrapsus sanguineus* (crab), *Balanus improvisus* (barnacle), *Brachidontes pharaonis* (mussel), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel) and *Crassostrea gigas* (oyster). Dampier Port posed the greatest domestic risk to Port Hedland Port based on the number of vessels arriving from there and the number of potentially compatible pests.

7.1 Port Hedland Port description

Port Hedland is located in WA's Pilbara region, approximately 1200 km north of Perth (Figure 28). Port Hedland is the largest export port in WA and it is primarily an export hub for the Pilbara resource sector (<1% import). The port recorded a total throughput of just over 199 million tonnes in 2010/11, the majority of which was the export of iron ore (Port Hedland Port Authority 2011). To match the industry, the port itself has been rapidly expanding for several years and constant dredging and construction activities are characteristic of this port.

The port's jurisdiction covers 41 822 ha, and contains the inner harbour and all areas within a 10 nautical mile (M) radius of Hunt Point Beacon. The natural maximum depth of the inner harbour was only 9 m. As such, there has been considerable change to the bathymetry through dredging practices. The Port Hedland Port Authority (PHPA) is responsible for all dredging activities in the channel, inner harbour and berthing pockets. Between 1965 and 1984, approximately 1.2 billion m^3 of material was dredged from the harbour to create the approach channel, inner harbour and berth pockets (Port Hedland Port Authority 2006). The majority of the material was placed on the eastern side of the entrance to the harbour, creating the spoil bank (GHD 2008). All materials resulting from the current maintenance and expansion dredging are disposed of at sea.

There are several clusters of berths in the Port Hedland harbour, currently totalling 14 berths. The PHPA directly operate four berths, three of which are on the eastern shore and one on the western shore. The western shore also contains four additional Finucane Island berths, operated by BHP Billiton (BHPB). BHPB also operate berths on the north-eastern side of the harbour at Nelson Point. To the south of the harbour, the Anderson Point facility is operated by Fortescue Metals Group (FMG). This facility comprises three operational berths and a fourth berth is currently under construction. Many of the larger creeks contain cyclone moorings for vessels during periods of very bad weather.

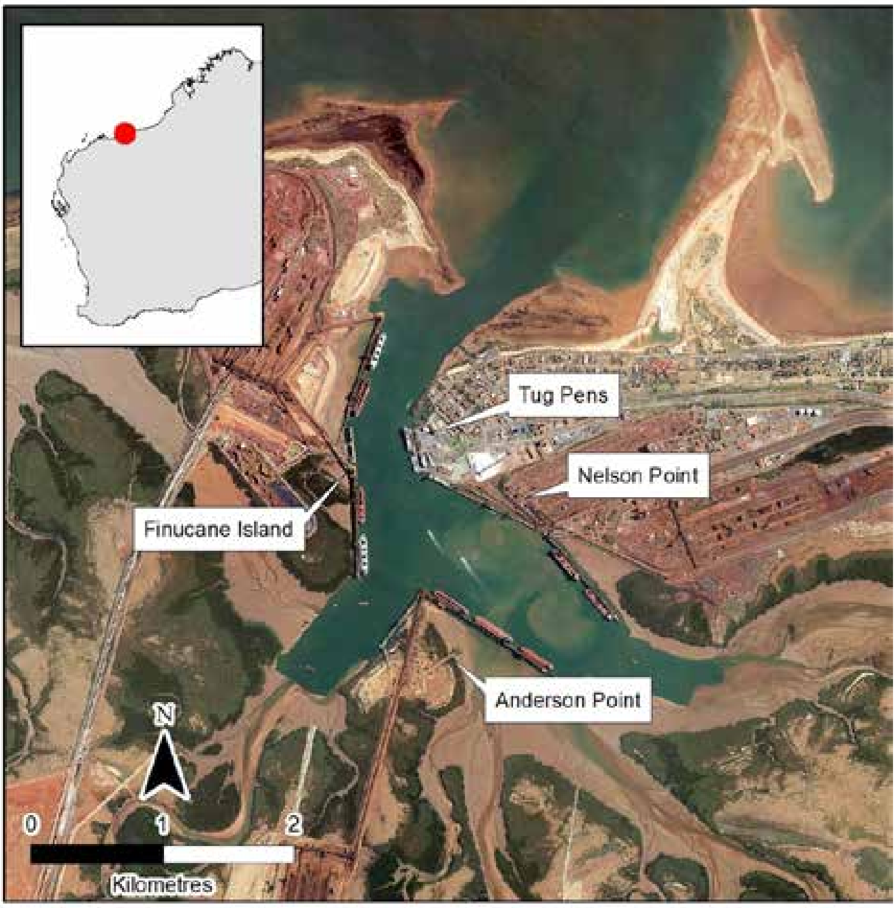


Figure 28 Port Hedland Port infrastructure and locality map

7.1.1 Environment

The region is characterised by hot summers with periodic heavy rainfall (summer monsoon) and mild, dry winters with occasional rainfall. The port waters include areas of open water, islands, tidal creeks, rock platforms and sediment beaches. There are some areas of coral, and algae are present in the subtidal zone, however the majority of the inner harbour is bare, soft sediment. The water is predominantly marine, with occasional small freshwater inputs from creeks and drains. Large inputs of mud and silt from the tidal creeks contribute to the highly turbid properties of the inner port's waters. Tidal water movements dominate the hydrodynamic regime of the region, with tidal ranges up to 7.6 m.

Environmental values used for the analysis were a water temperature range of 20.0 °C to 32.0 ° C and a salinity range of 25.0 – 45.0 ppt. These values were taken from the nationally approved marine pest monitoring design for Port Hedland Port by Bridgwood & Hourston (2009c).

7.1.2 Current knowledge of introduced marine pests

The primary reference on introduced marine species, including marine pest species in the Port Hedland marine area is the Port Hedland Port survey conducted by the Commonwealth Scientific and Industrial Research Organisation's (CSIRO) Centre for Research on Introduced Marine Pests (CRIMP) in May 1998 (CRIMP 1999). Seven species were identified as non-indigenous in the CRIMP survey, these were: *Amathia distans*, *Bugula neritina*, *Bugula stolonifera*, *Balanus amphrite*, *Megabalanus tintinnabulum*, *Gymnodinium* sp. and *Cochlodinium polykrikoides*.

Huisman *et al.* (2008) add a further seven species to the list of non-indigenous species from the Port Hedland Port region, drawing on several unpublished reports and museum records. These include *Antennella secundaria*, *Amathia vidovici*, *Bowerbankia gracilis*, *Savignyella lafontii*, *Zoobotryon verticillatum*, *Amphibalanus reticulatus* and *Megabalanus rosa*.

The DoF has conducted two full National System surveys of the Port Hedland port in 2011 and 2013 (Hourston 2012c and Hourston in prep. b), and maintains a complementary monitoring system which includes settlement arrays (Muñoz & Bridgwood 2013c). To date, no further IMPs have been confirmed in Port Hedland Port.

7.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the Methods section.

7.2.1 Inoculation likelihood

Port Hedland Port received a total of 1506 vessel visits based on the 2011 data examined. Bulk carriers were the dominant vessel type entering Port Hedland Port (91.3%, Figure 29). Just over half of the vessels (395 or 56.4%) visited the port only once during 2011 (Figure 30). Of the repeat visits, 256 (36.6%) visited 2 – 5 times, 48 (6.9%) visited 6 – 10 times and one (0.1%) visited more than 10 times. The average stay for all vessel types was between 0.4 and 2.2 days (Figure 31). Navy vessels with a high risk rating and general cargo vessels with a low risk rating stayed the longest i.e. 2.0 and 2.2 days respectively.

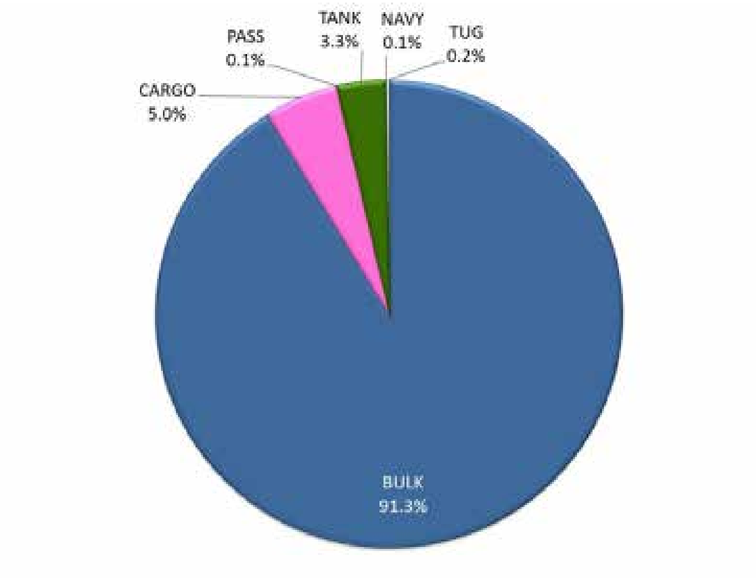


Figure 29 Summary of vessel type entering Port Hedland Port in 2011 (BULK = bulk vessels, CARGO = general cargo vessels, NAVY = navy vessels, PASS = passenger vessels, TANK = tankers, TUG = tugs)

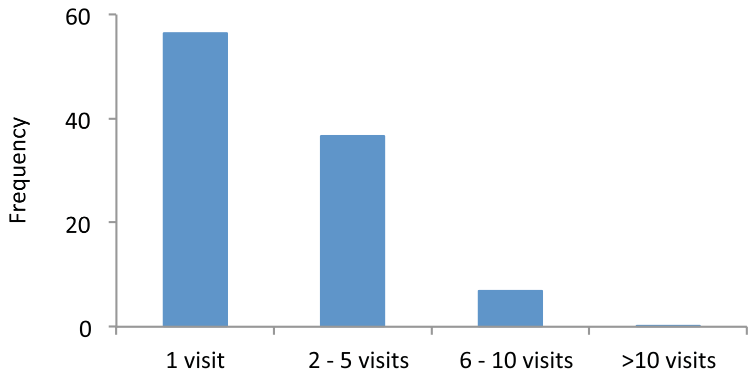


Figure 30 Frequency of repeat vessel visits to Port Hedland Port in 2011

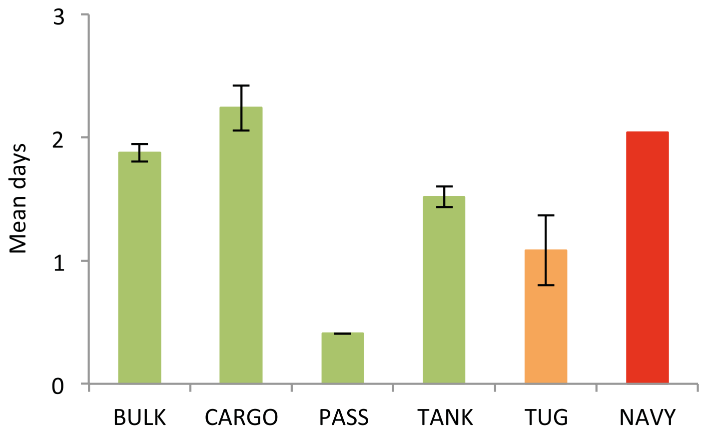


Figure 31 Mean residency time (days ± SE) for the vessel types and risk rating (green = low risk, orange = moderate risk and red = high risk) visiting Port Hedland Port in 2011 (BULK = bulk vessels, CARGO = general cargo vessels, NAVY = navy vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

The majority of vessel visits (1444 out of 1506, or 95.9%) to Port Hedland Port were from an international source (Table 7). These international vessel visits were from 14 countries. Over half (i.e. 812 visits, or 56.2%) of the total international visits were from China. The next most common sources were Japan (174 visits or 12.0%) and South Korea (150 visits or 10.4%). The majority of vessels from international sources were bulk vessels with a low risk rating (1350 visits or 93.5%, Figure 32).

Domestic visits (62) accounted for only 4.1 % of total visits. This included nine visits from six different interstate locations, all from vessels with a low risk rating, the majority being bulk vessels with eight visits (Table 7). Intrastate visits (53) made up the majority of the domestic vessel sources and were from nine different locations. Dampier Port, with 17 visits (32.1% of total intrastate visits) was the greatest source of intrastate vessels, followed by Fremantle Port with 13 visits (24.5%). Most of the intrastate vessel types had a low risk rating (50 visits; 94.3% of intrastate vessels), one vessel – a tug – had a moderate risk rating (3 visits; 5.7% of intrastate vessels) and one further vessel – a navy vessel – had a high risk rating (1 visit; 1.8% of intrastate vessels; Figure 32).

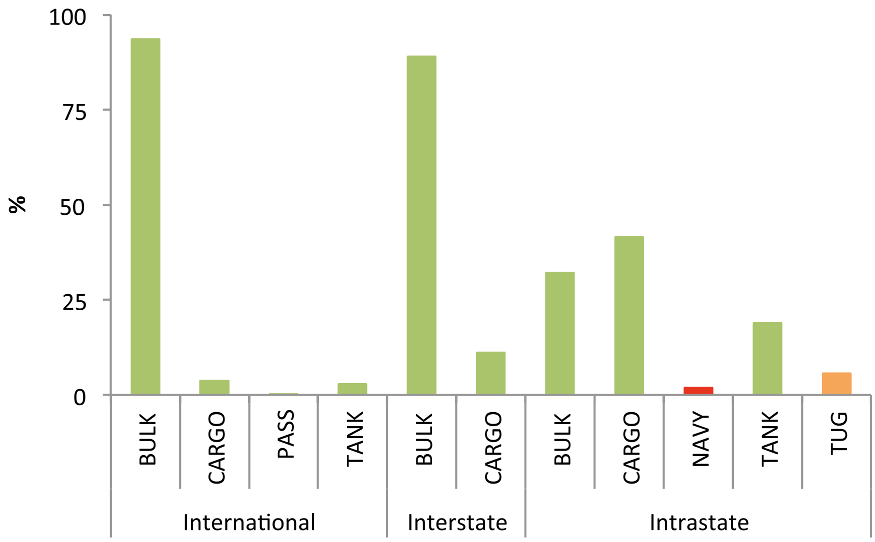


Figure 32 Percentage of vessels arriving into Port Hedland Port from international, interstate and intrastate sources by vessel type (BULK = bulk vessels, CARGO = general cargo vessels, NAVY = navy vessels, PASS = passenger vessels, TANK = tankers, TUG = tugs)

Table 7 Summary of vessel visits to Port Hedland port from source locations

Source	Number of visits	% of visits
International	**1444**	**95.9**
China	812	56.2
Hong Kong	30	2.1
India	3	0.2
Indonesia	32	2.2
Japan	174	12.0
Malaysia	16	1.1
Papua New Guinea	1	0.1
Philippines	12	0.8
Singapore	124	8.6
South Korea	150	10.4
Sri Lanka	2	0.1
Taiwan	71	4.9
Thailand	16	1.1
Vietnam	1	0.1
Domestic	**62**	**4.1**
Interstate	**9**	**% of interstate**
Dalrymple Inlet	1	11.1
Darwin	4	44.4
Mackey	1	11.1
Port Alma	1	11.1
Port Kembla	1	11.1
Portland	1	11.1

Source	Number of visits	% of visits
Intrastate	**53**	**% of intrastate**
Broome	3	5.7
Bunbury	2	3.8
Cape Cuvier	1	1.9
Cape Preston	1	1.9
Dampier	17	32.1
Exmouth	1	1.9
Fremantle	13	24.5
Geraldton	7	13.2
Kwinana	5	9.4
Port Hedland	3	5.7

7.2.2 Sociopolitical risk

The vessels visiting Port Hedland Port were from 35 different flag states. Of these, 10 (27.3%) were listed as FOC states (Figure 33, see 'A'). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 60.3% of all visits to Port Hedland port (Figure 33, see 'B'). The greatest proportion of FOC vessels came from Panama (62.7%, Figure 33, see 'C').

Of the 35 flag states, only 11 (18.7% of total visits) have ratified the IMO BWM. Further analysis revealed that 3 of these 11 were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 5.6% of total visits.

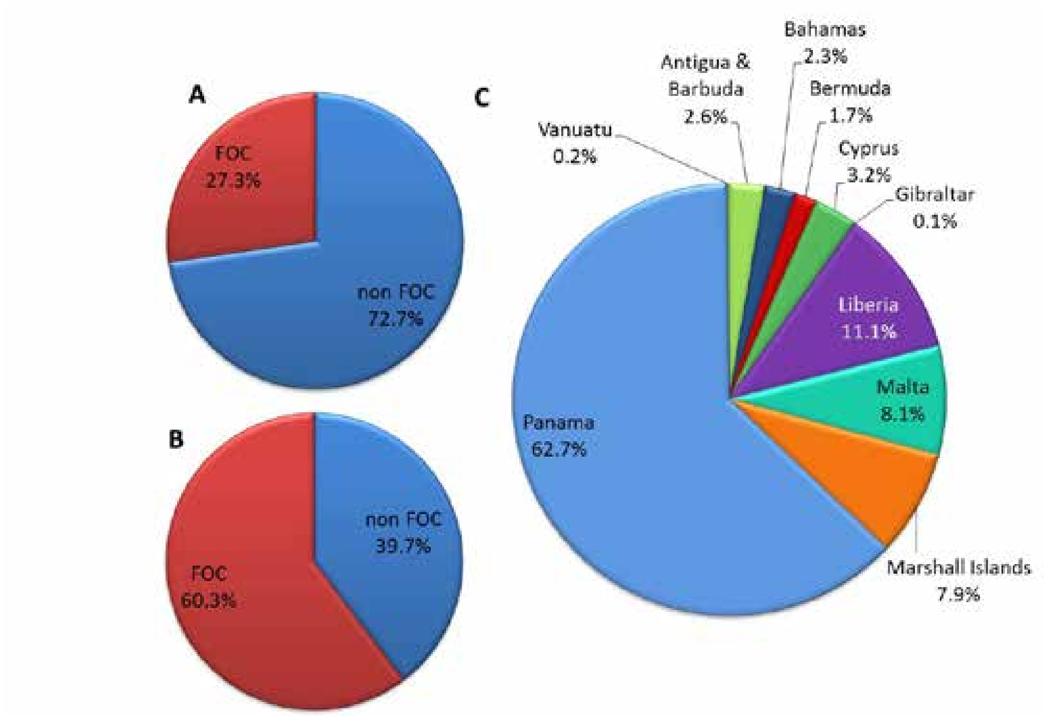


Figure 33 Percentage of FOC and non-FOC states entering Port Hedland Port (A). Percentage of vessel visits by registry of FOC and non-FOC state entering Port Hedland Port (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Port Hedland Port based on the 2011 data was low to moderate, as the majority of vessels had a low risk rating and stayed for short periods, but with moderate number of repeat visits. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Additionally, just under two-thirds of the vessels visiting Port Hedland Port were registered from countries considered to be FOCs and very few of the total number of vessels were from flag states that had ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

7.2.3 Infection and establishment likelihood

There were 30 IMP species present at LPOC locations of which 14 (47%) have temperature and salinity tolerances compatible with Port Hedland Port environs. All 14 compatible species were located at one or more of the international sources for vessels (Figure 34). For domestic LPOCs, there were two species located interstate and two species located intrastate. *Crassostrea gigas* occurred at the most sources (11), closely followed by *Balanus improvisus* and *Perna viridis*, both present at nine sources each.

C. gigas (oyster) could pose a significant threat to native oyster and mussel populations. *B. improvisus* (barnacle) is a common biofouler and once introduced into a new area, this species can dominate and outcompete native species for available habitat (Qvarfordt *et al.* 2006). *P. viridis* (mussel) can live in locations that are highly contaminated with industrial and human pollution. They can also potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure (Barber *et al.* 2005; Rajagopal *et al.* 2006).

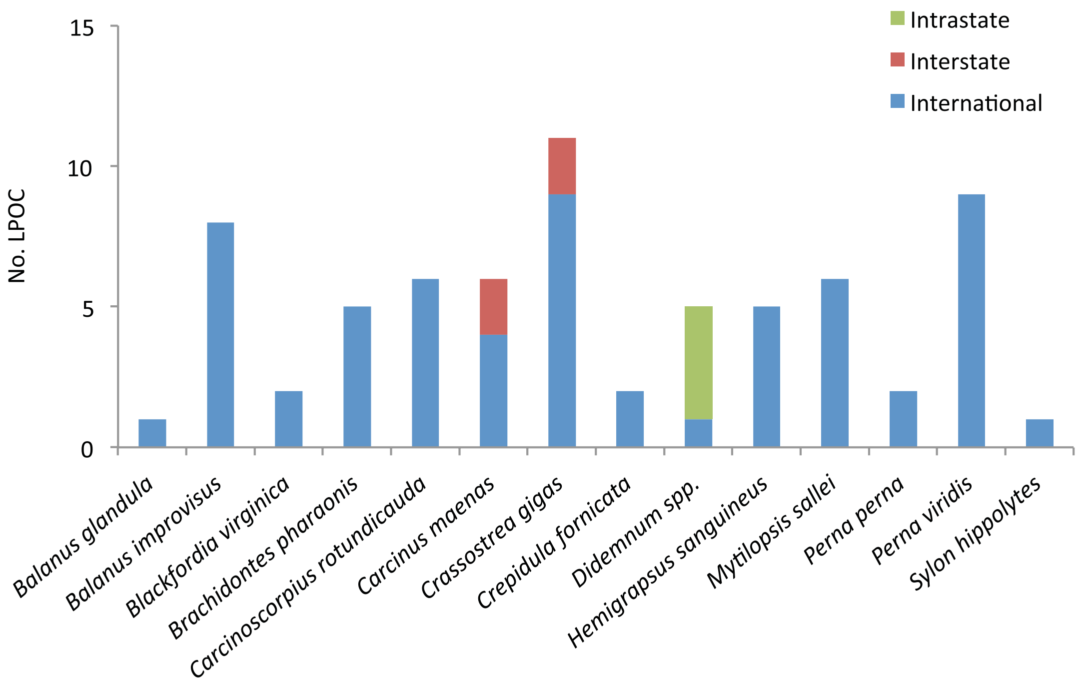


Figure 34 IMP species compatible with Port Hedland Port and the number of LPOCs (international, interstate and intrastate) at which they occur

There were 13 different LPOCs that contained IMPs with either a high or moderate risk that were compatible with Port Hedland Port's environment. Thailand and Japan had the greatest number of IMPs with nine species each. Seven of the IMPs from Thailand were high risk, and six of the IMPs from Japan were also high risk (Figure 35). China and India followed, with seven IMPs each, five of which were high risk.

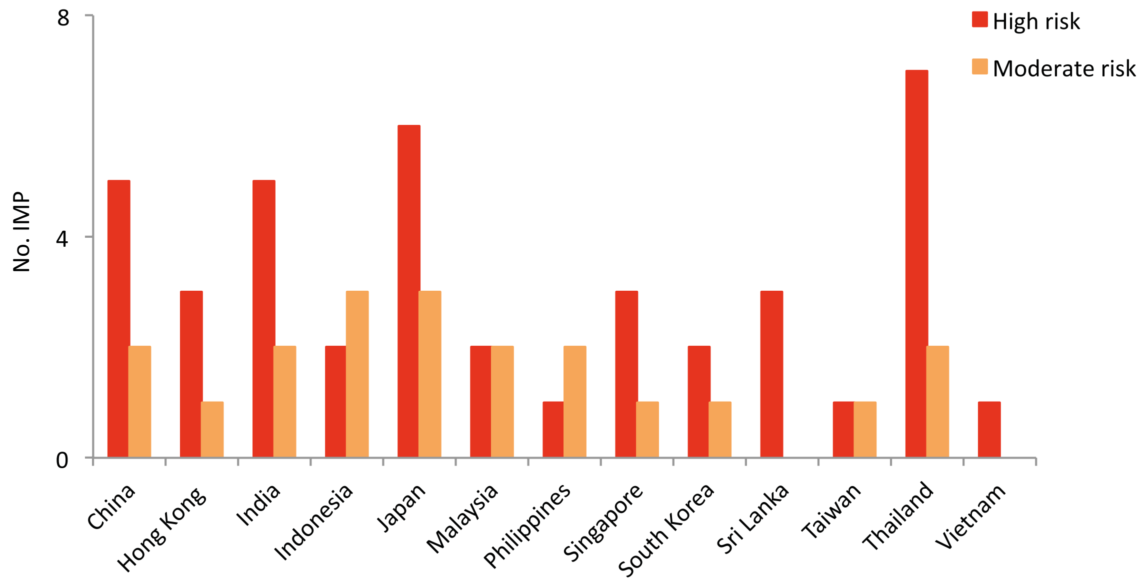


Figure 35 IMP species with a moderate or high risk rating, present at international LPOCs that were compatible with Port Hedland Port environs

When the cumulative effect of the number of vessel visits from an international LPOC and number of IMPs present at that LPOC is considered, the greatest infection and establishment risk to Port Hedland Port was from China (Figure 36). LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 36. Selected IMPs from China that posed a risk to Port Hedland Port are shown pictorially in Figure 37.

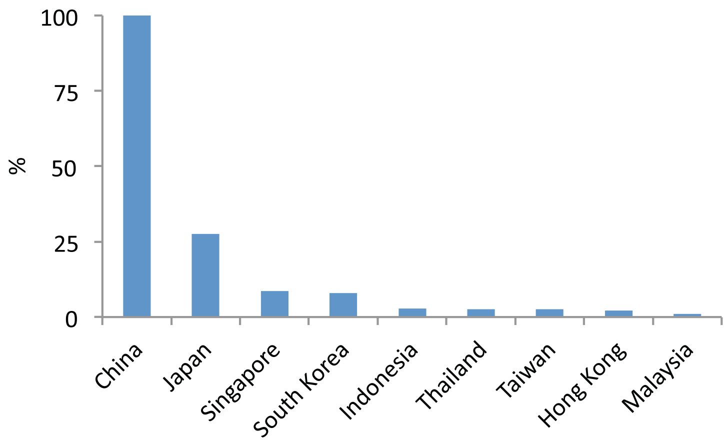


Figure 36 Ranking of the infection and establishment risk posed to Port Hedland Port by international LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. China 100%)

Figure 37 Map showing the proximity of China (red circle) to Port Hedland Port (yellow star) and the selected IMPs that posed the greatest risk to Port Hedland Port

IMP species were recorded at six domestic LPOCs, of which two were interstate and four of which intrastate (Table 8, Figure 38). The interstate ports of Port Kembla and Portland both had two pests present, one with a high risk and one with a moderate risk (Table 8). When the cumulative effect of the number of vessels visits from a domestic LPOC and the number of species present at that LPOC is considered, the greatest domestic infection and establishment risk to Port Hedland Port was from Dampier (Figure 38). Domestic LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 38. The domestic pest species that posed the greatest risk to Port Hedland Port are *Carcinus maenas* (crab, from New South Wales and Victoria) and *Crassostrea gigas* (oyster, from New South Wales and Victoria).

Table 8 Number of compatible IMPs with high and moderate risk ratings present at domestic (interstate and intrastate) LPOCs

LPOC Domestic	High risk	Moderate risk
Interstate		
Port Kembla (New South Wales)	1	1
Portland (Victoria)	1	1
Intrastate		
Broome	0	1
Dampier	0	1
Fremantle	0	1
Kwinana	0	1

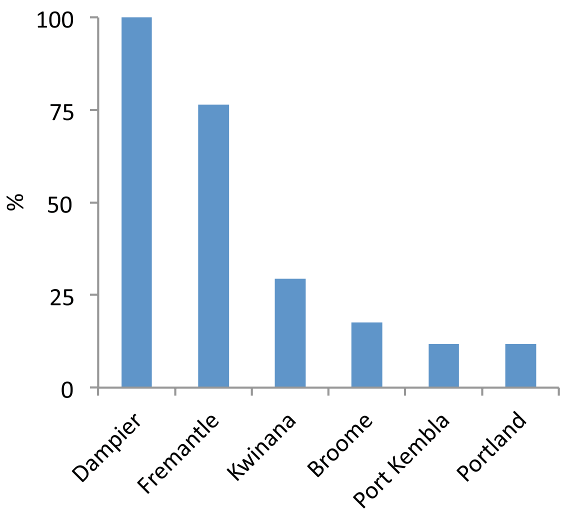


Figure 38 Ranking of the infection and establishment risk posed to Port Hedland Port by domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Dampier 100%)

There were six species from international and domestic sources that presented the greatest likelihood of infection and establishment to Port Hedland Port. One of the species, *Carcinus maenas* (crab), is listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining five species, although not listed in the top 100 worst, still pose a significant threat to Port Hedland Port for one or more of the following: the environment, sociocultural values, economic value or human health. Brief information on these species is provided in Table 9. For further information, images and references for these species please see Appendix 2.

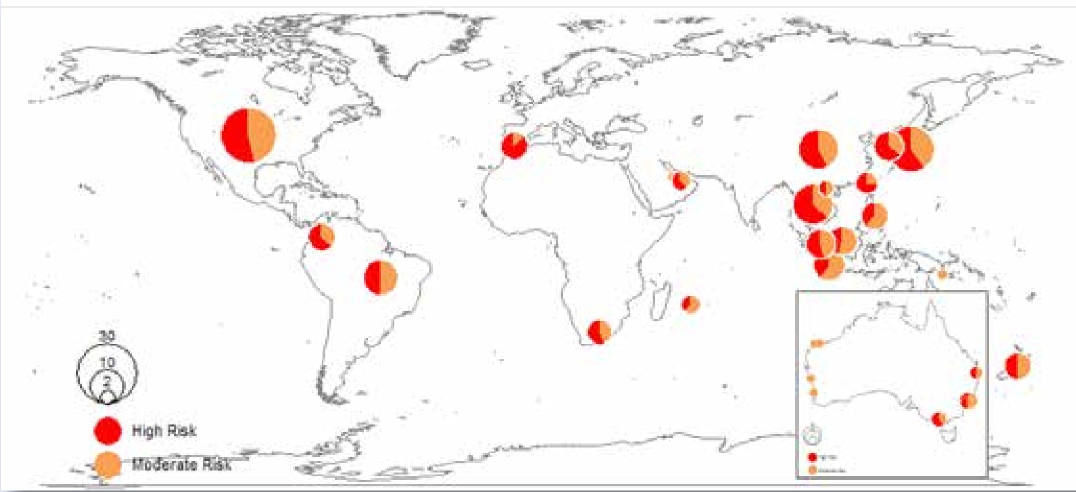
Table 9 The impact rank and examples of impacts for the 12 species which presented the greatest likelihood of infection and establishment to Fremantle Port

IMP species	Impact rank (M = medium, H = high)	Impacts
Carcinus maenas (crab)	H	This crab is a voracious predator, known to negatively impact population size and structure of many species, especially shellfish and crabs. In the US, financial losses to the shellfish industry due to this IMP have been reported at USD$22.6 million and this is predicted to rise significantly.
Undaria pinnatifida (algae)	H	This is an extremely fast-growing algae with two forms of efficient reproduction that result in a competitive advantage over native species for space.
Balanus improvisus (barnacle)	H	This barnacle is a fast-growing species that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.
Brachidontes pharaonis (mussel)	H	There is no impact information available for this mussel and the taxonomic status of the species is complex. As such, the species is currently considered cryptogenic.
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi River regions in the USA, M. sallei has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic-pelagic system, affecting the food web structure and its productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes, and reducing the efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder, it can pose a hazard for shellfish poisoning (paralytic shellfish poison toxins).
Hemigrapsus sanguineus (crab)	H	This is an aggressive crab that can outcompete and displace native crabs and other native species, thus altering ecosystem function.

8.0 Dampier Port

Dampier PORT AT A GLANCE

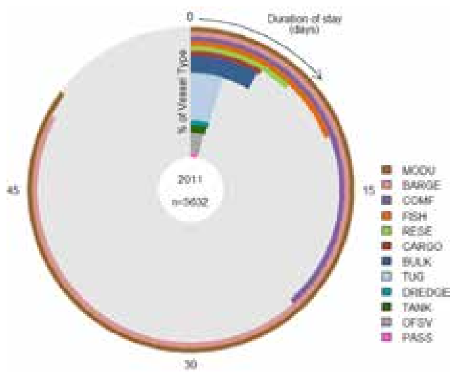
Multiple sources of high and moderate risk IMPs to Dampier



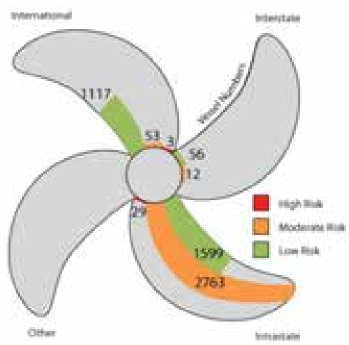
74% of inbound IMPs are compatible with Dampier Port environs

1315 visits from flags of convenience

4317 visits from recognized flags



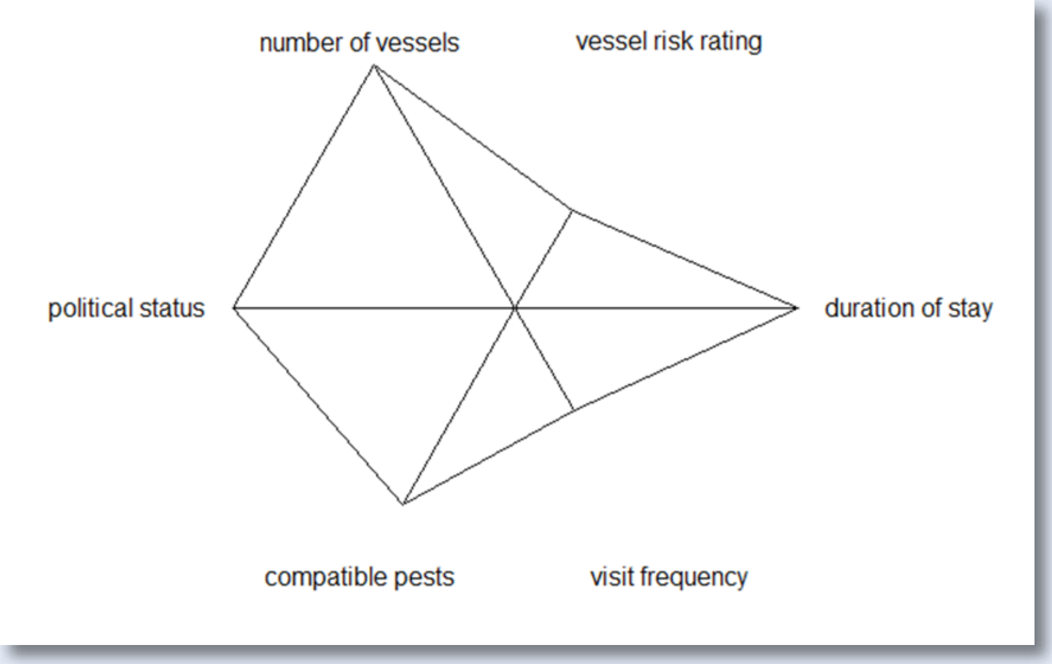
Mobile offshore drilling units (MODU) and barge vessels stay the longest but tug vessels are more common



Majority of vessels are from intrastate LPOCs and are moderate risk

Dampier Port

The drivers for Dampier Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Dampier Port. The length of the point indicates the degree to which that factor contributes to the risk.



The majority of vessels entering Dampier Port were vessels with a moderate risk rating that stayed for extended periods and often visited repeatedly during 2011. In addition, a quarter of the vessels visiting Dampier Port were registered from countries considered to be FOCs and only 14.5% of the total vessel visits were from flag states that had ratified the IMO BWM convention. There was a high compatibility (74%) between the potential incoming marine pests and the environment of Dampier Port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOCs that posed the greatest risk to Dampier Port were China and Japan. Between these two countries, they contain three species listed in the top 100 worst invasive species worldwide that are compatible with the environment of Dampier Port. These include: *Carcinus maenas*, (European shore crab), *Eriocheir sinensis* (Chinese mitten crab) and *Undaria pinnatifida* (wakame). Geelong Port posed the greatest domestic risk to Dampier Port based on the number of vessels from there and the number of potentially compatible pests.

8.1 Dampier Port description

The port of Dampier is located approximately 1300 km north of Perth, on the western side of the Burrup Peninsula, in the Pilbara region of WA (Figure 39). The port recorded a total throughput of 165 million tonnes in 2010/11, the majority of which was iron ore (82.5%) (Dampier Port Authority 2011). The port's limits encompass an area of approximately 660.4 km^2 and include the waters of Mermaid Sound and outer anchorages (Dampier Port Authority 2011). There are numerous berths and facilities operated by various stakeholders (Figure 39).

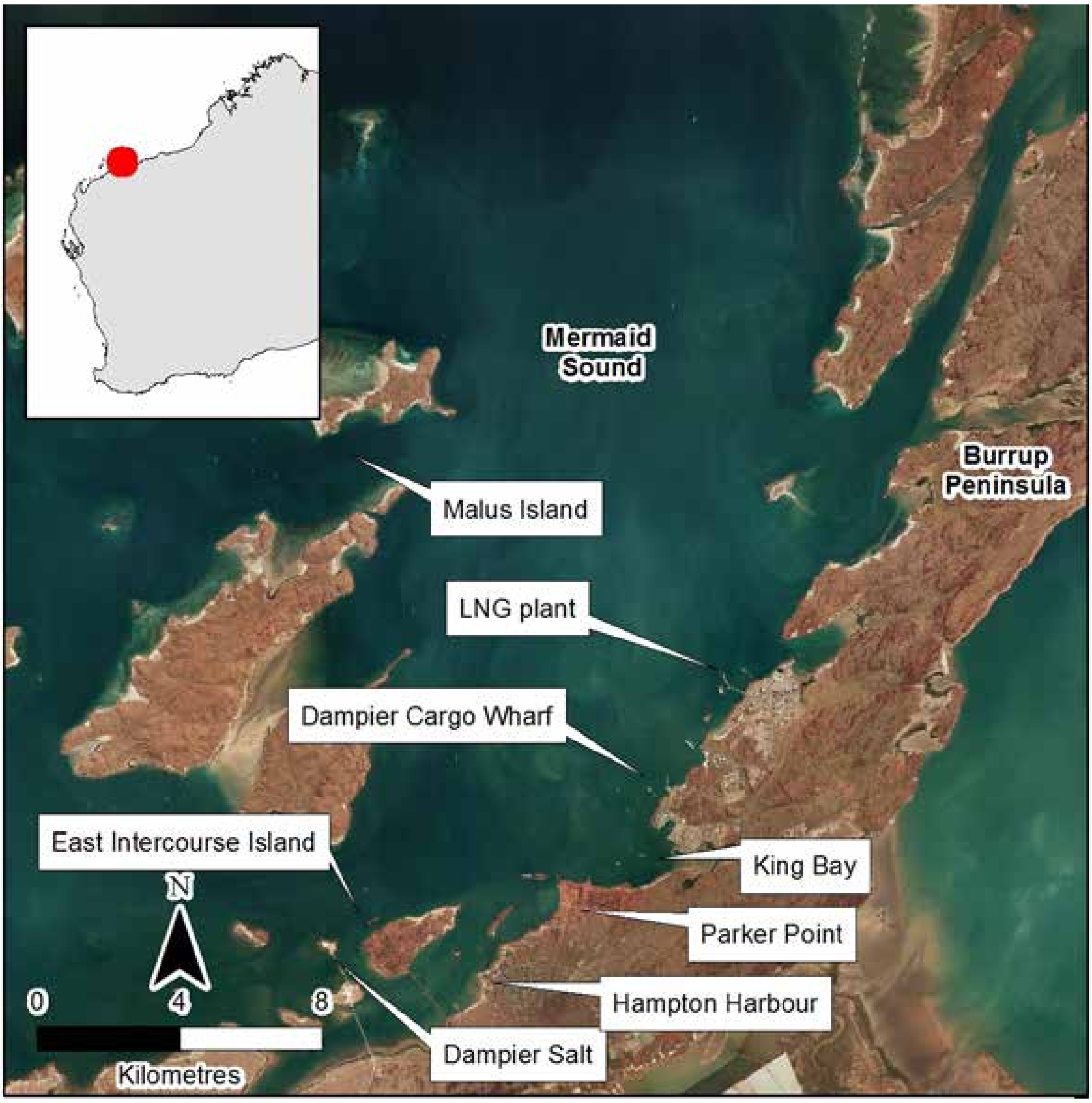


Figure 39 Dampier Port infrastructure and locality map

8.1.1 Environment

This region experiences hot, dry summers with periodic heavy rainfall and mild, dry winters with occasional rainfall. Tropical cyclones occur from November to April.

The port includes areas of open water, islands, mangroves, coral and rock platforms and sediment beaches. It is a marine environment dominated by tidal movements, with spring tidal ranges of up to 5.3 m. The majority of the basin is soft silt. This, coupled with the strong tidal range, produces highly turbid inshore waters.

Environmental values used for the analysis were a water temperature range of 20.4 °C to 31.3 °C and a salinity range of 33.8 – 39.0 ppt. These values were taken from the nationally approved marine pest monitoring design for Dampier Port (Bridgwood & Hourston 2009a).

8.1.2 Current knowledge of introduced marine pests

Huisman *et al.* (2008) have undertaken a review of introduced marine biota in WA waters, drawn from a variety of sources including scientific literature, several unpublished surveys of WA ports and unpublished information, including the Western Australian Museum surveys from the early 1970s and late 1990s. Five barnacle species and a single bryozoan were identified by Huisman *et al.* (2008) as occurring in the Dampier port region (Table 10).

The DoF has conducted two full National System surveys of Dampier port in 2011 and 2013 (Hourston, 2012a and Hourston, in prep. a) and maintains a complementary monitoring system which includes settlement arrays, crab traps and shoreline searches (Muñoz & Bridgwood 2013a). To date, surveys by the Department have detected only one IMP species, *Didemnum perlucidum* (colonial ascidian).

Table 10 Introduced species for the Dampier region as identified in Huisman *et al.* (2008) and detected during the Department's surveys

Taxonomic group	Species
Bryozoa	*Bugula neritina*
Crustacea	*Amphibalanus amphitrite*
	Amphibalanus reticulatus
	Megabalanus ajax
	Megabalanus rosa
	Megabalanus tintinnabulum
Ascidian	*Didemnum perlucidum*

8.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include the inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the Methods section.

8.2.1 Inoculation likelihood

Dampier Port received a total of 5632 vessel visits based on the 2011 data examined. Tugs were the dominant type of vessel recorded entering Dampier Port (49.4%, Figure 40). Offshore support vessels and bulk carriers were the next most abundant types of vessels (20.2 % and 18.3% respectively). There were 425 vessels (47.8%) that visited the port once (Figure 41). A total of 317 vessels (35.6%) visited 2 – 5 times, 48 vessels (5.4%) visited 6 – 10 times and 100 vessels (11.2%) visited more than 10 times.

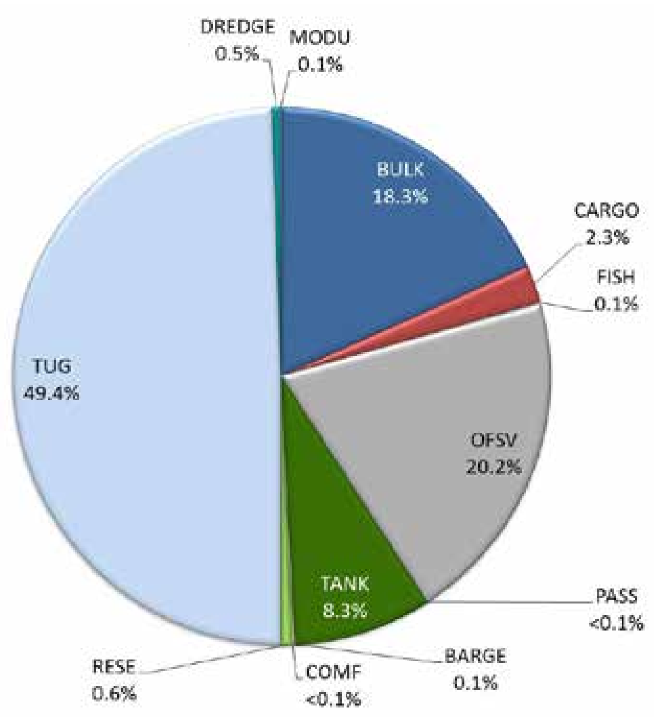


Figure 40 Summary of vessel type entering Dampier Port in 2011. (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, FISH = fisheries compliance/water police, MODU = mobile offshore drilling unit/floating production storage offshore vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

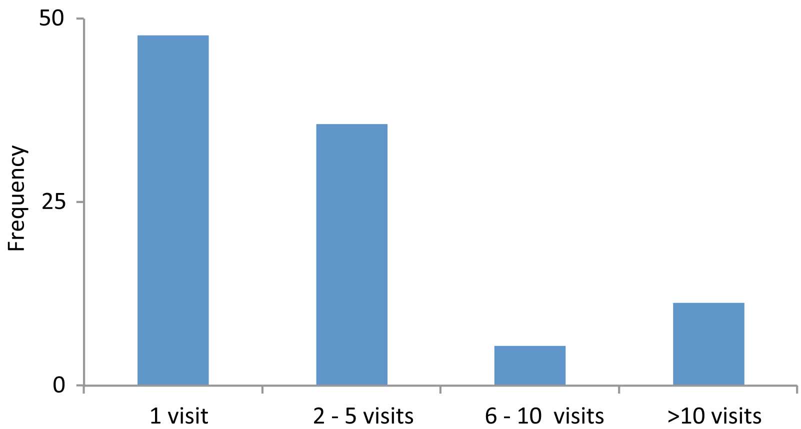


Figure 41 Frequency of repeat vessel visits to Dampier Port in 2011

The vessel type that stayed, on average, for the longest was the mobile offshore drilling unit, with a high risk rating. This vessel type stayed between 3 and 217 days (average of 51 days, Figure 42). Barges, with a moderate risk rating, stayed, on average, for 49 days (between 1 and 270 days).

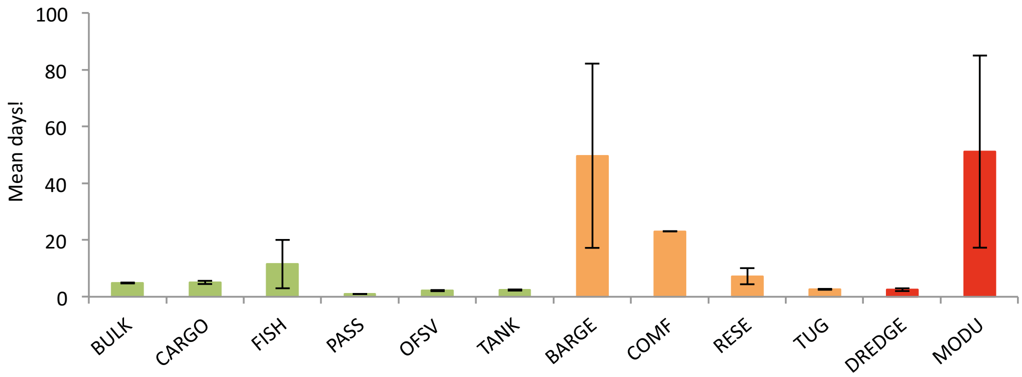


Figure 42 Mean residency time (days ± SE) for vessel types and risk rating (green = low risk, orange = moderate risk, red = high risk) visiting Dampier Port in 2011. (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, FISH = fisheries compliance/water police, MODU = mobile offshore drilling unit/floating production storage offshore vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

Based on LPOC data, the majority of vessel visits to Dampier Port (4391 out of 5632, or 78.0%) were from an intrastate source (Table 11). These intrastate vessel visits were from 21 locations, including offshore fields and terminals. The majority of these vessels were tugs with a moderate risk rating (2730 visits or 62.2%, Figure 43). There were only a small number of vessels visits from 13 different interstate sources (68 visits, of 1.3% of total visits) and the majority of those were tankers with a low risk rating (60.2%).

International vessel visits (1173) accounted for 20.8% of the total number of vessel visits to Dampier Port (Table 11). These international vessel visits were from 21 countries, of which 415 visits (i.e. 35.4% of the total international visits) were from China (Table 11). The next most common international sources were Japan (290 visits or 24.7%) and Singapore (189 visits, or 16.1%). The majority of vessels from international sources were bulk carriers with a low risk rating (726 visits or 61.9%, Figure 43).

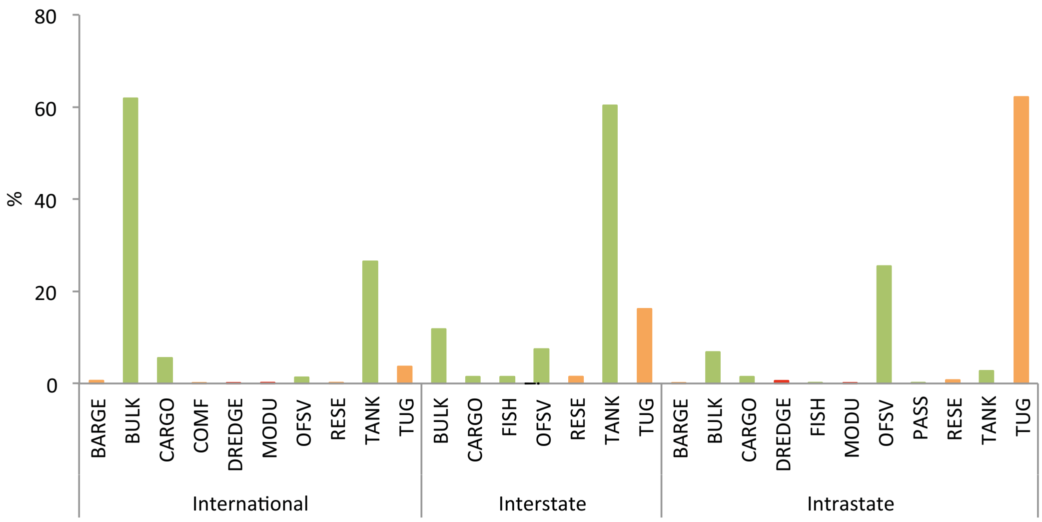


Figure 43 Percentage of vessels arriving into Dampier Port in 2011 from international, interstate and intrastate sources by vessel type and risk rating (green = low risk, orange = moderate risk and red = high risk). (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, FISH = fisheries compliance/water police, MODU = mobile offshore drilling unit/floating production storage offshore vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

Table 11 Summary of vessel visits to Dampier Port from source locations

Source	Number of visits	Percentage of visits (%)
International	**1173**	**20.8**
Brazil	1	0.1
China	415	35.4
Christmas Island	1	0.1
Colombia	1	0.1
Gibraltar	1	0.1
Indonesia	56	4.8
Japan	290	24.7
Malaysia	19	1.6
Mauritius	1	0.1
New Zealand	6	0.5
Papua New Guinea	3	0.3
Philippines	6	0.5
Qatar	1	0.1
Singapore	189	16.1
South Africa	4	0.3
South Korea	110	9.4
Taiwan	54	4.6
Thailand	4	0.3
United Arab Emirates	1	0.1
USA	2	0.2
Vietnam	8	0.7
Domestic	**4459**	**79.2**
Interstate	**68**	**% of interstate**
Abbot Point	1	1.5
Botany Bay	1	1.5
Brisbane	5	7.4
Darwin	22	32.4
Geelong	9	13.2
Gladstone	8	11.8
Gove	4	5.9
Melbourne	5	7.4
Newcastle	2	2.9
Port Alma	1	1.5
Port Kembla	1	1.5
Sydney	8	11.8
Whyalla	1	1.5

Source	Number of visits	Percentage of visits (%)
Intrastate	**4391**	**% of intrastate**
Barrow Island Terminal	496	11.3
Broome	28	0.6
Cape Cuvier	1	<0.1
Cossack Pioneer Terminal	82	1.9
Dampier	3167	72.1
Esperance	1	0.0
Exmouth	57	1.3
Fremantle	74	1.7
Geraldton	4	0.1
Legendre Terminal	43	1.0
Mutineer Terminal	23	0.5
Nganhurra Terminal	69	1.6
Port Hedland	75	1.7
Port Walcott	42	1.0
Pyrenees Field	12	0.3
Stag Terminal	94	2.1
Stybarrow Venture Terminal	12	0.3
Useless Loop	1	<0.1
Varanus Island Terminal	60	1.4
Wandoo Terminal	43	1.0
Woollybutt Terminal	7	0.2
Kwinana	8	24.2

8.2.2 Sociopolitical risk

Vessels visiting Dampier Port were registered from 47 different flag states and of these, 14 (29.8%) were listed as FOC states (Figure 44, see 'A'). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented almost a quarter (23.3%) of all visits to Dampier (Figure 44, see 'B'). The greatest proportion of FOC vessels came from the countries of Panama (35.6%), Liberia (13.4%) and Vanuatu (13.3%, Figure 44, see 'C').

Of the 47 flag states, only 10 (14.5% of total visits) have ratified the IMO BWM. However, further analysis revealed that three of these were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM to 7.8% of total visits.

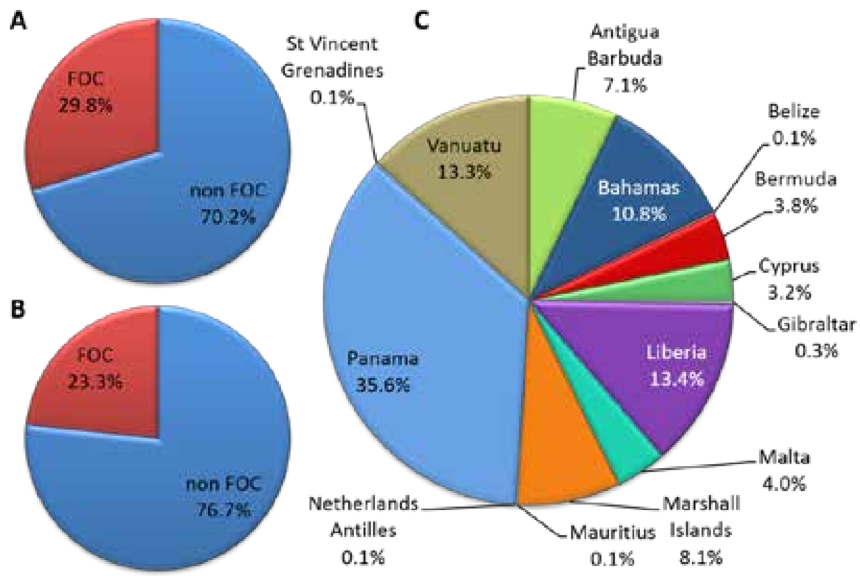


Figure 44 Percentage of FOC and non-FOC states entering Dampier Port (A). Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Dampier Port (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Dampier Port was moderate to high, as the majority of vessels had a moderate risk rating, they stayed for extended periods and often visited repeatedly. A quarter of the vessels visiting Dampier Port were registered from countries considered to be FOCs and very few of the total number of vessels were from flag states that had ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull. The greatest inoculation risks posed to Dampier Port for 2011 were from mobile offshore drilling unit vessels with a high risk rating, and barges with a moderate risk rating. These vessels stayed, on average, the longest.

8.2.3 Infection and establishment likelihood

There were 42 IMP species present at LPOC locations of which 31 (74%) had temperature and salinity tolerances compatible with Dampier Port environs. All 31 compatible species were located at one or more of the international sources for vessels (Figure 45). For domestic LPOCs there were six species located interstate and two located intrastate. *Caulerpa taxifolia* and *Crassostrea gigas* and were present at the most sources (17 and 16 respectively: international and domestic combined). The next most common species were *Balanus improvisus* (at 13 locations) and *Gymnodinium catenatum* (at 12 locations).

The macroalgae *C. taxifolia* occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe (Meinesz *et al.* 2001). *C. gigas* is a species that could pose a significant threat to native oyster and mussel populations. *B. improvisus* is a common biofouler and once introduced into a new range this species can dominate and outcompete native species for available habitat (Qvarfordt *et al.* 2006). *G. catenatum* is not regarded as a vessel biofouling species, however it may be transported as a cyst on equipment such as ropes and cages or in sediment present on a vessel.

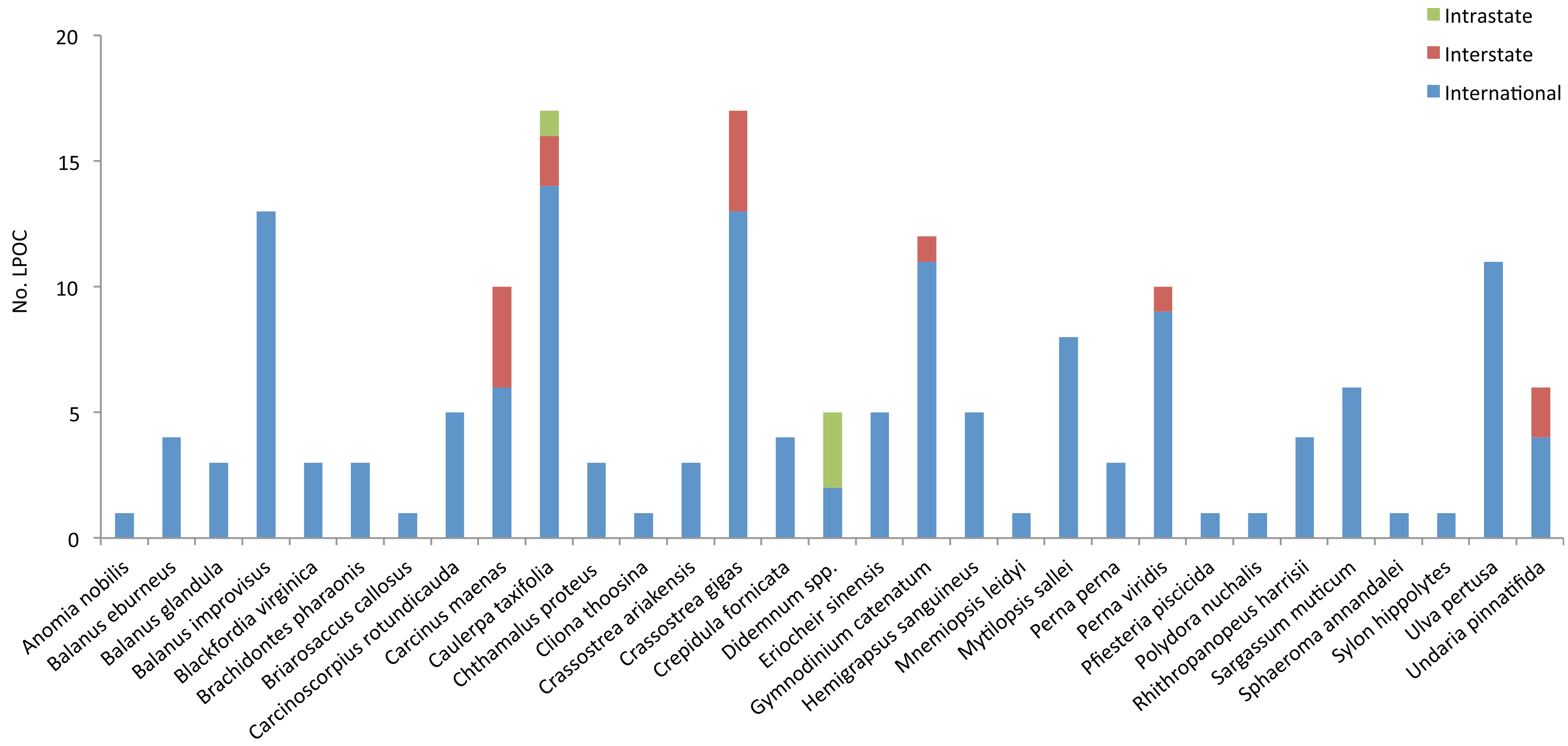


Figure 45 IMP species compatible with Dampier Port and the number of LPOCs (international, interstate and intrastate) at which they occur

There were 21 different LPOCs that contained an IMP that was compatible with Dampier Port environment with either a high or moderate risk rating. USA had the greatest number of IMPs with 25 species, 14 of which had a high risk rating. Japan had the greatest number of IMPs at 17 (11 with a high risk rating), followed by China with 14 IMPs (9 with a high risk rating) (Figure 46).

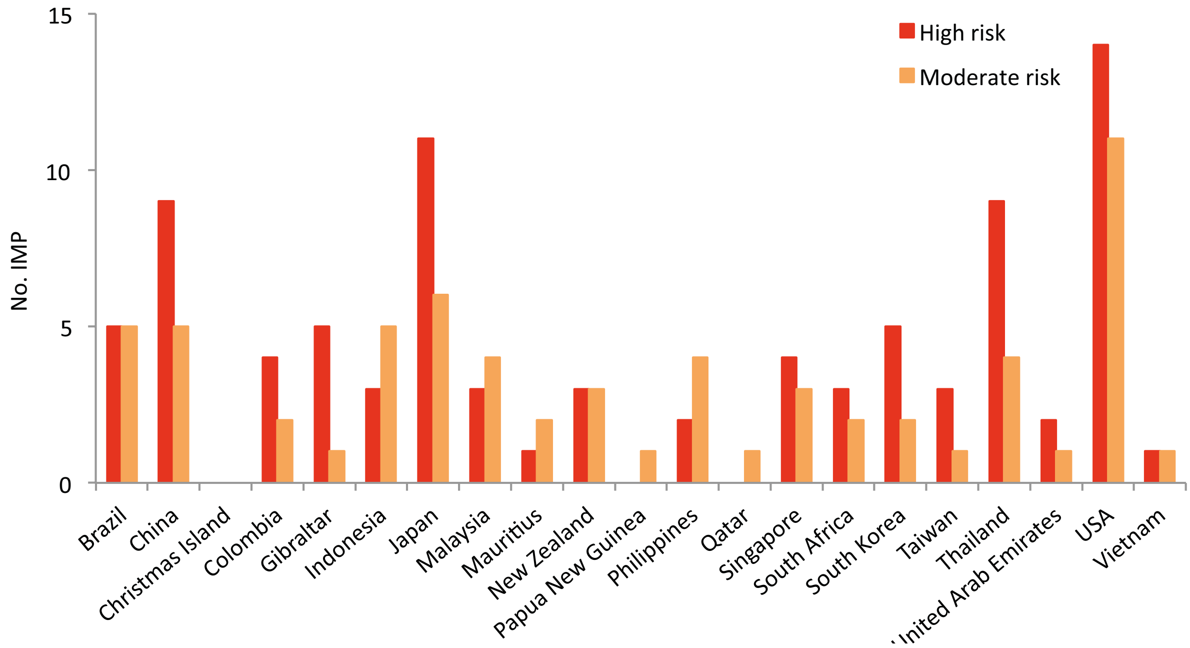


Figure 46 IMP species with a moderate or high risk rating, present at international LPOCs that were compatible with Dampier Port environs

When the cumulative effect of the number of vessel visits from an international LPOC and the number of IMPs present at that LPOC are considered, the greatest infection and establishment risk to Dampier Port was from China, followed closely by Japan (Figure 47). International LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 47. Selected IMPs from China and Japan that posed a risk to Dampier Port are shown pictorially in Figure 48.

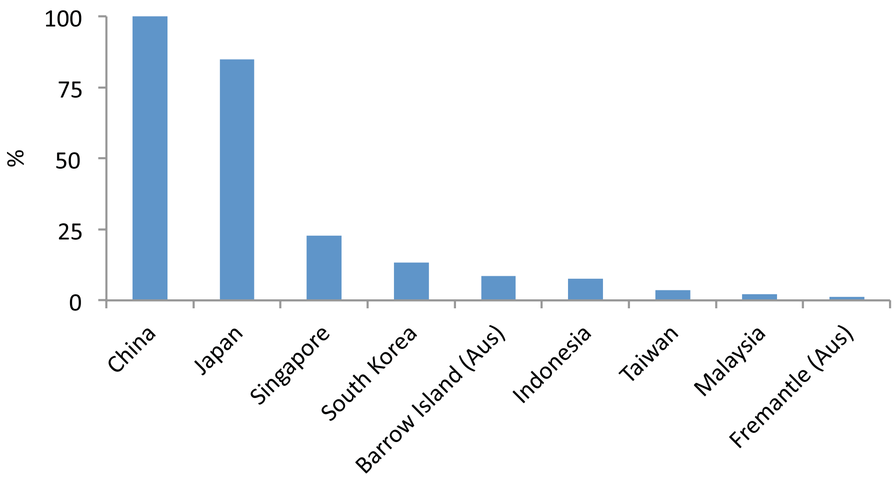


Figure 47 Ranking of the infection and establishment risk posed to Dampier Port by international and domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. China 100%)

Figure 48 Map showing the proximity of China (solid red circle) and Japan (broken red circle) to Dampier Port (yellow star) and the selected IMPs that pose the greatest risk to Dampier Port

IMP species were recorded at seven domestic LPOCs, four of which were interstate and three intrastate (Table 12). However, the moderate risk species present in the three intrastate locations was *Didemnum perlucidum* (colonial ascidian), a species which is known to also occur in Dampier Port. Geelong represented the greatest domestic infection and establishment risk for a ‘new’ pest to Dampier Port. The domestic pest species that posed the greatest risk to Dampier Port are *Carcinus maenas* (crab from New South Wales and Victoria) and *Undaria pinnatifida* (algae from Victoria).

Table 12 Number of compatible IMPs with a high or moderate risk rating present at domestic (interstate and intrastate) LPOCs

LPOC domestic	High risk	Moderate risk
Interstate		
Botany Bay (New South Wales)	1	3
Port Kembla (New South Wales)	1	1
Brisbane (Queensland)	1#	1
Geelong (Victoria)	2	1
Melbourne	2	1
Intrastate		
Barrow Island	0	1*
Fremantle	0	1*
Geraldton	0	1*

* indicates the pest species *Didemnum perlucidum*, this species is already known to occur in Dampier port

# indicates the species *Perna viridis*, although listed on marine invasive databases as present in Brisbane, the authors acknowledge that the species is not currently detected in the Brisbane Port environment (NIMPIS website)

There were 12 species from international and domestic sources that presented the greatest likelihood of infection and establishment to Dampier Port. Three of the species, *Carcinus maenas* (crab), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining nine species, although not listed in the top 100 worst, still posed a significant threat to Dampier Port for one or more of the following: the environment, sociocultural values, economic value or human health. Brief information on these species is provided in Table 13. For further information, images and references for these species please see Appendix 2.

Table 13 The impact rank and examples of impacts for the 12 species which presented the greatest likelihood of infection and establishment to Dampier Port

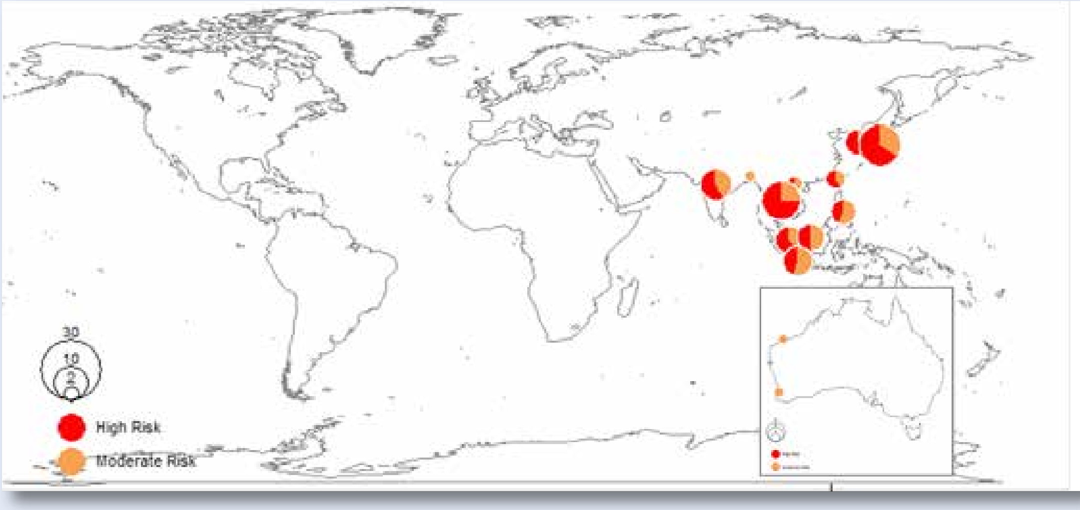
IMP species	Impact rank (M = medium, H = high)	Impacts
Carcinus maenas (crab)	H	This is a voracious predator, known to negatively impact population size and structure of many species especially shellfish and crabs. In the US, financial losses to the shellfish industry have been reported at USD$22.6 million and this is predicted to rise significantly.
Eriocheir sinensis (crab)	H	Large economic costs following the introduction of this species have been reported (EUR€80 million). These costs arise from ongoing management requirements to stabilise river banks damaged by the crabs, losses to commercial fisheries (crab predation), installation of barriers and ramps to prevent further crab migration and population control methods.
Undaria pinnatifida (algae)	H	This is an extremely fast-growing algae with two forms of efficient reproduction that result in a competitive advantage over native species for space.
Balanus improvisus (barnacle)	H	This is a fast-growing barnacle that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.
Crepidula fornicata (limpet)	H	This limpet is known to increase sedimentation rates, creating muddy anoxic conditions that negatively impact endofauna, outcompete and negatively impact the density of other species and negatively modify benthic communities.
Brachidontes pharaonis (mussel)	H	There is no impact information available for this mussel and the taxonomic status of the species is complex. As such, the species is currently considered cryptogenic.
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi river region in the USA, *M. sallei* has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic/pelagic system, affected the food web structure and productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes and reducing efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder, it can pose a hazard for shellfish poisoning (paralytic shellfish poison (PSP) toxins).

IMP species	Impact rank (M = medium, H = high)	Impacts
Hemigrapsus sanguineus (crab)	H	This is an aggressive crab that can outcompete and displace native crabs and other native species, thus altering ecosystem functioning.
Rhithropanopeus harrisii (crab)	H	Can compete with native crabs and benthic feeding fishes for food, alter food webs, foul water intake pipes, cause economic losses to gill net fisheries by spoiling fish caught in the fill nets and can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Sargassum muticum (algae)	H	This algae is known to outcompete native species (e.g. algae and seagrass) for space and through exclusion (i.e. shading), it can heavily foul marine equipment, clog intake pipes, increase the rate of sedimentation as it slows the water flow (dense stands) and reduce the social amenity of an area (floating mats and through decay).
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication.

9.0 Useless Loop Port

USELESS LOOP AT A GLANCE

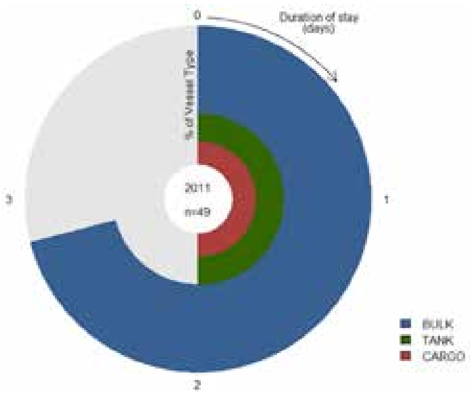
Asia is the greatest source of high and moderate risk IMPs to Useless Loop



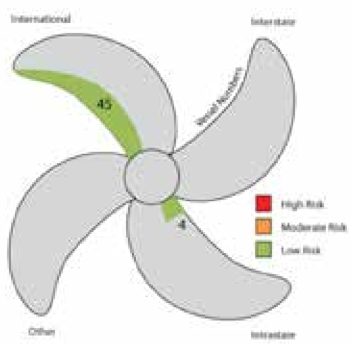
66% of inbound IMPs are compatible with Useless Loop Port environs

18 visits from recognized flags

31 visits from flags of convenience



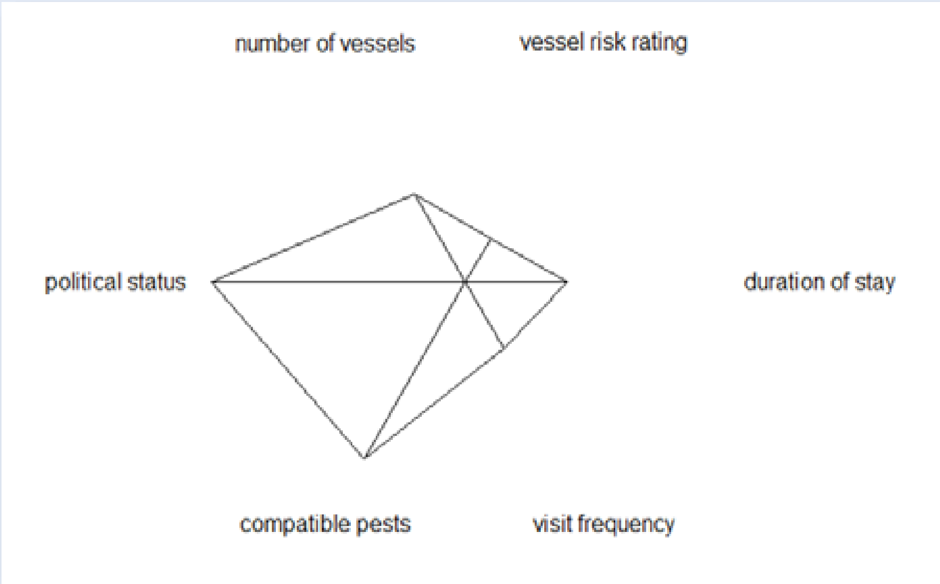
Bulk vessels stay the longest and are the most common



Majority of vessels are from international LPOCs and are low risk

Useless Loop Port

The drivers for Useless Loop Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Useless Loop Port. The length of the point indicates the degree to which that factor contributes to the risk.



All vessels entering Useless Loop Port had a low risk rating and stayed for only a short duration of time. Almost two-thirds of the vessels visiting Useless Loop Port were registered from countries considered to be FOCs and only a few of the total number of vessels were from flag states that had ratified the IMO BWM convention. However, there was a moderate level of compatibility (66%) between the potential incoming marine pests and the environment of Useless Loop Port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOCs that posed the greatest risk to Useless Loop Port were Japan and Malaysia. Japan also has four species listed in the top 100 worst invasive species worldwide, three of which were compatible with the environment of Useless Loop Port. These include: *Asterias amurensis* (northern pacific sea star), *Carcinus maenas*, (European shore crab) and *Undaria pinnatifida* (wakame). Dampier Port posed the greatest domestic risk to Useless Loop Port based on the number of vessels arriving from there and the number of potentially compatible pests.

9.1 Useless Loop Port description

The town of Useless Loop is situated on Denham Sound, on the western peninsula of Shark Bay, 600 km north of Perth, WA (Figure 49). The town is a closed company town, dedicated entirely to the Shark Bay Salt operations in the area. Likewise, the port at Useless Loop exclusively services the Shark Bay Salt production facility. The Shark Bay Salt facility produces and ships up to 1.3 million tonnes of salt per year.

There are only two main port areas. The northern part consists of a 2 km long rock wall causeway connecting Slope Island to the mainland, and then a further loading jetty from the island with a single berth. To the south there is a rock wall which semi-encloses a small marina, berthing the service vessels for the loading jetty.

The evaporation ponds themselves are separated from the ocean by a rock wall approximately 3 km long.

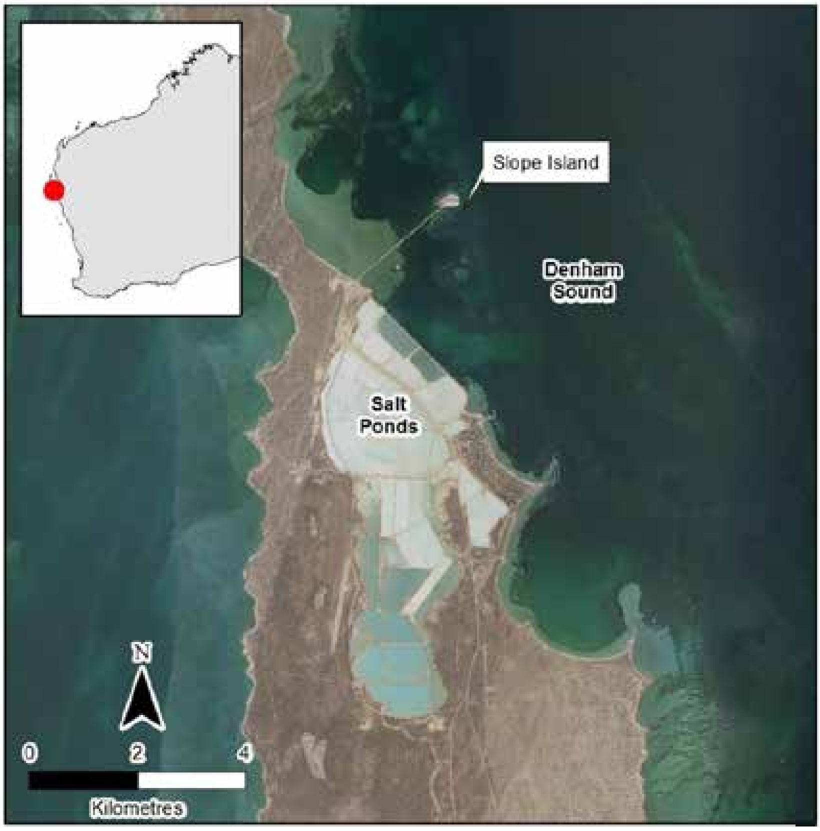


Figure 49 Useless Loop Port infrastructure and locality map

9.1.1 Environment

The vicinity of Shark Bay is known for its sheltered, warm waters and extensive seagrass beds and sand flats which host enormous native biodiversity. The Useless Loop Port facilities lie inside the boundaries of the Shark Bay World Heritage Area, within a general use zone.

Aside from the natural habitats of Shark Bay, the port structures – including the rock walls of the causeway, the evaporation pond and marina breakwaters – may provide hard substrates suitable for IMP colonisation. The evaporation ponds themselves are unlikely to provide suitable habitat as they become hypersaline during the evaporation process.

Environmental values used for the analysis were water a temperature range of 18.0 °C to 28.0°C and a salinity range of 36.8 – 41.0 ppt. These values were based on data used in the Global Ballast Water Management Programme (GloBallast).

9.1.2 Current knowledge of introduced marine pests

A survey for IMPs was conducted at the Useless loop Port facilities in 2006, however the information is not available in the public domain. Huisman *et al.* (2008) identifies two species of introduced barnacles present in Shark Bay, from specimens in the Western Australian Museum i.e. Megabalanus ajax and *Megabalanus tintinnabulum*. The former species has a widespread Indo-Pacific distribution, while the latter has a worldwide distribution. Both are common fouling species and are likely to have been transported via vessel movements.

9.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the Methods section.

9.2.1 Inoculation likelihood

There were 49 vessels that were recorded as visiting Useless Loop Port in 2011. All had a low risk rating. Of these, bulk carriers were the dominant vessel type (63.3%, Figure 50). The majority of vessels (16 or 64.0%) visited the port once, seven (28.0%) visited 2 – 5 times and two (8.0%) visited 6 – 10 times (Figure 51). All vessels stayed, on average, between two and three days (Figure 52).

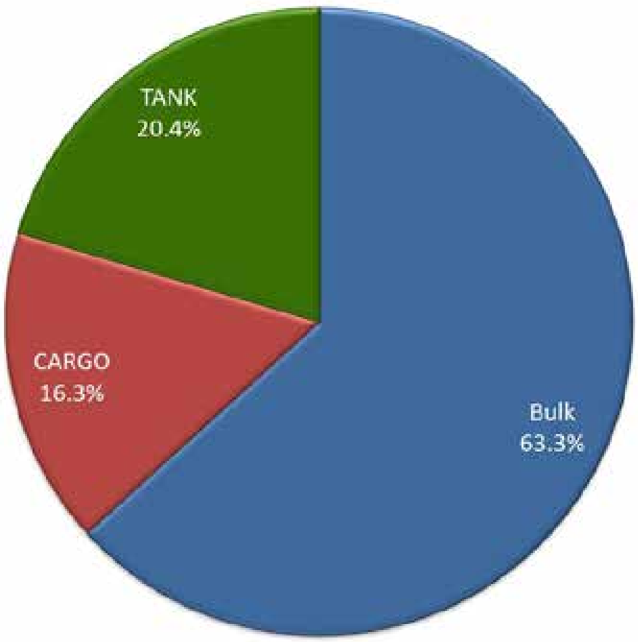


Figure 50 Summary of vessel type entering Useless Loop. (BULK = bulk vessels, CARGO = general cargo vessels, TANK = tankers)

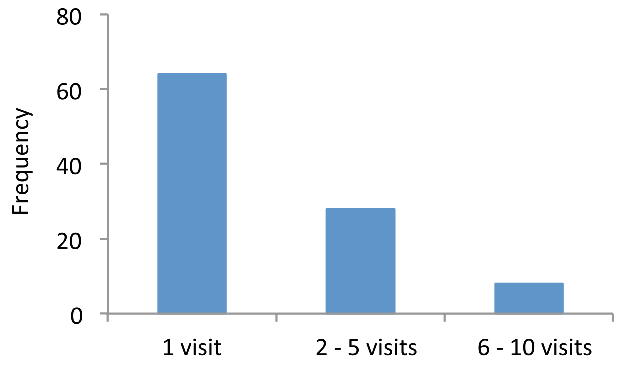


Figure 51 Frequency of repeat vessel visits to Useless Loop in 2011

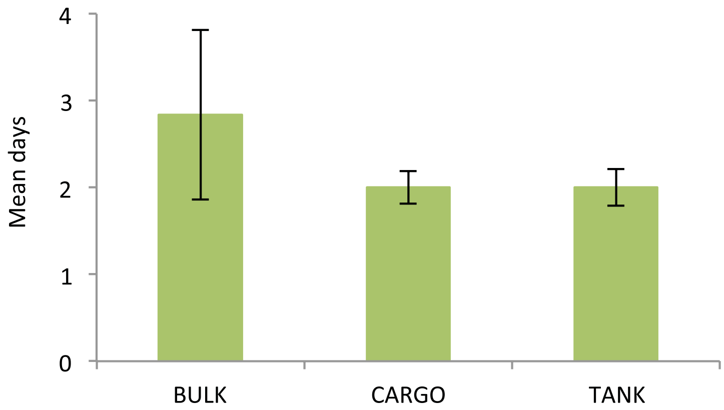


Figure 52 Mean residency time (days ± SE) for the different vessel types visiting Useless Loop Port in 2011 and their risk rating (green = low risk) (BULK = bulk vessels, CARGO = general cargo vessels, TANK = tankers)

The majority of vessel visits (45 out of 49, or 91.8%) to Useless Loop were from an international source and were bulk carriers (Table 14; Figure 53). These international vessel visits were from 11 countries. Of these, 13 visits (i.e. 28.9% of the total international visits) were from Malaysia. The next most common sources were Singapore and Taiwan with eight visits each (17.8%, Table 14). There were only four visits (8.2%) from domestic sources and all were from intrastate.

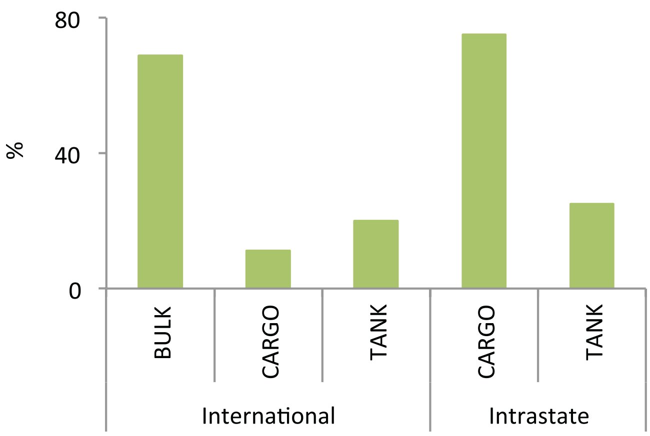


Figure 53 Percentage of vessels arriving into Useless Loop Port in 2011 from international, interstate and intrastate sources by vessel type and risk rating (green: low risk). (BULK = bulk vessels, CARGO = general cargo vessels, TANK = tankers)

Table 14 Summary of vessel visits to Useless Loop from source locations

Source	Number of visits	Percentage of visits (%)
International	**45**	**91.8**
Bangladesh	1	2.2
India	1	2.2
Indonesia	4	8.9
Japan	6	13.3
Malaysia	13	28.9
Philippines	1	2.2
Singapore	8	17.8
South Korea	1	2.2
Taiwan	8	17.8
Thailand	1	2.2
Vietnam	1	2.2
Domestic	**4**	**8.2**
Interstate	**0**	
Intrastate	**4**	**% of intrastate**
Dampier	1	25
Esperance	1	25
Kwinana	1	25
Port Hedland	1	25

9.2.2 Sociopolitical risk

Vessels visiting Useless Loop Port were registered from eight different flag states and of these, five (62.5%) were listed FOC states (Figure 54, see ‘A’). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 63.3% of all visits to Useless Loop (Figure 54, see ‘B’). The greatest proportion of FOC vessels came from Panama (64.5%, Figure 54, see ‘C’).

Of the eight flag states, four (22.4% of total visits) have ratified the IMO BWM and all four are FOC states. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 0% of total visits.

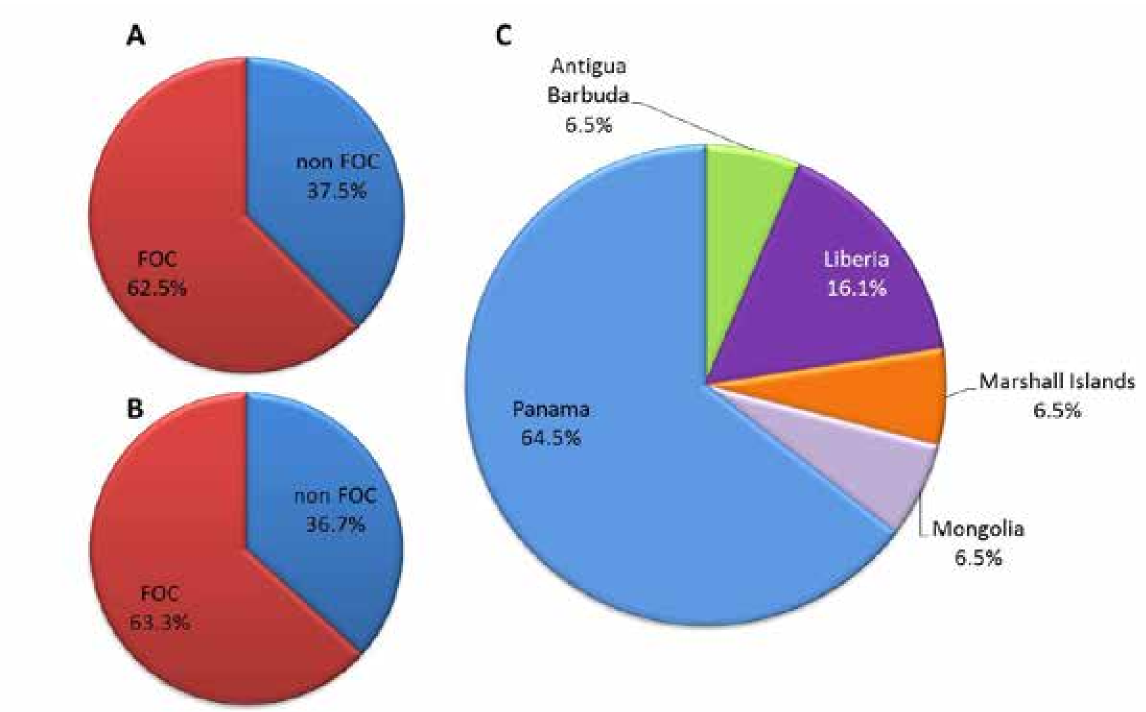


Figure 54 Percentage of FOC and non-FOC states entering Useless Loop (A). Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Useless Loop (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Useless Loop Port based on the 2011 data was low, as all vessels were had a low risk rating, had single visits and stayed for a short time. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Additionally, almost two-thirds of the vessels visiting Useless Loop Port were registered from countries considered to be FOCs and only a few of the total number of vessels were from flag states that had ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

9.2.3 Infection and establishment likelihood

There were 29 IMPs present at LPOC locations, 19 (66%) of which had temperature and salinity tolerances compatible with Useless Loop environs (Figure 55). All 19 compatible species were located at one or more of the international sources for vessels. For domestic LPOCs there was only one compatible species, *Didemnum* spp. which was from two intrastate sources. *Crassostrea gigas* occurred at the most sources (nine, all international). The next most common species, from seven international sources each, were *Balanus improvisus*, *Caulerpa taxifolia*, *Perna viridis* and *Ulva pertusa* (Figure 55).

C. gigas (oyster) is a species that could pose a significant threat to native oyster and mussel populations. *B. improvisus* (barnacle) is a common biofouler and once introduced into a new area, this species can dominate and outcompete native species for available habitat (Qvarfordt *et al.* 2006). The macroalgae *C. taxifolia* occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe (Meinesz *et al.* 2001). *P. viridis* (mussel) can live in locations that are highly contaminated with industrial and human pollution. They can also potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure (Barber *et al.* 2005; Rajagopal *et al.* 2006). *U. pertusa* (macroalgae) can become a dominant species in sheltered conditions where there are readily available nutrients and light (Seaweed Industry Association 2013). This species can be invasive due to its fast growth rate, high reproductive potential and broad environmental tolerances (CAB International 2013b).

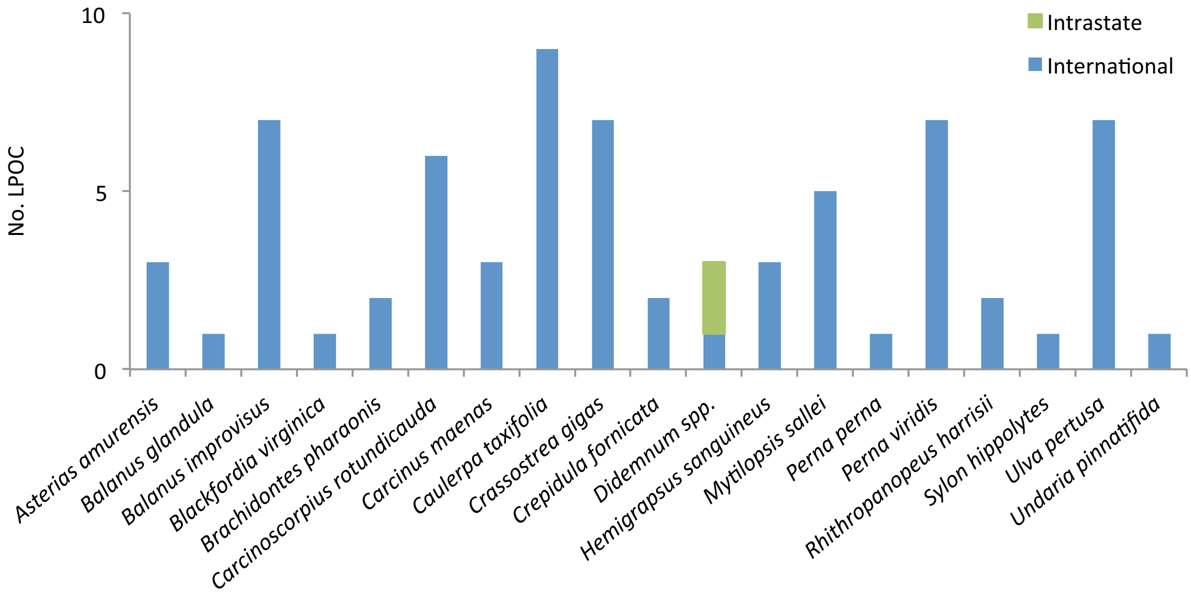


Figure 55 IMP species compatible with Useless Loop Port and the number of LPOCs (international and intrastate) at which they occur

There were 13 different international LPOCs that contained an IMP that was compatible with Useless Loops marine environment with either a high or moderate risk rating. The international source of Japan had the greatest number of IMPs with 14 species (10 with a high risk rating). Thailand had the next greatest number of IMPs with 12 each (9 with a high risk rating) (Figure 56). There were no domestic sources with a high risk IMP identified in the 2011 data for Useless Loop. There were, however, two intrastate sources (Dampier and Kwinana) with the pest *Didemnum* spp. that has a medium risk rating.

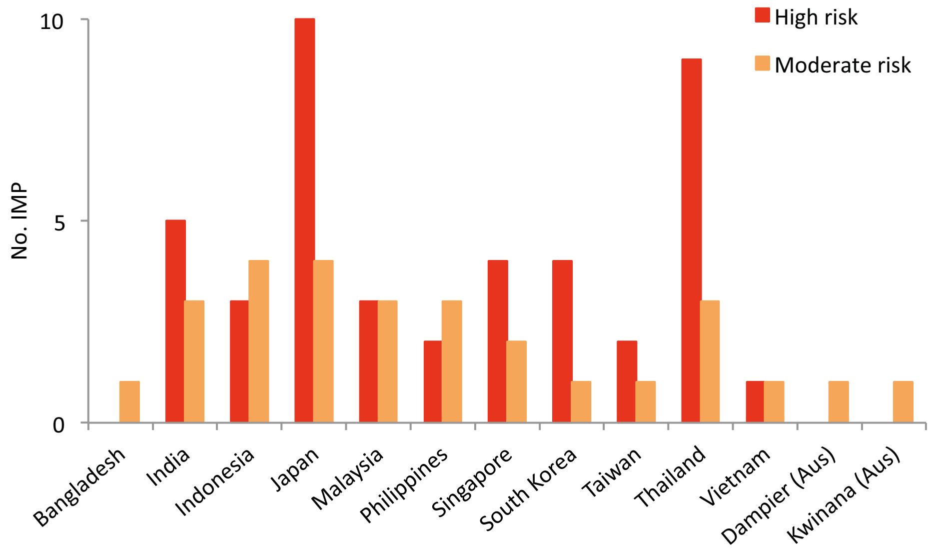


Figure 56 IMP species with a moderate or high risk rating, present at international and domestic LPOCs that were compatible with Useless Loop port environs

When the cumulative effect of the number of vessel visits from a LPOC and the number of IMP present at that LPOC is considered, the greatest infection and establishment risk to Useless Loop was from Japan and Malaysia (Figure 57). LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 57. There were only two domestic LPOCs, both intrastate (Dampier and Kwinana), that had an IMP which posed a risk to Useless Loop (i.e. *Didemnum perlucidum*: ascidian).

There were 10 species from international and domestic sources that presented the greatest likelihood of infection and establishment to Useless Loop. Three of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining seven species, although not listed in the top 100 worst, still pose a significant threat to Useless Loop for one or more of the following: the environment, sociocultural values, economic value or human health. Brief information on these species is provided in Table 15. For further information, images and references for these species please see Appendix 2.

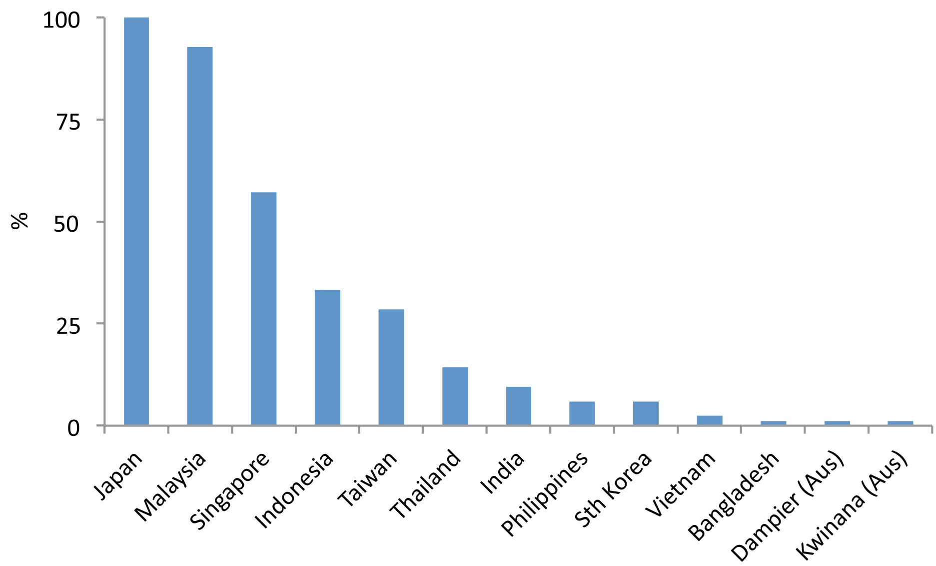


Figure 57 Ranking of the infection and establishment risk posed to Useless Loop Port by international and domestic LPOCs. Each LPOC value is a relative percentage of the largest LPOC value (i.e. Japan 100%)

Figure 58 Map showing the proximity of Japan (solid red circle) and Malaysia (broken red circle) to Useless Loop (yellow star) and the selected IMPs that posed the greatest risk to Useless Loop

Table 15 The impact rank and examples of impacts for the 10 species which presented the greatest likelihood of infection and establishment to Useless Loop Port

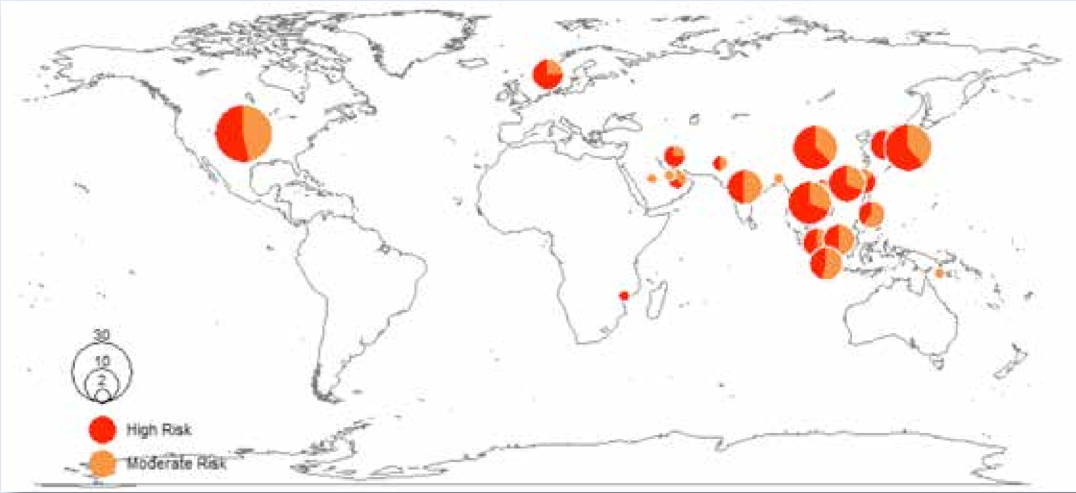
IMP species	Impact rank (M = medium, H = high)	Impacts
Asterias amurensis (sea star)	H	This is a voracious predator, known to outcompete native and commercial fish species. The Tasmanian scallop industry has reported losses of AU$1 million to their fishery as a result of the introduction of this sea star.
Carcinus maenas (crab)	H	This voracious predator is known to negatively impact population size and structure of many species, especially shellfish and crabs. In the US, financial losses to the shellfish industry have been valued at USD$22.6 million and this is predicted to rise significantly.
Undaria pinnatifida (algae)	H	This is an extremely fast-growing algae with two forms of efficient reproduction that result in a competitive advantage over native species for space.
Balanus improvisus (barnacle)	H	This barnacle is a fast-growing species that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.
Brachidontes pharaonis (mussel)	H	There is no impact information available for *Brachidontes pharaonis* (mussel) and the taxonomic status of the species is complex. As such, the species is currently considered cryptogenic.

IMP species	Impact rank (M = medium, H = high)	Impacts
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi River region in the USA, *M. sallei* has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic/pelagic system, affected the food web structure and productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes and reducing efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder, it can pose a hazard for shellfish poisoning (paralytic shellfish poison toxins).
Hemigrapsus sanguineus (crab)	H	This is an aggressive crab that can outcompete and displace native crabs and other native species thus altering ecosystem functioning.
Rhithropanopeus harrisii (crab)	H	This crab can compete with native crabs and benthic feeding fishes for food, alter food webs, foul water intake pipes, cause economic losses to gill net fisheries by spoiling fish caught in the fill nets and can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication.

10.0 Geraldton Port

GERALDTON PORT AT A GLANCE

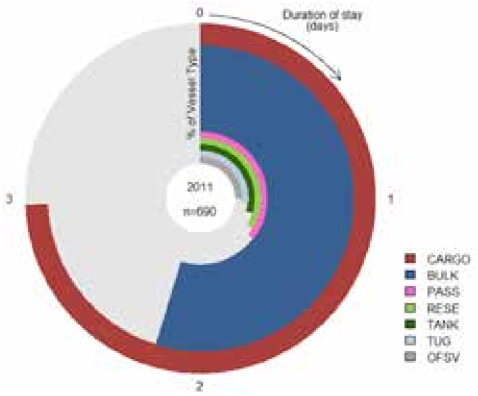
Asia is the greatest source of high and moderate risk IMPs to Geraldton



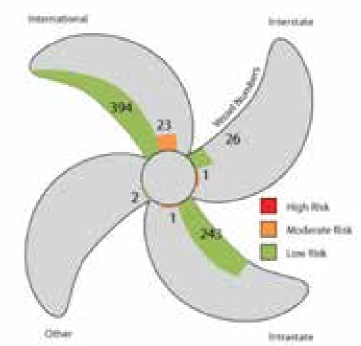
80% of inbound IMPs are compatible with Geraldton Port environs

322 visits from recognized flags

368 visits from flags of convenience



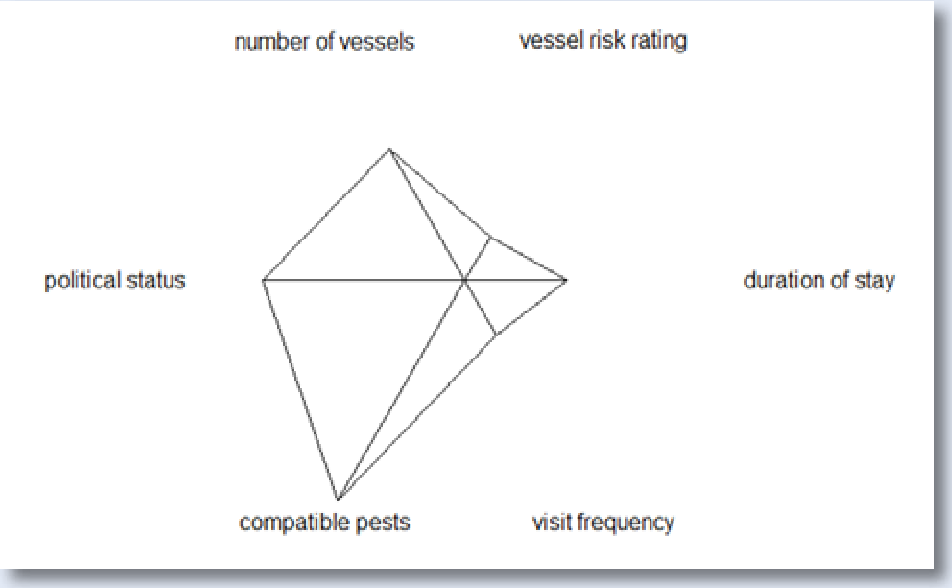
Cargo vessels stay the longest but bulk vessels are more common



Majority of vessels are from international LPOCs and are low risk

Geraldton Port

The drivers for Geraldton Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Geraldton Port. The length of the point indicates the degree to which that factor contributes to the risk.



The majority of vessels entering Geraldton Port were from international LPOCs and most had a low risk rating. There were no vessels with a high risk rating recorded in the 2011 data. Additionally, over half of the vessels visiting Geraldton port were registered from countries considered to be FOCs and three-quarters of the total number of vessels were from flag states that had not ratified the IMO BWM convention. There was a very high compatibility (80%) between the potential incoming marine pests and the environment of Geraldton Port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOC that posed the greatest risk to Geraldton Port was China. China also has three species listed in the top 100 worst invasive species worldwide, all compatible with the environment of Geraldton Port. These include: *Asterias amurensis* (northern pacific sea star), *Eriocheir sinensis* (Chinese mitten crab) and *Undaria pinnatifida* (wakame). Fremantle and Kwinana ports posed the greatest domestic risk to Geraldton Port based on the number of vessels from those locations and the number of potentially compatible pests.

10.1 Geraldton Port description

The port of Geraldton is located approximately 450 km north of Perth, in the mid-west region of WA (Figure 59). The mid-west has agricultural activity near the coast where the rainfall is sufficient, while the industry in inland areas is dominated by mining and other activities related to resource extraction. The Geraldton commercial harbour services the mid-west's industrial production, handling the export of iron ore, grain, metals, mineral sands, talc and garnet, as well as the import of fuel and fertilisers (Geraldton Port Authority 2011). Bulk tonnage for the port reached its peak in the 2010/11 financial year, reaching 10 million tonnes. Predictions are for the port to continue to expand in both size and trade statistics with the planned port expansion at nearby Oakajee.

The port is situated in Champion Bay, on the northern side of Moore Point. Major port infrastructure includes:

- the Commercial Harbour
- the Fishing Boat Harbour
- the Batavia Coast Boat Harbour (recreational vessel harbour).

The Commercial Harbour is the largest and the primary vector node in the area that hosts international vessels; predominantly bulk carriers to support trade for the region's resources industry. The harbour covers approximately 1 sq km, and is maintained at a depth of 8 – 14 m by regular dredging. Likewise, the shipping channel through Four Fathom Bank (as shallow as 4 m) is maintained to a depth of 14 m. A series of navaids and channel markers define the boundaries of the channel and commercial port waters.

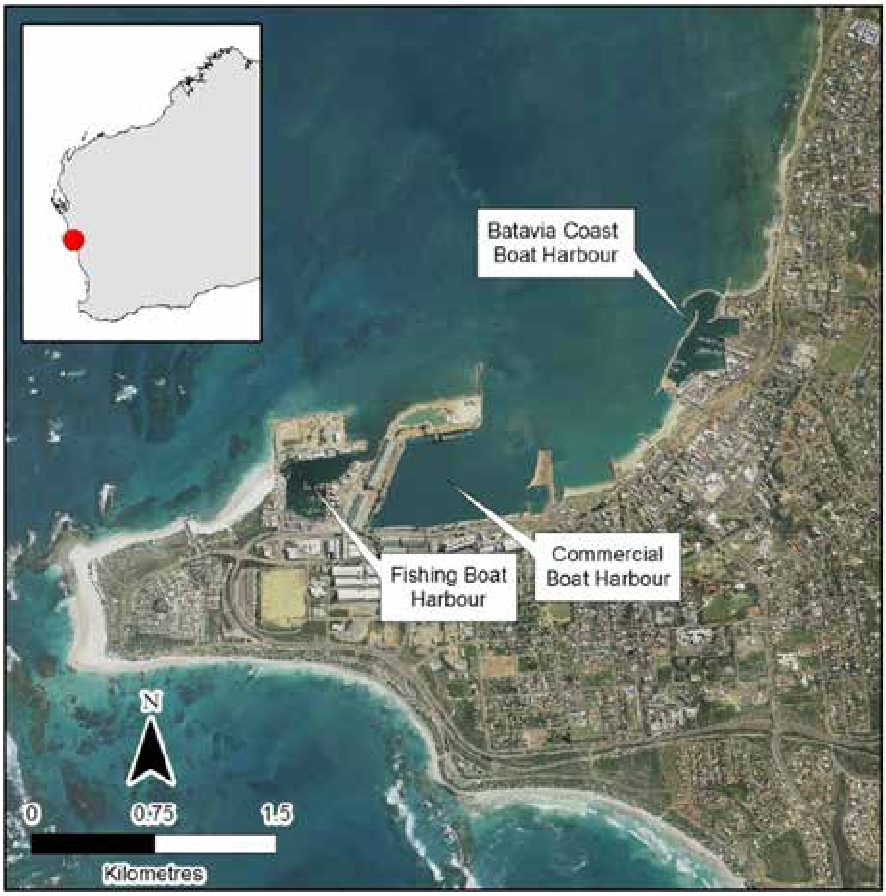


Figure 59 Geraldton Port infrastructure and locality map

The Geraldton Port is notable because it is the closest commercial port to the Abrolhos Islands. The waters around the Abrolhos Islands are an important resource for commercial fisheries such as for the Western Rock Lobster, as well as containing areas designated for fish habitat protection and various other levels of nature reserves and marine parks.

10.1.1 Environment

Geraldton experiences a subtropical, warm temperate climate. Hot, dry summers and cool, wet winters are normal with the majority of the regions 500 mm of average annual rainfall occurring between May and August. Average temperatures range between 18 °C and 23 °C in winter and increase to between 27 °C and 36 °C in summer.

Natural benthic habitats in the port are typical of the region, with algal-dominated limestone reefs being common, as are seagrass beds. The port environment has substantial amounts of artificial hard structures such as limestone armoured breakwaters, land-backed wharves and jetty pylons. Relatively new structures can be found in the Batavia Coast Boat Harbour, including floating pontoon jetties.

Environmental values used for the analysis were a water temperature range of 20.5°C to 24.8 °C and a salinity range of 37.0 – 38.3 ppt. These values were based on data used in the Global Ballast Water Management Programme (GloBallast).

10.1.2 Current knowledge of introduced marine pests

At least four IMP surveys have been conducted in the port of Geraldton. The first, in November 2001, attempted to conduct a nationally approved baseline survey in the same manner as the CRIMP baseline studies of the late 1990s. Two were in response to the possible incursion event initiated by the *Leonardo Da Vinci*, a cutter-suction dredge that arrived in Geraldton heavily fouled with non-native species. While a considerable number of IMPs were identified during those studies, none of these appear on either the National System's monitoring target species or the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) trigger lists (NIMPCG 2010a).

Campbell (2003b) details the first study of introduced marine species in the vicinity of Geraldton Port. This study was conducted by Geraldton Port Authority staff in November 2001 and was designed to comprise a baseline study of the fauna of the region, in the manner of the CRIMP surveys conducted at other locations around Australia. Unfortunately, there were inconsistencies between the methods used in the survey reported on by Campbell (2003b) and those set out for the CRIMP surveys (Hewitt & Martin 2001), which resulted in that survey not meeting the minimum requirements of the CRIMP techniques. Despite this, the survey does provide substantial and useful information about introduced marine species in the study area. Nine introduced species were identified in Campbell (2003b) as occurring in the port of Geraldton's jurisdiction. This included one barnacle and eight bryozoans, none of which are on the current national system target list.

The *Leonardo Da Vinci* arrived in Geraldton in October 2002 with a significant biofouling load of suspected Caribbean origin attached to the vessel (Wells *et al.* 2009). The biofouling was examined by a variety of researchers and a considerable number of non-native species were identified (Table 16). As the vessel was too large for any of the local dry dock facilities, in-water cleaning was initiated with several measures employed to mitigate transfer of organisms from the vessel to the port infrastructure. Two follow-up surveys have since been completed (2003 and 2007), targeting those species detected in the vessel biofouling. The first survey did not find any of the target species and the second found only *Amphibalanus reticulatus*, which, while an introduced species, is not on the current National System target list and has a cosmopolitan distribution (Wells *et al.* 2009). *Amphibalanus amphitrite*, the only other cryptogenic species identified for the Geraldton coastline (Huisman *et al.* 2008) is not a species of concern and is commonly regarded as having a cosmopolitan distribution. The DoF has also conducted one full National System survey of Geraldton Port in 2012 finding evidence of only one IMP species on the National System target list whose population was of a detectable size, i.e. *Didemnum perlucidum* (*Didemnum* spp. on the National System list) (Hourston, 2013b). Two other introduced species detected from the Department's survey included *Ciona intestinalis* (not a listed species of concern) and the cryptogenic species *Theora lubrica*.

Table 16 Introduced marine species that have been detected in the Geraldton area as well as those species that were present in biofouling from the *Leonardo Da Vinci*. This table has been synthesised from several sources including Campbell (2003b), Huisman *et al.* (2008), Hourston (2013b) and Wells *et al.* (2009) *indicates cryptogenic species

Taxonomic group	Species	Taxonomic group	Species
Molluscs	*Brachidontes exustus*	Crabs	*Atergatis integerrimus*
	Cronia avellana		*Leptodius exaratus*
	Crepidula plana		*Pachygrapsus* sp.
	Ostrea angasi		*Percnon* sp.
	Stavelia horrida	Barnacles	*Amphibalanus amphitrite**
	Thais haemastoma floridana		*Amphibalanus reticulatus**
	Thais orbita		*Austromegabalanus nigrescens*
	Thais rustica		*Balanus trigonus*
	*Theora lubrica**		*Chthamalus* sp.
Bryozoans	*Amathia distans*		*Lepas anatifera*
	Bugula neritina		*Megabalanus coccopoma*
	Schizoporella errata		*Megabalanus tintinnabulum*
	Schizoporella unicornis		*Striatobalanus amaryllis*
	Thalamoporella gothica		*Tetraclita squamosa*
	Tricellaria occidentalis	Ascidians	*Didemnum perlucidum*
	Watersipora arcuata		*Ciona intestinalis*
	Watersipora subtorquata		
	Zoobotryon verticillatum		

10.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the *Methods* section.

10.2.1 Inoculation likelihood

Geraldton Port received a total of 690 vessel visits based on the 2011 data examined. Bulk carriers were the dominant vessel type entering Geraldton Port (69.2%, Figure 60). General cargo vessels were the next most abundant type (17.6%). The majority of vessels (388 or 79.7%) visited the port once during 2011 (Figure 61). Ninety (18.5%) visited 2 – 5 times, five (1.0%) visited 6 – 10 times and four (0.8%) visited more than 10 times.

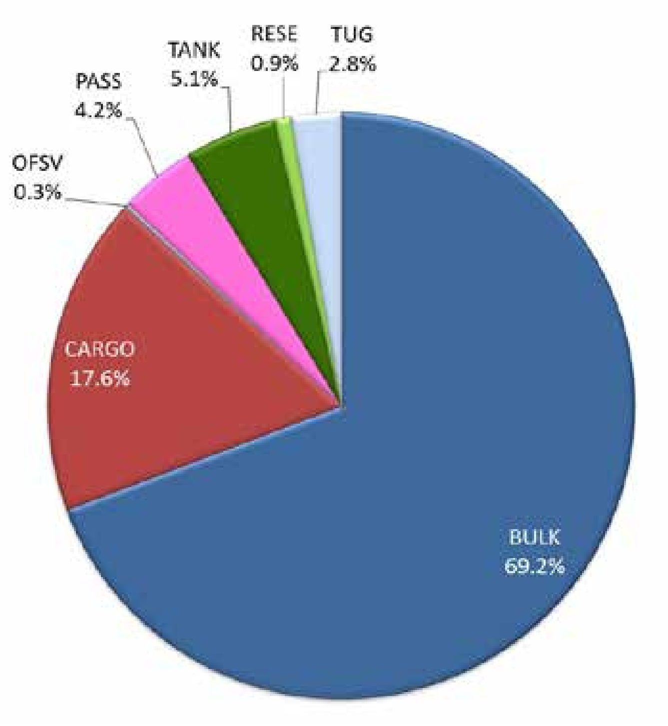


Figure 60 Summary of vessel type entering Geraldton Port in 2011. (BULK = bulk vessels, CARGO = general cargo vessels, FISH = fisheries compliance/water police, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

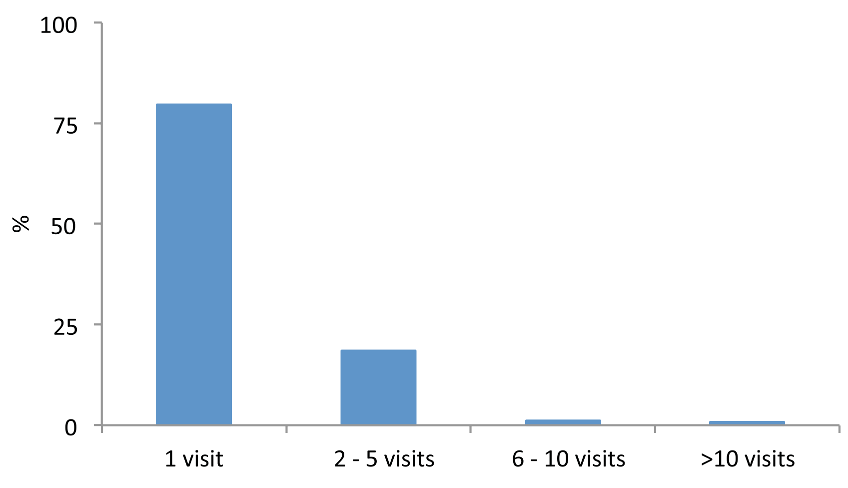


Figure 61 Frequency of repeat vessel visits to Geraldton Port in 2011

Bulk vessels and general cargo vessels, both vessels with a low risk rating, stayed the longest (average of 2.2 days and 3.0 days respectively) (Figure 62). Research vessels and tugs, both with a moderate risk rating, stayed, on average, 1.3 days and 1.1 days respectively. There were no vessels with a high risk rating at Geraldton port based on the data provided for 2011.

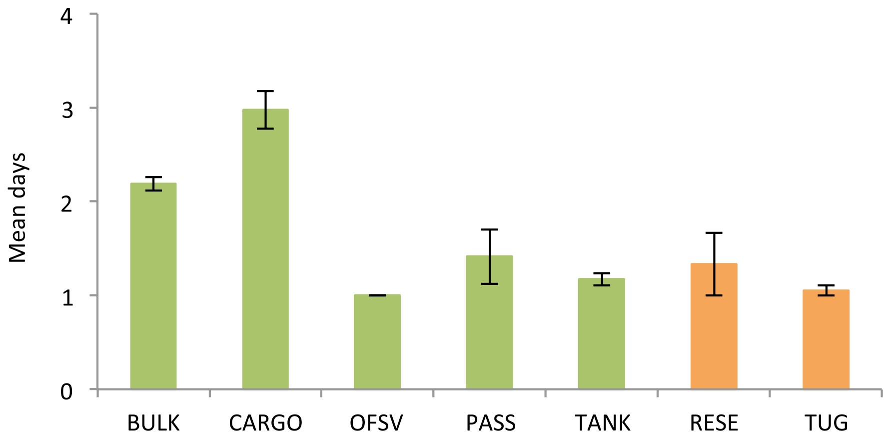


Figure 62 Mean residency time (days ± SE) for the different vessel types visiting Geraldton Port in 2011 and their risk rating (green = low risk, orange = moderate risk and red = high risk). (BULK = bulk vessels, CARGO = general cargo vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

The majority of vessel visits (417 out of 690, or 60.4%) to Geraldton Port were from an international source (Table 17). These international vessel visits were from 24 countries. Eighty-nine of these visits (i.e. 21.3% of the total international visits) were from Singapore. The next most common sources were China (83 visits or 19.9%) and Indonesia (66 visits or 15.8%). The majority of vessels from international sources were bulk vessels with a low risk rating (417 visits or 72.9%, Figure 63).

Domestic visits (271) accounted for 39.3% of the remaining visits. This included 27 visits from 14 different interstate locations (Table 17). Portland and Adelaide were the most common source of interstate vessel visits (6 and 5 visits; i.e. 22.2% and 18.5% respectively of the total interstate visits, Table 17). The interstate vessel types included four low and one moderate risk rated vessel types (Figure 63). Bulk vessels (low risk rated) were the most common with 19 visits (70.4%, Figure 63). Three of the remaining vessel types, general cargo, passenger vessels and tankers were also all low risk rated and visited between one (3.7%) and five times (18.5%, Figure 63). A tug (1 visit or 3.7%) was the only moderate risk rated interstate vessel visiting Geraldton Port (Figure 63).

Intrastate visits (244) were from 12 different locations (Table 17). Kwinana, with 61 visits (25.0% of total intrastate visits) was the greatest source of intrastate vessels, followed by the ports of Fremantle and Thevenard at 47 (19.3%) and 43 (17.6%) visits respectively. The intrastate vessel types included four vessels with a low risk rating and one with a moderate risk rating (Figure 63). Bulk vessels with a low risk rating represented the majority of vessels (154 visits or 63.1%). There were three other vessel types with a low risk rating: general cargo vessels (57 visits or 23.4%), tankers (21 visits or 8.6%) and passenger vessels (11 visits or 4.5%, Figure 63). A tug (1 visit or 0.4%) was the only intrastate vessel with a moderate risk rating.

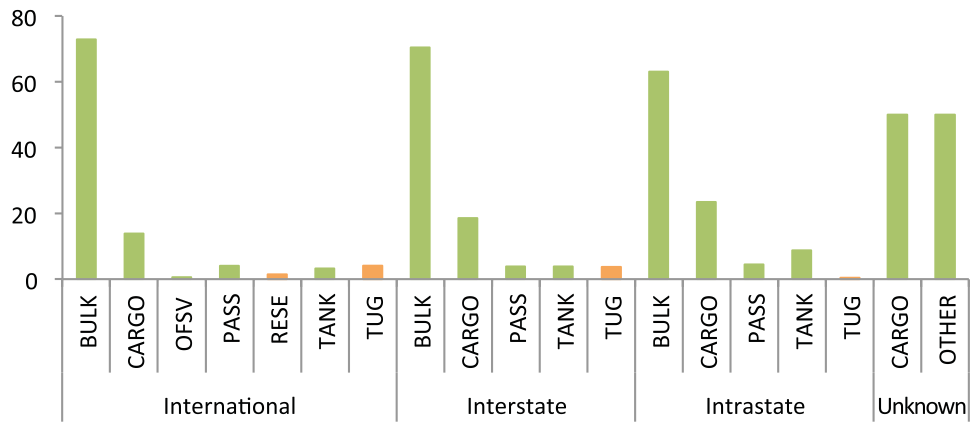


Figure 63 Percentage of vessels arriving into Geraldton Port in 2011 from international, interstate and intrastate sources by vessel type and risk rating (green = low risk, orange = moderate risk). (BULK = bulk vessels, CARGO = general cargo vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

Table 17 Summary of vessel visits to Geraldton Port from source locations

Source	Number of visits	Percentage of visits (%)
International	**417**	**60.4**
Bangladesh	1	0.2
Brunei	1	0.2
China	83	19.9
Hong Kong	32	7.7
India	21	5.0
Indonesia	66	15.8
Iran	1	0.2
Japan	10	2.4
Malaysia	25	6.0
Mozambique	1	0.2
Norway	1	0.2
Oman	1	0.2
Pakistan	2	0.5
Papua New Guinea	2	0.5
Philippines	12	2.9
Qatar	3	0.7
Saudi Arabia	2	0.5
Singapore	89	21.3
South Korea	21	5.0
Taiwan	21	5.0
Thailand	12	2.9
United Arab Emirates	2	0.5
USA	2	0.5
Vietnam	6	1.4

Source	Number of visits	Percentage of visits (%)
Domestic	**271**	**39.3**
Interstate	**27**	**% of interstate**
Adelaide	5	18.5
Bell Bay	1	3.7
Bing Bong	1	3.7
Christmas Island	1	3.7
Darwin	1	3.7
Gladstone	1	3.7
Karumba	2	7.4
Melbourne	1	3.7
Port Kembla	1	3.7
Port Lincoln	2	7.4
Port Pirie	1	3.7
Portland	6	22.2
Townsville	2	7.4
Whyalla	2	7.4
Intrastate	**244**	**% of intrastate**
Albany	7	2.9
Broome	10	4.1
Bunbury	30	12.3
Dampier	18	7.4
Dongara	7	2.9
Esperance	4	1.6
Fremantle	47	19.3
Geraldton	7	2.9
Kwinana	61	25.0
Port Hedland	9	3.7
Thevenard	43	17.6
Other	**2**	**0.3**

10.2.3 Sociopolitical risk

Vessels visiting Geraldton Port were registered from 33 different flag states. Nine of these (27.3%) were listed FOC states (Figure 64, see ‘A’). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 53.3% of all visits to Geraldton Port (Figure 64, see ‘B’). The greatest proportion of FOC vessels came from Panama (39.4%, Figure 64, see ‘C’).

Of the 33 flag states, only 10 (25.4% of total visits) have ratified the IMO BWM. Further analysis revealed that 4 of these 10 were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 9.1% of total visits.

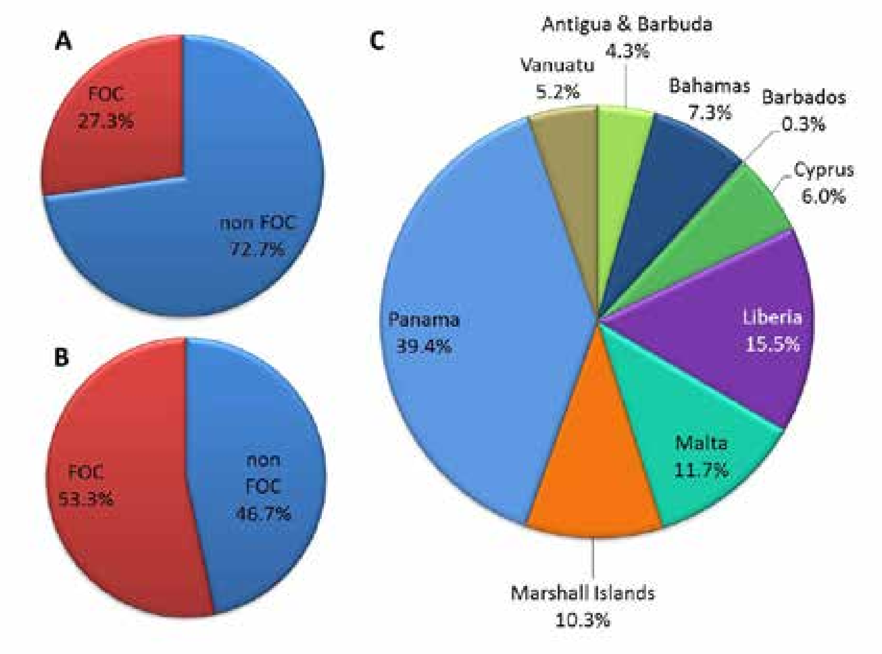


Figure 64 Percentage of FOC and non-FOC states entering Geraldton Port (A). Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Geraldton Port (B). FOC states shown by country of registry and percentage (C).

The overall inoculation risk to Geraldton Port was low as the majority of vessels had a low risk rating, visited once and stayed for a short time. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Additionally, over half of the vessels visiting Geraldton Port were registered from countries considered to be FOCs and three-quarters of the total number of vessels were from flag states that had not ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull. Although not large in number, there are vessels with a moderate risk rating using the port that do present a higher risk of inoculation based on their operating profiles.

10.2.4 Infection and establishment likelihood

There were 41 IMP species present at LPOC locations, 33 (80%) of which have temperature and salinity tolerances compatible with Geraldton Port environs (Figure 65). All 33 compatible species were located at one or more of the international sources for vessels (Figure 65). For domestic LPOCs there were six species located interstate and three species located intrastate. *Caulerpa taxifolia* was present in the most sources (18) followed closely by and *Crassostrea gigas* which was present at 15 different sources. The next most common species were *Gymnodinium catenatum* (13 locations) and *Balanus improvisus* (11 locations).

C. taxifolia (macroalgae) occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe (Meinesz *et al.* 2001). *C. gigas* (oyster) is a species that could thrive in Geraldton and if it entered the 'wild', it could pose a significant threat to native oyster and mussel populations. *G. catenatum* (dinoflagellate) is not regarded as a vessel biofouling species, however it may be transported as a cyst on equipment such as ropes and cages or in sediment present on a vessel. *B. improvisus* (barnacle) is a common biofouler and once introduced into a new area this species can dominate and outcompete native species for available habitat (Qvarfordt *et al.* 2006).

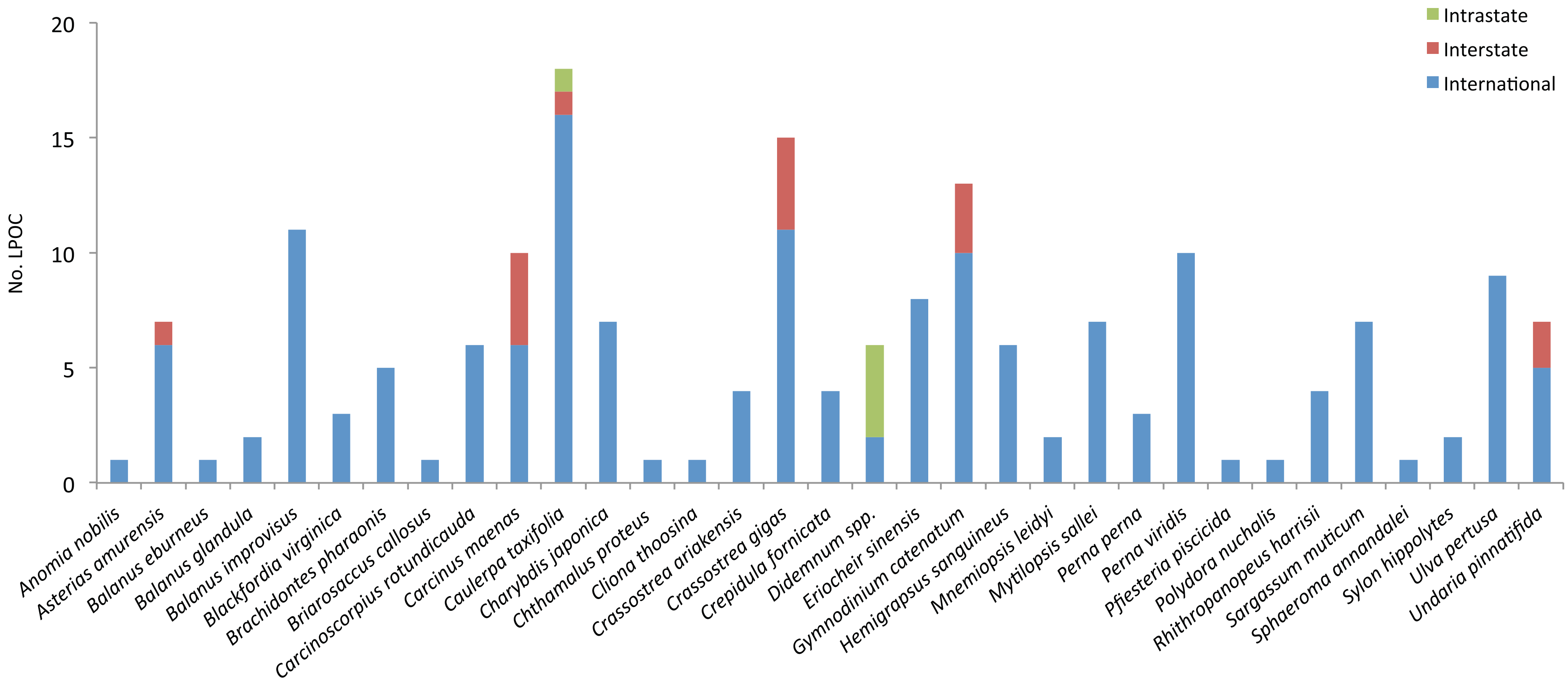


Figure 65 IMP species compatible with Geraldton Port and the number of LPOCs (international, interstate and intrastate) at which they occur

There were 22 different international LPOCs that contained an IMP with either a high or moderate risk rating that was compatible with Geraldton Port's environment. USA had the greatest number of IMPs with 27 species, 15 of which were classed as high risk. Japan had the next greatest number of IMPs with 18, 12 of which were classed as high risk, followed by China with 16 IMPs, 11 of which were classed as high risk (Figure 66).

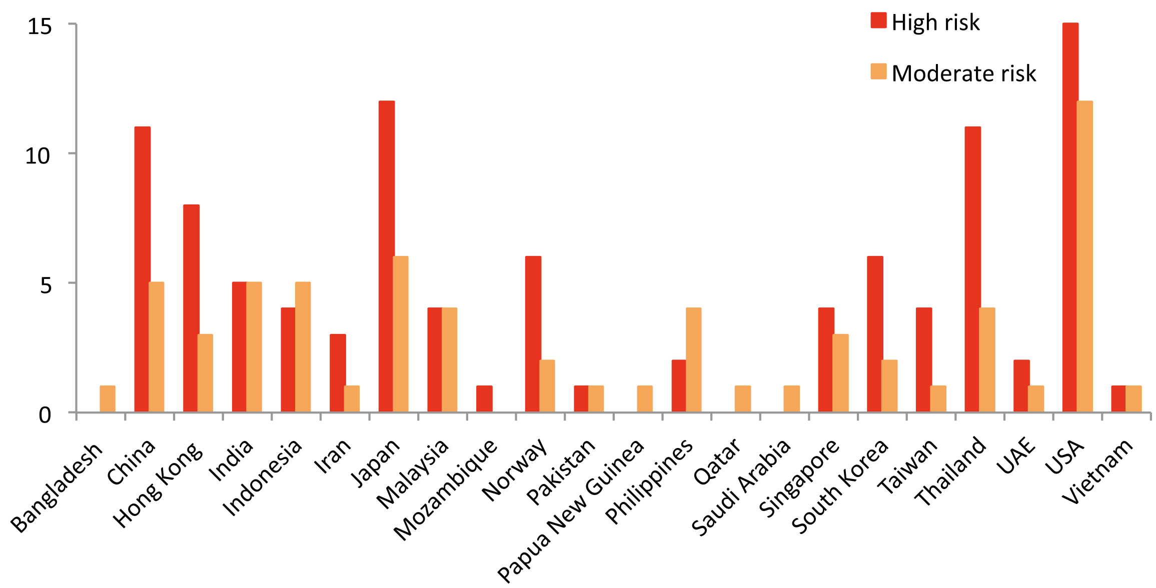


Figure 66 IMP species with a moderate or high risk rating, present at international LPOCs that were compatible with Geraldton Port environs

When the cumulative effect of the number of vessel visits from an international LPOC and number of IMP present at that LPOC is considered, the greatest infection and establishment risk to Geraldton Port was from China (Figure 67). Singapore and Indonesia also represented a considerable infection and establishment risk. LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 67. IMPs from China that posed a risk to Geraldton Port are shown pictorially in Figure 68.

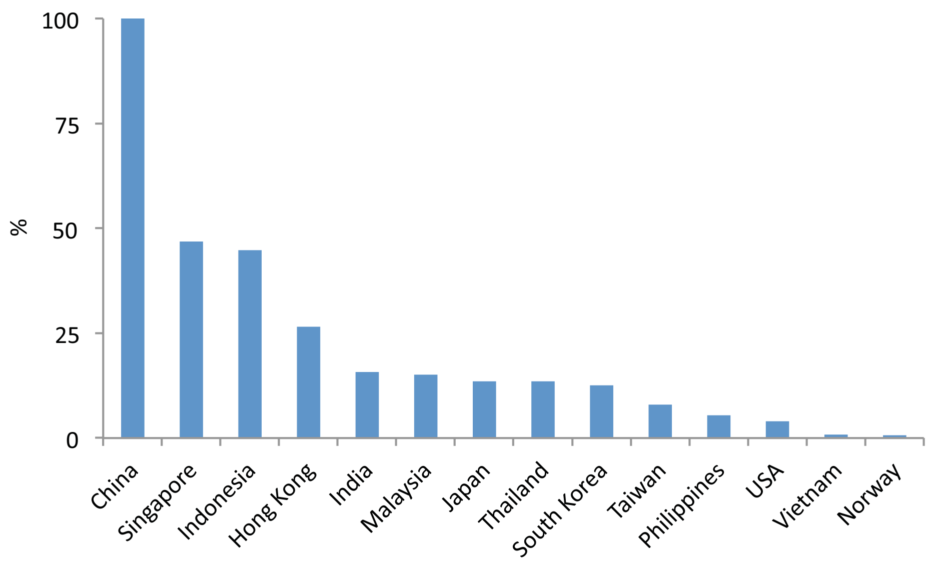


Figure 67 Ranking of the infection and establishment risk posed to Geraldton Port by international LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. China 100%)

Figure 68 Map showing the proximity of China (red circle) to Geraldton Port (yellow star) and the selected IMPs that pose the greatest risk to Geraldton Port

IMP species were recorded at 10 domestic LPOCs, five species from interstate and four species from intrastate locations (Table 18, Figure 69). Victorian sources had the greatest number of high risk IMPs. The port of Melbourne had three species with a high risk and Portland port had two species with a high risk (Table 18). When the cumulative effect of the number of vessels visits from a domestic LPOC and the number of species present at that LPOC is considered, Kwinana represented the greatest domestic infection and establishment risk to Geraldton Port (Figure 69). Fremantle also posed a considerable risk to Geraldton Port. Domestic locations from which the risk was negligible are not shown in Figure 69. The domestic pest species that posed the greatest risk to Geraldton Port include *Asterias amurensis* (seastar: Vic), *Carcinus maenas* (crab from South Australia, New South Wales and Victoria) and *Undaria pinnatifida* (algae from Victoria).

Table 18 Number of high and moderate risk IMPS present at domestic (interstate and intrastate) LPOCs

LPOC Domestic	High risk	Moderate risk
Interstate		
Port Kembla (New South Wales)	1	1
Adelaide (South Australia)	1	3
Port Lincoln (South Australia)	0	1
Melbourne (Victoria)	3	1
Portland (Victoria)	2	2
Intrastate		
Broome	0	1
Dampier	0	1
Fremantle	0	1
Kwinana	0	1

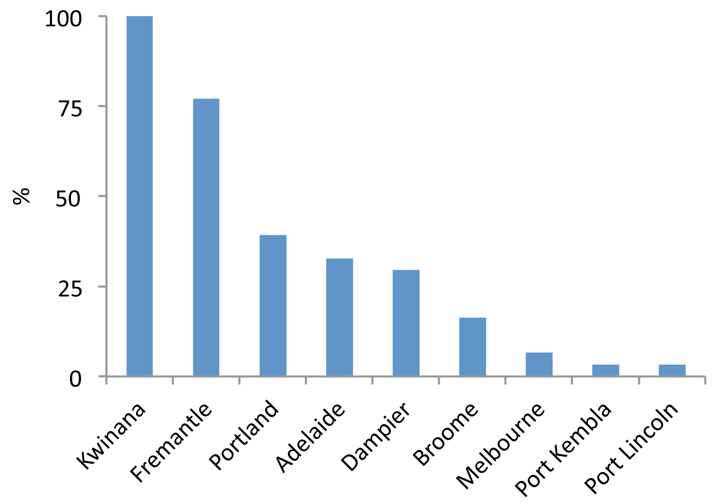


Figure 69 Ranking of the infection and establishment risk posed to Geraldton Port by domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Kwinana 100%)

There were 12 species that presented the greatest likelihood of infection and establishment to Geraldton Port, from international and domestic sources. Four of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining 8 species, although not listed in the top 100 worst, still pose a significant threat to Geraldton Port for one or more of the following: the environment, sociocultural values, economic value or human health. Brief information on these species is provided in Table 19. For further information, images and references for these species please see Appendix 2.

Table 19 The impact rank and examples of impacts for the 12 species which presented the greatest likelihood of infection and establishment to Geraldton Port

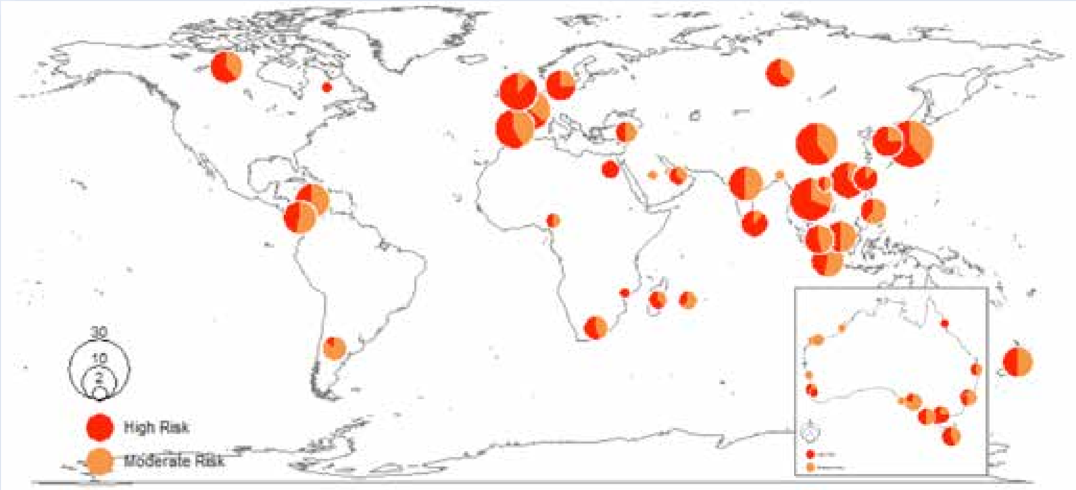
IMP species	Impact rank (M = medium, H = high)	Impacts
Asterias amurensis (sea star)	H	This voracious predator is known to outcompete native and commercial fish species. The Tasmanian scallop industry has reported losses of AU$1 million to their fishery as a result of the introduction of this sea star.
Carcinus maenas (crab)	H	This voracious predator is known to negatively impact population size and structure of many species especially shellfish and crabs. In the US, financial losses to the shellfish industry have been reported valued at USD$22.6 million and this is predicted to rise significantly.
Eriocheir sinensis (crab)	H	Large economic costs following the introduction of this species have been reported (EUR€80 million). These costs arise from ongoing management requirements to stabilise river banks damaged by the crabs, losses to commercial fisheries (crab predation), installation of barriers and ramps to prevent further crab migration and population control methods.

IMP species	Impact rank (M = medium, H = high)	Impacts
Undaria pinnatifida (algae)	H	This is an extremely fast-growing algae with two forms of efficient reproduction that result in a competitive advantage over native species for space.
Balanus improvisus (barnacle)	H	This barnacle is a fast-growing species that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.
Brachidontes pharaonis (mussel)	H	There is no impact information available for Brachidontes pharaonis (mussel) and the taxonomic status of the species is complex. As such, the species is currently considered cryptogenic.
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi River region in the USA, *M. sallei* has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic/pelagic system, affected the food web structure and productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes and reducing efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder it can pose a hazard for shellfish poisoning (paralytic shellfish poison toxins).
Charybdis japonica (crab)	H	This is a highly aggressive crab and opportunistic omnivore, consuming mostly bivalves, crustaceans and polychaetes. This crab can outcompete native species for space and food. It can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Hemigrapsus sanguineus (crab)	H	This is an aggressive crab that can outcompete and displace native crabs and other native species thus altering ecosystem functioning.
Sargassum muticum (algae)	H	This algae is known to outcompete native species (e.g. algae and seagrass) for space and through exclusion (i.e. shading) it can heavily foul marine equipment, clog intake pipes, increase the rate of sedimentation as it slows the water flow (dense stands) and reduce the social amenity of an area (floating mats and through decay).
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication.

11.0 Fremantle Port

FREMANTLE PORT AT A GLANCE

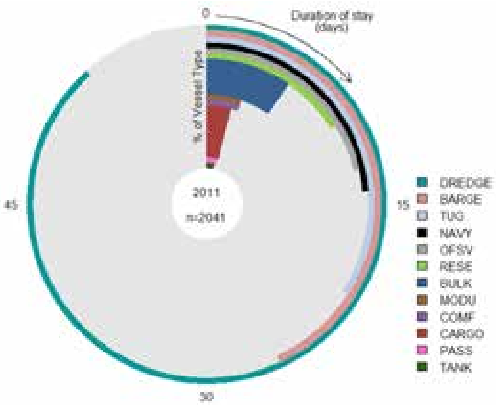
Multiple sources of high and moderate risk IMPs to Fremantle



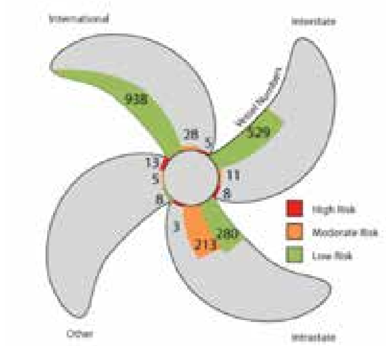
79% of inbound IMPs are compatible with Fremantle Port environs

846 visits from flags of convenience

1195 visits from recognized flags



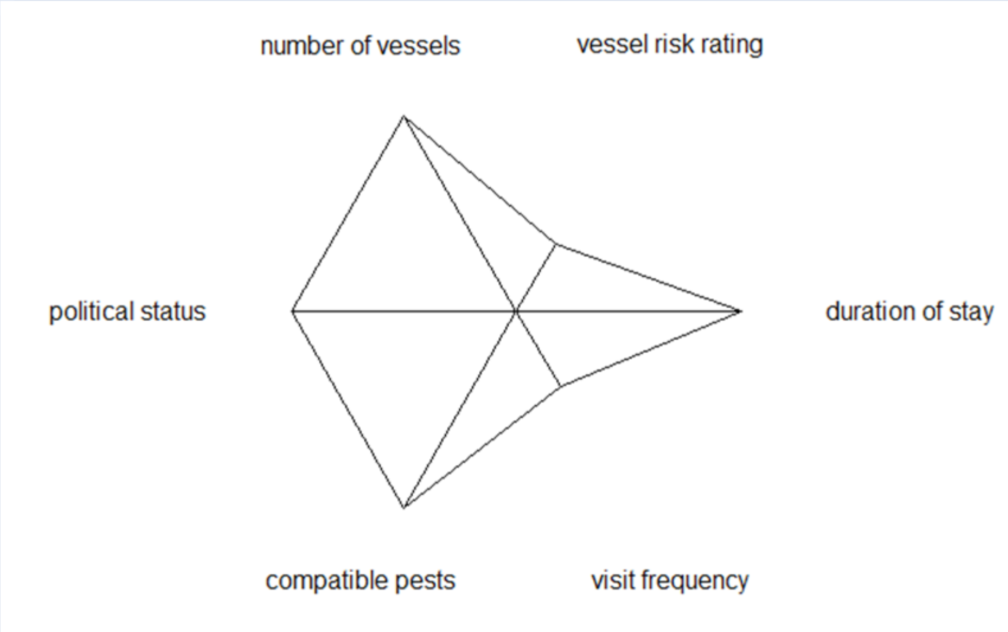
Dredge vessels stay the longest but cargo vessels are more common



Majority of vessels are from international LPOCs and are low risk

Fremantle Port

The drivers for Fremantle Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Fremantle Port. The length of the point indicates the degree to which that factor contributes to the risk.



There were vessels with low, moderate and high risk ratings entering Fremantle Port during 2011. The majority had a low risk rating; however the vessels with a moderate and high risk rating tended to stay the longest. Just under half of the vessels visiting Fremantle Port were registered from countries considered to be FOCs and about two-thirds of the total number of vessels were from flag states that had not ratified the IMO BWM convention. There was a high compatibility (79%) between the potential incoming marine pests and the environment of Fremantle Port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOCs that posed the greatest risk to Fremantle Port were Singapore and Indonesia. Both Singapore and Indonesia have *Caulerpa taxifolia* (algae, invasive strain), a species listed in the top 100 worst invasive species worldwide and its tolerances are compatible with Fremantle Port. Port Adelaide posed the greatest domestic risk to Fremantle Port based on the number of vessels arriving from there and the number of potentially compatible pests.

11.1 Fremantle Port description

Fremantle is located 25 km south of Perth in WA (Figure 70). Fremantle port is one of the three largest ports in WA and handles the majority of the state's imports. In 2011, Fremantle Port's combined import and export tonnage was 26.123 million tonnes (Fremantle Port Authority 2011).

The Fremantle Port area is complex. In the northern part, the inner harbour is built in the mouth of the Swan River estuary, and is surrounded by several artificial marina and harbour developments. In the northern parts of the outer harbour are several mooring grounds. In the southern parts, including Cockburn Sound, the industrial areas of Henderson and Kwinana are the main areas of port infrastructure.

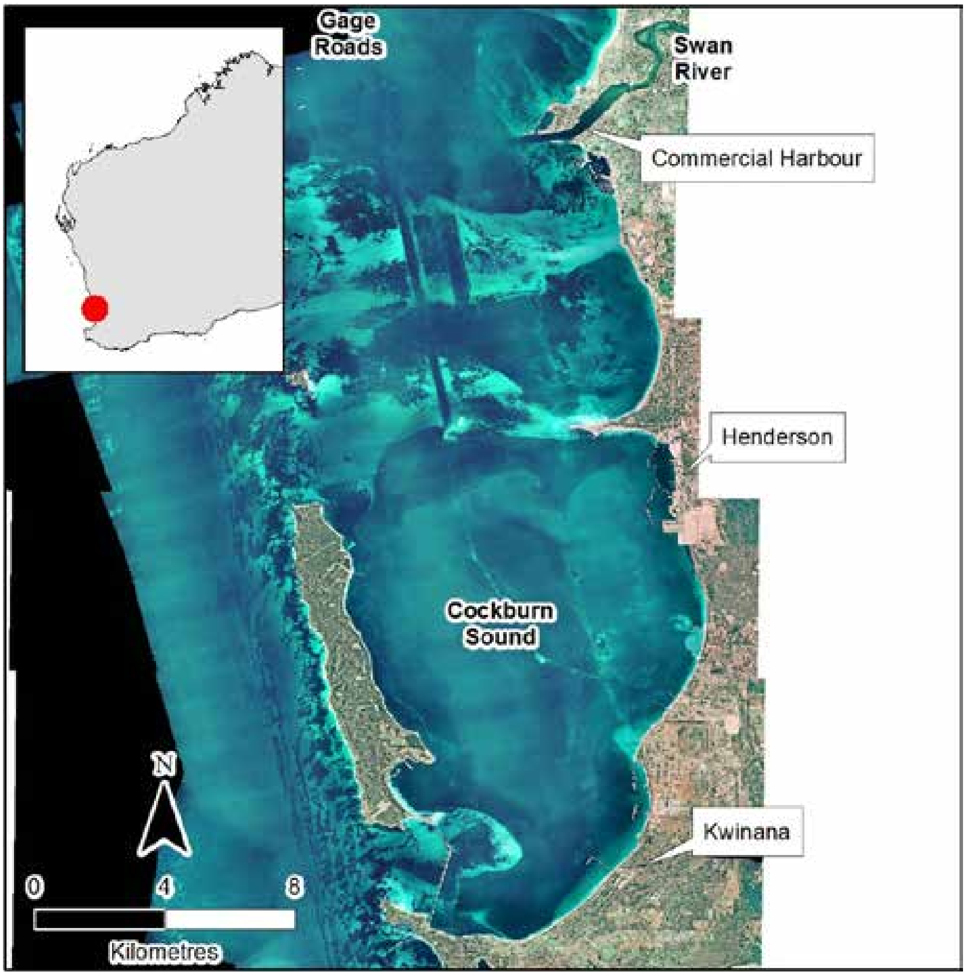


Figure 70 Fremantle port infrastructure and locality map

11.1.1 Environment

The climate is classed as Mediterranean with warm, dry summers and cool, wet winters. Typically, mean summer temperatures range between 25 °C and 28 °C and in winter, temperatures range between 18 °C and 20 °C. However, minimum and maximum temperatures in the vicinity of 0 °C and above 40 °C may occur in the winter and summer respectively. Rainfall occurs primarily during the winter months of June to August, with lesser amounts falling in April to May and September to October.

The tidal regime is microtidal, with a maximum range in the order of 1.5 m. The entire coastline is relatively sheltered from oceanic swells, with two offshore limestone reef systems running parallel to the shoreline. Cockburn Sound is almost completely sheltered from oceanic swell by Garden Island.

The habitat mosaic within Fremantle Port is as complex and diverse as the port users. Significant areas of seagrass and soft substrates are present in the outer harbour; estuarine areas can be found in the Swan River; and substantial areas of algal-dominated reef can be found throughout the outer port. Artificial structures are common, including breakwaters, marinas, slipways, groynes, harbours, jettys and wharves.

Environmental values used for the analysis were a water temperature range of 15.7 °C to 24.8°C and a salinity range of 29.7 – 37.4 ppt. These values were taken from the nationally approved marine pest monitoring design for Fremantle Port (Bridgwood & Hourston 2009b).

11.1.2 Current knowledge of introduced marine pests

Huisman *et al.* (2008) records 46 introduced marine species in and around the Fremantle Port areas, incorporating records from a CRIMP survey in 2000 and subsequent museum records. Since publication of that article, a further four species have been detected by DoF, increasing the total to 50 species (Table 20). Many of these of these detections are not recent, and the species have not been sighted since their first record (e.g. *Carcinus maenas*), while others are recognised as established (e.g. *Sabella spallanzanii*). Seven of those 50 species are on the current national system monitoring target species list i.e. *Alexandrium minutum*, *Alexandrium catenella, C. maenas*, *Charybdis japonica*, *Arcuatula (Musculista) senhousia*, *Sabella spallanzanii* and *Didemnum perlucidum*. DoF has conducted two full National System surveys of Fremantle Port in 2011 and 2013 (Hourston 2012b and Hourston 2013a) and maintain a complementary monitoring system which includes settlement arrays, crab traps and shorelines searches (Muñoz & Bridgwood 2013b).

On several occasions, IMPs have been detected on vessels entering port waters, but these are not considered to be records from the Fremantle region as they have not been found in the local environment. Examples of these species include *Amphibalanus improvisus*, *Amphibalanus pulchellus* and *Perna viridis*.

Table 20 List of the 46 introduced marine species noted in Huisman *et al.* (2008) and detected by DoF

Taxonomic group	Species	Taxonomic group	Species
Marine algae	*Pseudocodium devriesii*	Hydroids	*Eudendrium carneum*
	Grateloupia imbricata		*Ectopleura crocea*
Dinoflagellates	*Alexandrium minutum*		*Halecium delicatulum*
	Alexandrium catenella		*Antennella secundaria*
Bryozoans	*Bugula flabellata*	Molluscs	*Godiva quadricolor*
	Bugula neritina		*Okenia pellucida*
	Tricellaria occidentalis		*Velacumantus australis*
	Cryptosula pallasiana		*Polycera hedgpethi*
	Schizoporella errata		*Mytilus edulis planulatus*
	Schizoporella unicornis		*Musculista senhousia*
	Watersipora arcuata		*Scaeochlamys livida*
	Watersipora arcuata		*Theora lubrica*

Taxonomic group	Species	Taxonomic group	Species
Crustaceans	*Carcinus maenas*	Polychaetes	*Alitta succinea*
	Charybdis japonica		*Sabella spallanzanii*
	Cirolana harfordi		*Ficopomatus enigmaticus*
	Paracerceis sculpta		*Boccardia proboscidea*
	Paradella dianae	Ascidians	*Ascidiella aspersa*
	Sphaeroma serratum		*Botryllus schlosseri*
	Monocorophium acherusicum		*Ciona intestinalis*
	Monocorophium insidiosum		*Didemnum perlucidum*
	Amphibalanus amphitrite		*Styela plicata*
	Amphibalanus reticulatus		*Styela clava*
	Megabalanus rosa	Fish	*Acentrogobius pflaumii*
	Megabalanus tintinnabulum		*Tridentiger trigonocephalus*
	Tesseropora rosea		*Sparidentex hasta*

11.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the *Methods* section.

11.2.1 Inoculation likelihood

Fremantle Port received a total of 2041 vessel visits based on the 2011 data examined. General cargo vessels (47.9%) and bulk carriers (33.0%) were the most common vessel types entering Fremantle port (Figure 71). Ten other vessel types entered Fremantle Port, of which barges (6.2%) and tugs (5.2%) were the next most common. The majority of vessels (623 or 65.3%) visited the port once (Figure 72). Almost one-third (266 or 27.9%) of vessels visited 2 – 5 times, 44 vessels (4.6%) visited 6 – 10 times and 21 vessels (2.2%) visited more than 10 times in 2011.

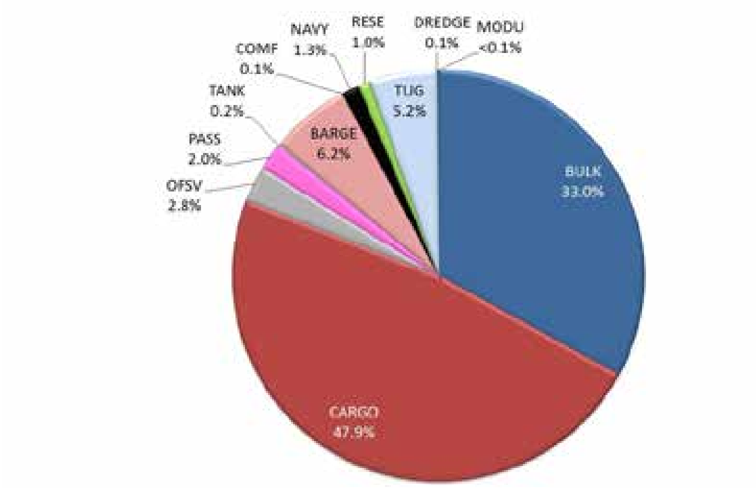


Figure 71 Summary of vessel type entering Fremantle Port. (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, NAVY = navy vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

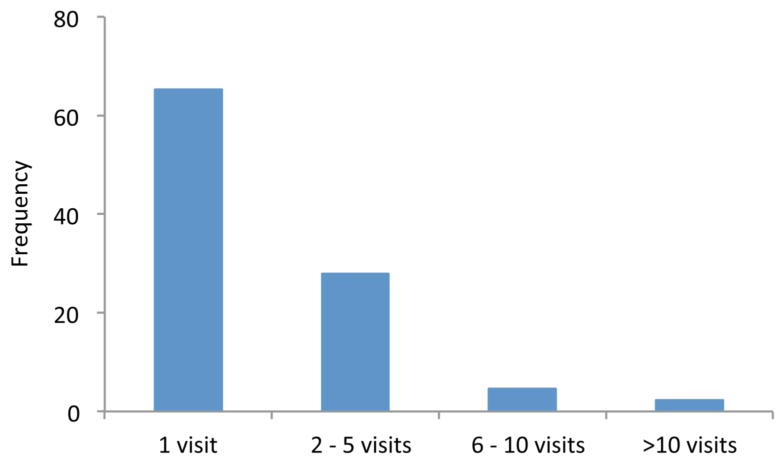


Figure 72 Frequency of repeat vessel visits to Fremantle Port in 2011

There were five vessel types with a low risk rating, four with a moderate risk rating and three with a high risk rating using Fremantle Port in 2011 (Figure 73). The vessels with a high risk stayed between 3 and 53 days. Dredges, with a high risk rating, stayed the longest at 53 days. The vessels with a moderate risk rating stayed between 3 and 25.9 days.

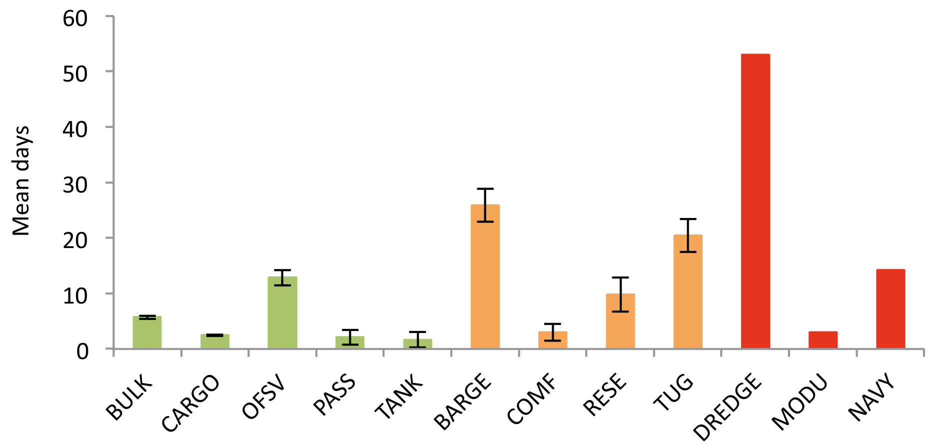


Figure 73 Mean residency time (days ± SE) for the different vessel types visiting Fremantle Port in 2011 and their risk rating (green = low risk, orange = moderate risk and red = high risk). (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, MODU = mobile offshore drilling unit/floating production storage offshore vessels, NAVY = navy vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

The LPOCs for vessels visiting Fremantle Port were evenly split between international and domestic sources (975 visits or 47.6%, and 1044 visits or 51.2% respectively, Table 21). The international vessel visits were from 41 countries. A third of these were from Singapore (320 visits or 33.0% of the total international visits). The next most common source was Indonesia (160 visits or 16.5%). The majority of vessels (93.7%) from international sources had a low risk rating and predominantly consisted of general cargo vessels (524 visits or 53.7%) and bulk vessels (400 visits or 41.0%, Figure 74). There were two vessels with a high risk rating – dredges and navy vessels – that accounted for 0.6% of the visits.

There were 548 visits from 27 different interstate locations (Table 21). Port Adelaide was the most common source of interstate vessels visits (275 or 50.2% of interstate vessels), then Melbourne with 116 visits (21.2%). Again, the majority of vessels from interstate sources had a low risk rating (94.7%) with general cargo vessels (356 visits or 65.0%) and bulk vessels (163 visits or 29.7%) being the most common types. There were two vessel types with a high risk rating – a mobile offshore drilling unit and navy vessels – that accounted for 1.5% of the visits (Figure 74).

There were 496 intrastate visits from 17 different locations (Table 21). Barrow Island was by far the most common source of intrastate vessels, accounting for almost half of all visits (214 visits; 43.1%, Table 21). Low (280 visits; 56.5%) and moderate (215 visits; 43.3%) risk rated vessels were the most common intrastate vessels types. Of the moderate risk rated vessels the majority were barges (115 visits; 23.2%) and tugs (92 visits; 18.5%) (Figure 74). The two high risk rated vessels, dredges and navy vessels accounted for 0.6% of the visits.

There were also a variety of vessels (including those with a low and moderate risk rating) for which no information regarding source was provided. Of these, the high risk rated navy vessel type was the largest, accounting for 12 visits or 54.5% of vessels with no source recorded (Figure 74).

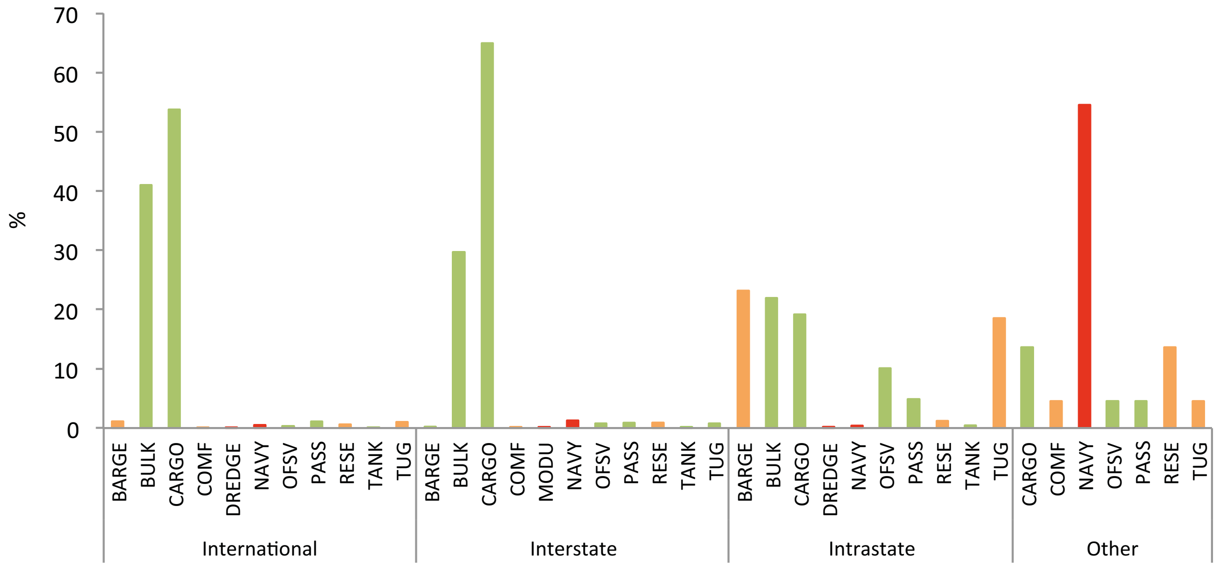


Figure 74 Percentage of vessels arriving into Fremantle Port in 2011 from international, interstate and intrastate sources by vessel type and risk rating (green = low risk, orange = moderate risk and red = high risk). (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, COMF = commercial fishing vessels, DREDGE = dredge vessels, MODU = mobile offshore drilling unit/floating production storage offshore vessels, NAVY = navy vessels, OFSV = offshore support vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

Table 21 Summary of vessel visits to Fremantle Port from source locations

Source	Number of visits	Percentage of visits (%)
International	**975**	**47.6**
Antarctica	1	0.1
Argentina	4	0.4
Bangladesh	4	0.4
British Indian Ocean Territory	1	0.1
Brunei	2	0.2
Canada	4	0.4
Caribbean	2	0.2
China	46	4.7
Denmark	1	0.1
East Coast Canada	1	0.1
Egypt	53	5.5
England	2	0.2
France	1	0.1
Hong Kong	11	1.1
India	22	2.3
Indonesia	160	16.5
Japan	42	4.3
Kuwait	1	0.1
Madagascar	1	0.1
Malaysia	62	6.4
Mauritius	10	1.0
Mozambique	12	1.2
New Zealand	10	1.0
Nigeria	1	0.1
Oman	3	0.3
Panama	5	0.5
Philippines	8	0.8
Qatar	1	0.1
Reunion	1	0.1
Russia	1	0.1
Saudi Arabia	16	1.6
Singapore	320	33.0
South Africa	56	5.8
South Korea	26	2.7
Spain	3	0.3
Sri Lanka	3	0.3
Taiwan	13	1.3
Thailand	18	1.9
Turkey	2	0.2
United Arab Emirates	36	3.7
Vietnam	5	0.5

Source	Number of visits	Percentage of visits (%)
Domestic	**1044**	**51.2**
Interstate	**548**	**% of interstate**
Bell Bay	13	2.4
Botany Bay	16	2.9
Brisbane	6	1.1
Burnie	1	0.2
Cairns	1	0.2
Christmas Island	7	1.3
Darwin	8	1.5
Devonport	1	0.2
Geelong	20	3.6
Groote Eylandt	1	0.2
Hay Point	3	0.5
Hobart	4	0.7
Indian Ocean Territories	6	1.1
Melbourne	116	21.2
Newcastle	5	0.9
Port Adelaide	275	50.2
Port Alma	1	0.2
Port Giles	4	0.7
Port Kembla	3	0.5
Port Lincoln	14	2.6
Port Pirie	1	0.2
Portland	29	0.4
Risdon	1	0.4
Thevenard	7	1.3
Townsville	1	0.2
Wallaroo	2	0.4
Whyalla	2	0.4
Intrastate	**498**	**% of intrastate**
Albany	15	3.0
Barrow Island	214	43.1
Broome	11	2.2
Bunbury	54	10.9
Carnarvon	2	0.4
Cossack Pioneer	2	0.4
Dampier	63	12.7
Derby	1	0.2
Esperance	12	2.4
Exmouth	7	1.4
Fremantle	19	3.8
Geraldton	56	11.3
Kwinana	2	0.4

Source	Number of visits	Percentage of visits (%)
Onslow	1	0.2
Port Hedland	26	5.2
Port Walcott	2	0.4
Wyndham	9	1.8
Other	**26**	**1.3**

11.2.2 Sociopolitical risk

Vessels visiting Fremantle Port were registered from 51 different flag states and of these, 14 (27.5%) were listed FOC states (Figure 75, see 'A'). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 41.5% of all visits to Fremantle Port (Figure 75, see 'B'). The greatest proportion of FOC vessels came from the countries of Panama (41.3%) and Liberia (21.9%) (Figure 75, see 'C').

Of the 51 flag states, only 16 (30.9% of total visits) have ratified the IMO BWM. Further analysis revealed that 4 of these 16 were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 4.4% of total visits.

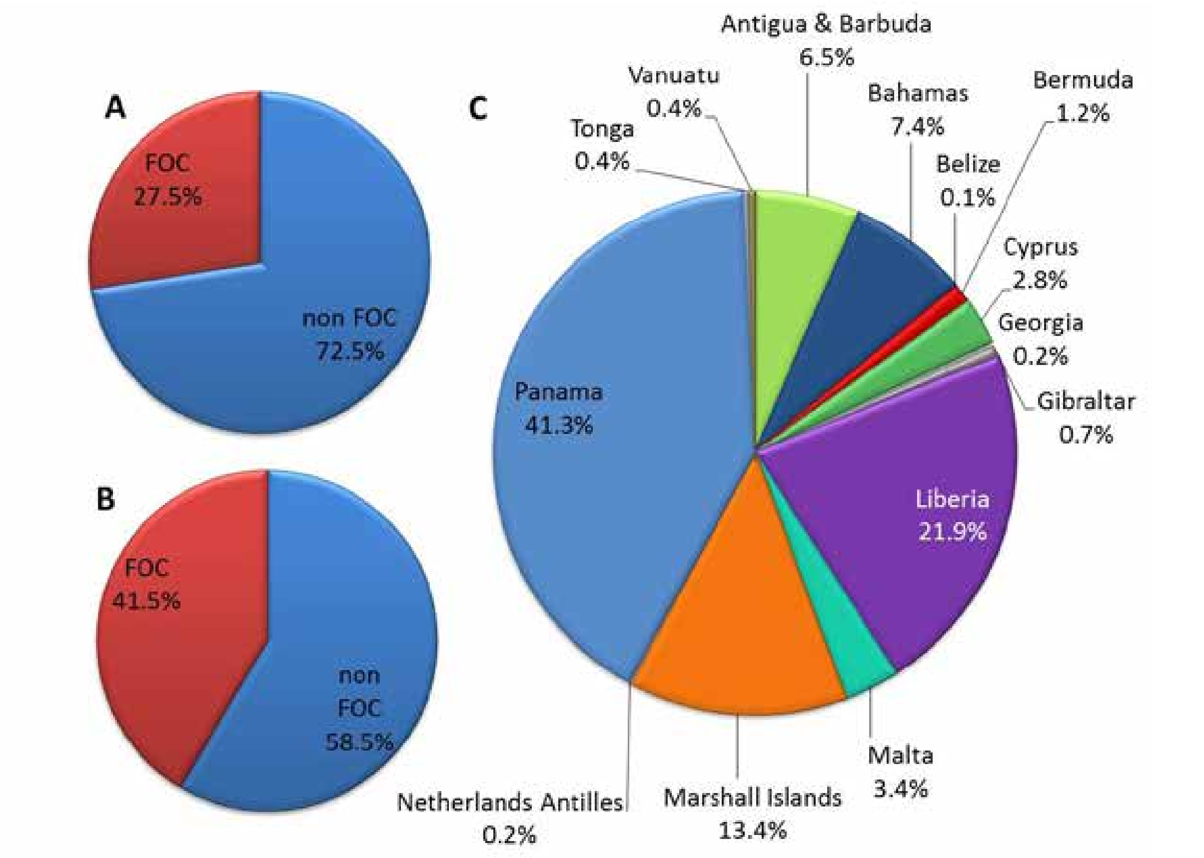


Figure 75 Percentage of FOC and non-FOC states entering Fremantle Port (A). Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Fremantle Port (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Fremantle Port was moderate to high because of the presence of vessels with a moderate and high risk rating and the extended duration of stay of these types of vessels. Additionally, just under half of the vessels visiting Fremantle Port were registered from countries considered to be FOCs and about two-thirds of the total number of vessels were from flag states that had not ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness increasing the risk that an IMP might be present on the hull. The greatest inoculation risks to Fremantle Port were from dredges (high risk rating) and barges and tugs (moderate risk rating), which stayed, on average, the longest in the port.

11.2.3 Infection and establishment likelihood

There were 38 IMP species present at LPOC locations of which 30 (79%) had temperature and salinity tolerances compatible with Fremantle Port environs. All 30 compatible species were located at one or more of the international sources for vessels (Figure 76). For domestic sources, there were seven species located interstate and three species located intrastate. *Crassostrea gigas* occurred at the most sources (28), closely followed by *Caulerpa taxifolia* which occurred at 26 sources. The next most common species were *Balanus improvisus* (21 locations) and *Carcinus maenas* (20 locations).

C. gigas (oyster) is a species that could thrive in Fremantle and if it entered the 'wild', it could pose a significant threat to native oyster and native and farmed mussel populations. The macroalgae *C. taxifolia* occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe. *B. improvisus* (barnacle) is a common biofouler and once introduced into a new area this species can dominate and outcompete native species for available habitat (Qvarfordt *et al.* 2006). *C. maenas* (crab) is well known for its negative impacts on native biodiversity, and has a demonstrated capacity for significant economic impact upon fisheries (Lovell *et al.* 2007).

There were 35 different international LPOCs that contained an IMP with either a high or moderate risk rating that was compatible with Fremantle's environment. Japan had the greatest number of IMPs with 18 species (12 were classed as high risk). Thailand and China had the next greatest number of IMPs at 15 each, of which 11 and 10 respectively had a high risk rating (Figure 77).

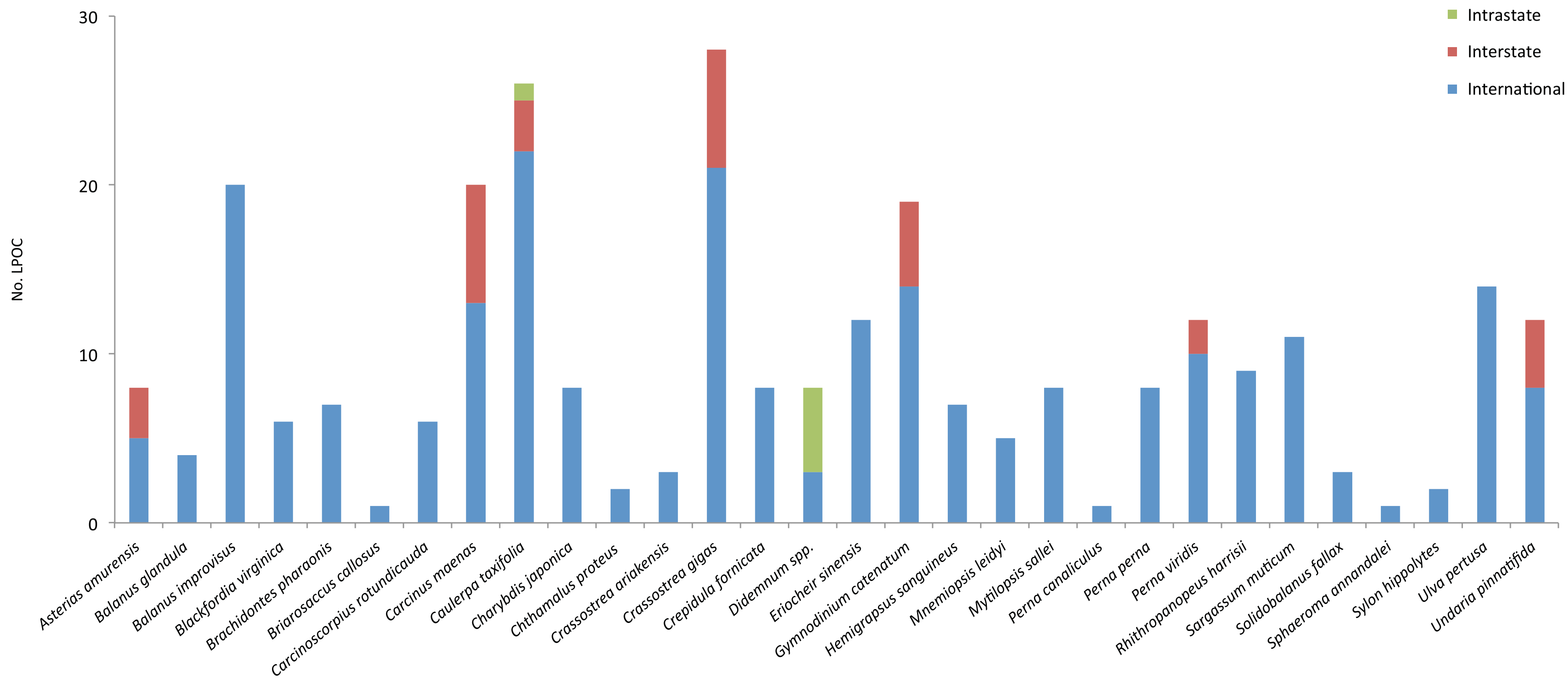


Figure 76 IMP species compatible with Fremantle Port and the number of LPOCs (international, interstate and intrastate) at which they occur

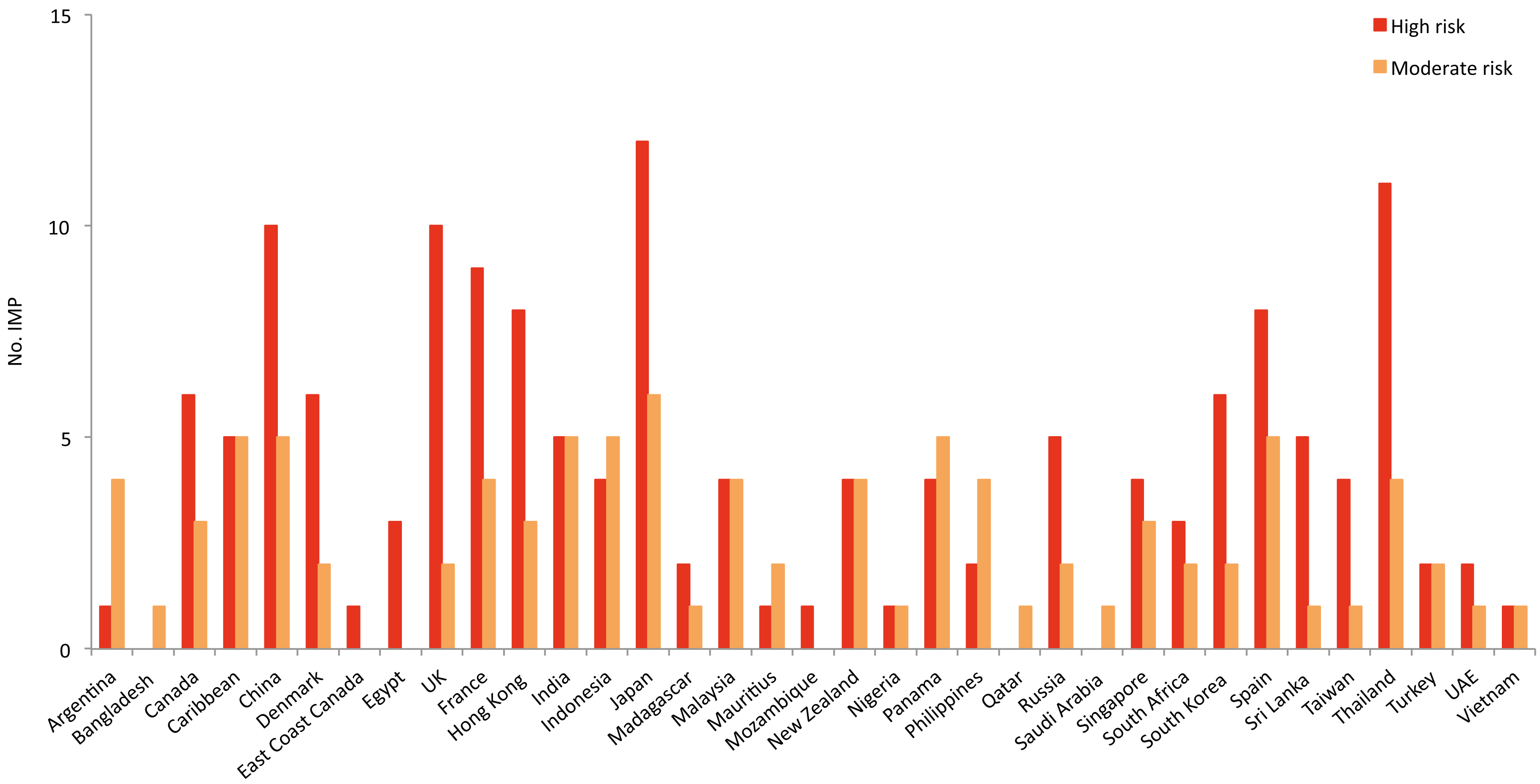


Figure 77 IMP species with a moderate or high risk rating, present at international LPOCs that were compatible with Fremantle Port environs

When the cumulative effect of the number of vessel visits from an international LPOC and the number of IMP present at that LPOC is considered, the greatest infection and establishment risk to Fremantle Port was from Singapore (Figure 78). Indonesia also represented a considerable infection and establishment risk. LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 78. Selected IMPs from Singapore and Indonesia that posed a risk to Fremantle Port are shown pictorially in Figure 79.

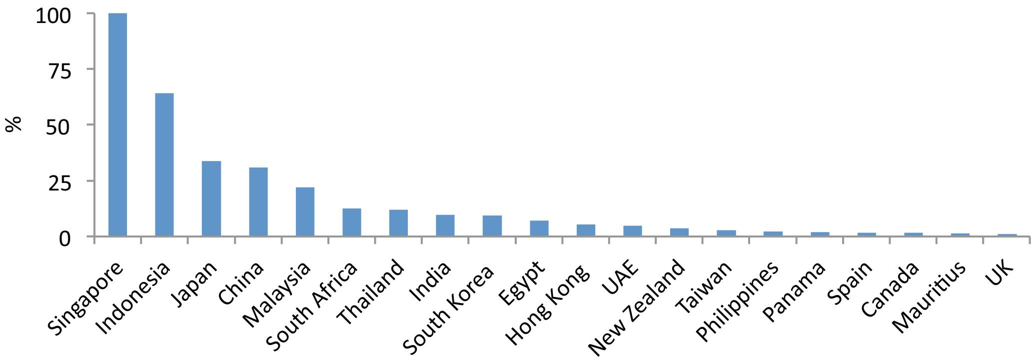


Figure 78 Ranking of the infection and establishment risk posed to Fremantle Port from international LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Singapore 100%)

Figure 79 Map showing the proximity of Singapore and Indonesia (red circle) to Fremantle Port (yellow star) and the selected IMPs that posed the greatest risk to Fremantle Port. Note that *Didemnum perlucidum* is already known to occur in Fremantle Port

IMP species were recorded at 16 domestic LPOCs, 10 of which were interstate, and 6 intrastate (Table 22, Figure 80). Victorian sources had the greatest number of high risk IMPs. The ports of Geelong and Melbourne both had three species with a high risk, and Portland had two species with a high risk (Table 22). When the cumulative effect of the number of vessels visits from a domestic LPOC and the number of compatible IMPs present at that LPOC is considered, Port Adelaide represented the greatest domestic infection and establishment risk to Fremantle Port (Figure 80). Domestic locations from which the relative risk was negligible are not shown in Figure 80. The domestic pest species that posed the greatest risk to Fremantle Port included

Asterias amurensis (seastar from Victoria and Tasmania), *Carcinus maenas* (crab from South Australia, Tasmania, New South Wales and Victoria) and *Undaria pinnatifida* (algae from Victoria and Tasmania).

Table 22 Number of high and moderate risk IMPS present at domestic (interstate and intrastate) LPOCs

LPOC domestic	High risk	Moderate risk
Interstate		
Botany Bay (New South Wales)	1	3
Port Kembla (New South Wales)	1	1
Brisbane (Queensland)	1#	1
Cairns (Queensland)	1#	0
Port Adelaide (South Australia)	1	3
Port Lincoln (South Australia)	0	1
Hobart (Tasmania)	3	2
Geelong (Victoria)	3	1
Melbourne (Victoria)	3	1
Portland (Victoria)	2	2
Intrastate		
Barrow	0	1
Broome	0	1
Dampier	0	1
Fremantle	0	1
Geraldton	0	1
Kwinana	0	1

# indicates the species *Perna viridis*: although listed on marine invasive databases as present in Brisbane and Cairns, the authors acknowledge that the species is not currently detected in either port's environment (NIMPIS website).

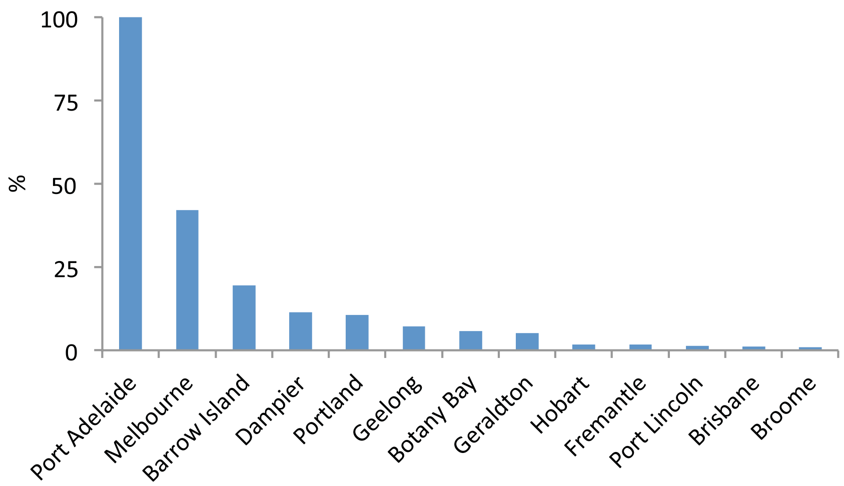


Figure 80 Ranking of the infection and establishment risk posed to Fremantle Port by domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Port Adelaide 100%)

There were 12 species that presented the greatest likelihood of infection and establishment to Fremantle Port, from international and domestic sources. Three of the species, *Asterias* *amurensis* (sea star), *Carcinus maenas* (crab), *Caulerpa taxifolia* (clone strain macroalgae) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining eight species, although not listed in the top 100 worst, still pose a significant threat to Fremantle Port for one or more of the following: the environment, sociocultural values, economic value or human health. Brief information on these species is provided in Table 23. For further information, images and references for these species please see Appendix 2. Please note that the colonial ascidian *Didemnum perlucidum* is already known to occur in Fremantle Port and surrounding waters.

Table 23 The impact rank and examples of impacts for the 12 species which presented the greatest likelihood of infection and establishment to Fremantle Port

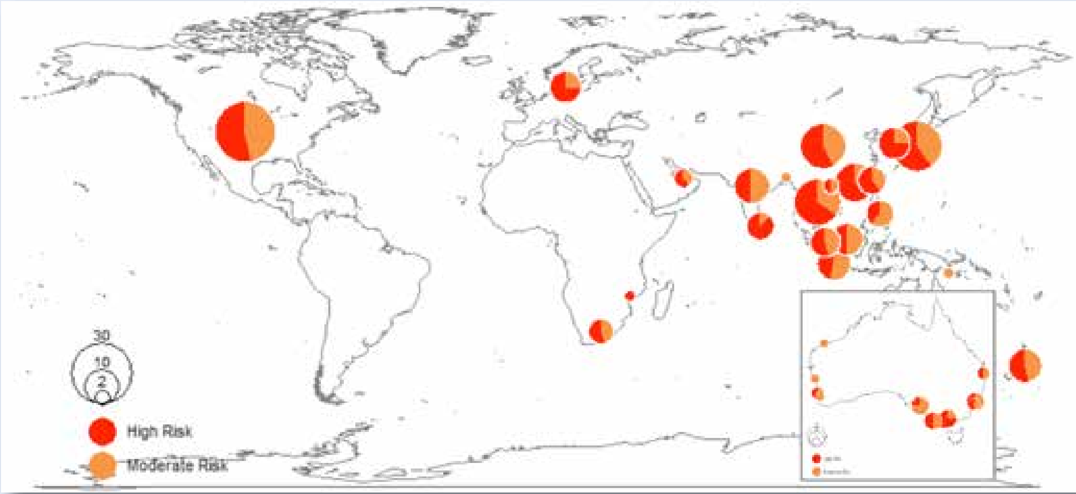
IMP species	Impact rank (M = medium, H = high)	Impacts
Asterias amurensis (sea star)	H	This is a voracious predator, known to outcompete native and commercial fish species. The Tasmanian scallop industry has reported losses of AU$1 million to their fishery as a result of the introduction of this sea star.
Carcinus maenas (crab)	H	This voracious predator is known to negatively impact population size and structure of many species especially shellfish and crabs. In the US, financial losses to the shellfish industry have been reported at USD$22.6 million and this is predicted to rise significantly.
Caulerpa taxifolia (algae, clone strain)	M	This invasive algae has the potential to grow rapidly, alter marine habitats and affect biodiversity. It can potentially invade seagrass beds and modify organic and inorganic components of the sediment.
Undaria pinnatifida (algae)	H	This is an extremely fast-growing algae with two forms of efficient reproduction that result in a competitive advantage over native species for space.
Balanus improvisus (barnacle)	H	This barnacle is a fast-growing species that can outcompete native species for space, foul aquaculture species and infrastructure resulting in higher maintenance costs.
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi River region in the USA, *M. salle*i has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic/pelagic system, affected the food web structure and productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes and reducing efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder, it can pose a hazard for shellfish poisoning (paralytic shellfish poison toxins).
Crassostrea gigas (oyster)	M	This oyster has the potential to smother marine life, exclude species, hybridise with other oyster species, alter ecosystems and destroy habitats, including their social amenity.

IMP species	Impact rank (M = medium, H = high)	Impacts
Carcinoscorpius rotundicauda (horseshoe crab)	M	While listed by the Australian Government's Department of Agriculture as a species of concern and likely to do harm, there is no clear evidence of this species posing a pest risk. The only documented detection of this species as introduced was one instance in New Zealand in 1910. This species is currently listed on the International Union for Conservation of Nature and Natural Resources' (IUCN's) Red List of Threatened Species (IUCN 2013).
Charybdis japonica (crab)	H	This is a highly aggressive crab and opportunistic omnivore, consuming mostly bivalves, crustaceans and polychaetes. This crab can outcompete native species for space and food. It can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication.
Didemnum perlucidum (colonial ascidian)		This species can heavily foul artificial substrates including buoys, ropes, pylons and vessels and shellfish farms. This species is already known to occur in Fremantle Port and surrounding waters.

12.0 Bunbury Port

BUNBURY PORT AT A GLANCE

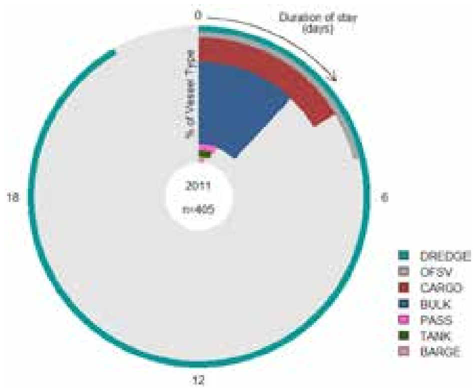
Asia is the greatest source of high and moderate risk IMPs to Bunbury



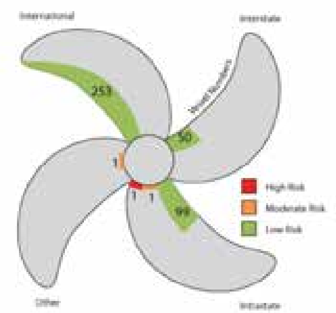
83% of inbound IMPs are compatible with Bunbury Port environs

176 visits from recognized flags

229 visits from flags of convenience



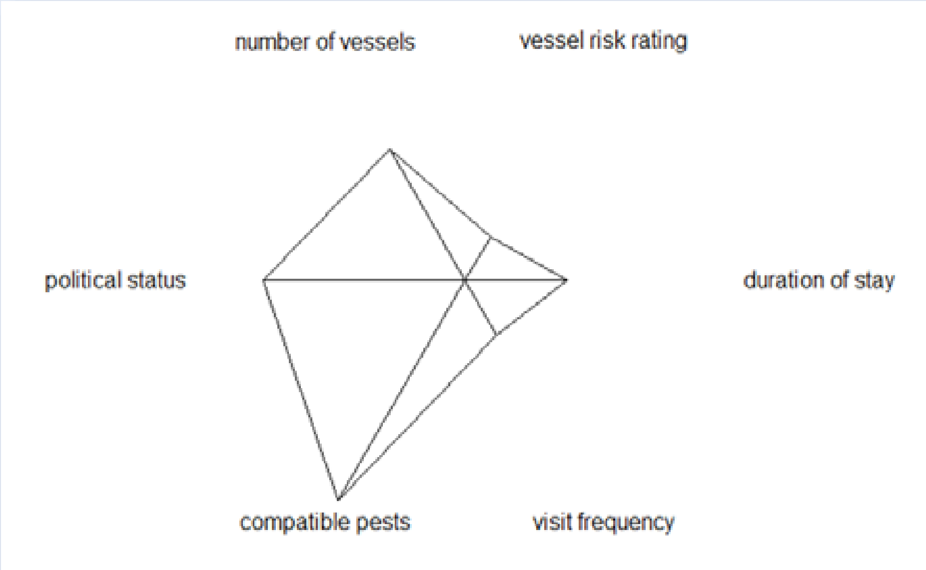
Dredge vessels stay the longest but bulk vessels are more common



Majority of vessels are from international LPOCs and are low risk

Bunbury Port

The drivers for Bunbury Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Bunbury Port. The length of the point indicates the degree to which that factor contributes to the risk.



The majority of vessels entering Bunbury Port were from an international source, most had a low risk rating and only stayed for short durations. There was one vessel with a high risk rating from an intrastate source and this vessel stayed the longest at 22 days. Over half of the vessels visiting Bunbury were registered from countries considered FOCs and only 27% of the total vessel visits were from flag states that had ratified the IMO BWM convention. There was a very high compatibility (83%) between the potential incoming marine pests and the environment of Bunbury Port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOC that posed the greatest risk to Bunbury Port was Japan. Japan also has 4 species listed in the top 100 worst invasive species worldwide, all compatible with the environment of Bunbury Port. These include: *Asterias amurensis* (northern pacific sea star), *Carcinus maenas*, (European shore crab), *Eriocheir sinensis* (Chinese mitten crab) and *Undaria pinnatifida* (wakame). Adelaide Port posed the greatest domestic risk to Bunbury Port based on the number of vessels from there and the number of potentially compatible pests.

12.1 Bunbury Port description

The port of Bunbury is located along the south-west coast of WA, approximately 180 km south of Perth. The port is the product of extensive works and changes to the Leschenault Inlet, with the entire inner harbour being artificial, as well as the main breakwater at Casuarina Harbour, which is an extension of a natural headland (Figure 81).

Bunbury Port is the fourth largest in the state, behind the ports of Fremantle, Dampier and Port Hedland. Bunbury is primarily an export port with 85–90% of its trade going offshore. Annual trade for 2011 was just under 14 million tonnes, primarily comprising exports of alumina, with lower contributions of woodchips, mineral sands and spodumene and its chief import, caustic soda (Bunbury Port Authority 2011).

The commercial port has seven operational berths, two in the outer harbour and five in the inner harbour. These are a mix of dolphin-style berths and land-backed wharves. Casuarina Harbour services recreational and light commercial vessels, with most vessels moored in its sheltered waters, however there are also a limited number of jetty berths. Other recreational vessel berths are located in the remnants of the Leschenault Inlet's entrance channel to the south of the harbour.

Figure 81 Bunbury port infrastructure and locality map

12.1.1 Environment

Within the port, the substrates are predominantly silt and soft sediment, changing to sand and seagrass habitats further out into Koombana Bay. Hard structures within the port are predominantly artificial and include rockwall moorings, jetties and berths. The Leschenault Inlet is adjacent to the port's facilities and connected to it by a series of artificial channels. The inlet is primarily soft sediment and the salinity may range from almost freshwater to hypersaline.

Environmental values used for the analysis were a water temperature range of 18.0 °C to 26.1°C and a salinity range of 34.6 – 36.3ppt. These values were based on data used in the Global Ballast Water Management Programme (GloBallast).

12.1.2 Current knowledge of introduced marine pests

Huisman *et al.* (2008) recorded a total of 24 introduced marine species in Bunbury port (Table 24).

Table 24 List of the 24 introduced marine species in Bunbury Port noted in Huisman *et al.* (2008)

Taxonomic group	Species	Taxonomic group	Species
Dinoflagellates	*Alexandrium minutum*	Hydroids	*Eudendrium carneum*
Bryozoans	*Bugula flabellata*		*Obelia dichotoma*
	Bugula neritina		*Halecium delicatulum*
	Bugula stolonifera		*Antennella secundaria*
	Cryptosula pallasiana	Molluscs	*Mytilus edulis planulatus*
	Schizoporella errata	Polychaetes	*Sabella spallanzanii*
	Schizoporella unicornis	Ascidians	*Ascidiella aspersa*
	Watersipora arcuata		*Ciona intestinalis*
	Watersipora subtorquata		*Styela plicata*
Crustaceans	*Paracerceis sculpta*	Fish	*Tridentiger trigonocephalus*
	Paradella dianae		
	Monocorophium sextonae		
	Monocorophium acherusicum		
	Amphibalanus amphitrite		

12.1.3 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the Methods section.

12.1.4 Inoculation likelihood

Based on the analysed data, in 2011, Bunbury Port received a total of 405 vessel visits. Bulk carriers and general cargo carriers accounted for 91.6% of the vessel types entering Bunbury Port (Figure 82). The remaining vessel types i.e. tankers, passenger vessels, barges, offshore support vessels and dredges, together only contributed 8.3%. The vast majority of vessels (268 vessels or 85.6%) only visited the port once (Figure 83). Forty-one (13.1%) visited 2 – 5 times, three (0.9%) visited 6 – 10 times and one (0.3%) visited more than 10 times.

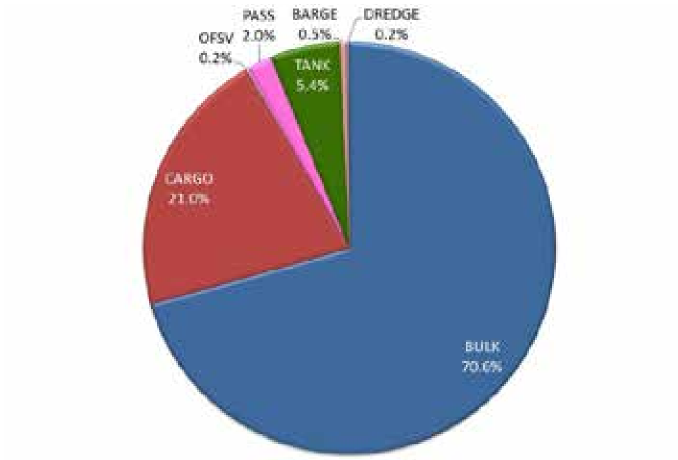


Figure 82 Summary of vessel type entering Bunbury port in 2011. (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, DREDGE = dredge vessels, OFSV = offshore support vessels, PASS = passenger vessels, TANK = tankers)

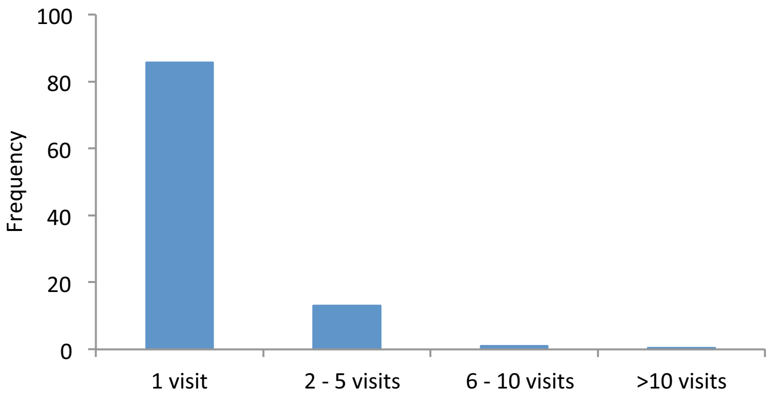


Figure 83 Frequency of repeat vessel visits to Bunbury port in 2011

In 2011, it was a dredge with a high risk rating that stayed for the longest duration, 22 days (Figure 84). Vessels with a low risk rating stayed the next longest, between 1 and 5 days. There was one vessel with a moderate risk rating (barge) that stayed less than 1 day.

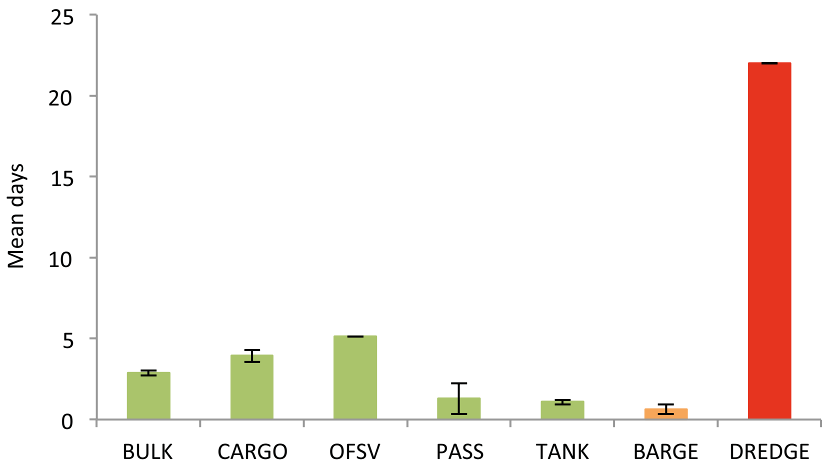


Figure 84 Mean residency time (days ± SE) for the different vessel types visiting Bunbury in 2011 and their risk rating (green = low risk, orange = moderate risk and red = high risk). (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, DREDGE = dredge vessels, OFSV = offshore support vessels, PASS = passenger vessels, TANK = tankers)

The majority of vessel visits (254 out of 405; i.e. 52.5%) to Bunbury Port were from an international source (Table 25). Most were vessels with a low risk rating: bulk vessels (189 visits or 74.4%), general cargo vessels (55 visits or 21.7%) and tankers (9 visits or 3.5%) (Figure 85). A barge with a moderate risk rating visited the port only once and accounted for 0.4% of the total international visits. These international vessel visits were from 24 countries, of which the majority, 59 visits (i.e. 23.3% of the total international visits) were from Singapore, while Japan (42 or 16.6%) and China (38 or 15%) were the next two most frequent sources.

Domestic visits (151) accounted for 37.3% of the remaining visits. This included 50 visits from 11 different interstate LPOC locations (Table 25). Adelaide was the most frequent source (19 visits or 38.0% of the total interstate visits), then Portland (13 visits or 26.0%) and Melbourne (6 visits or 12.0%). The interstate vessel types were all vessels with a low risk rating (Figure 85). Bulk vessels were the most common with 36 visits, accounting for 70.6% of all interstate vessels visits. Intrastate visits (101) were from eight different LPOC locations (Table 25). Kwinana, with 49 visits, accounted for 48.5% of intrastate visits to Bunbury Port, then Fremantle (21 visits or 20.8%) and Geraldton (11 visits or 10.9%) were the next most common sources. The intrastate vessels visits were predominantly from vessels with a low risk rating (99 visits or 98.0%), bulk vessels being the most common (61 visits or 61.0%) (Figure 85). There was one vessel with a high risk rating (dredge) and one with a moderate risk rating (barge) both which visited only once (1%) during 2011.

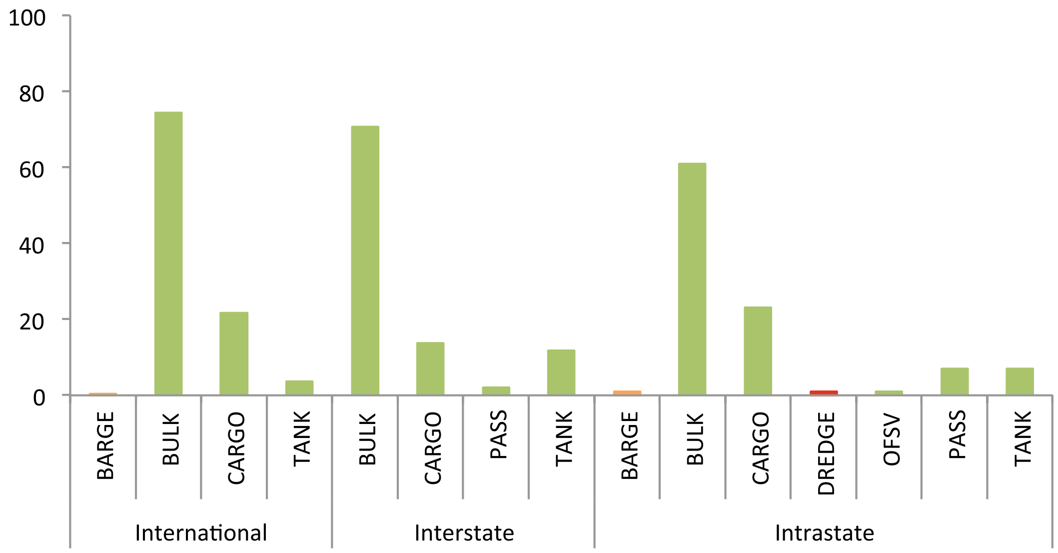


Figure 85 Percentage of vessels arriving to Bunbury Port in 2011 from international, interstate and intrastate sources by vessel type and risk rating (green = low risk, orange = moderate risk and red = high risk). (BARGE = barges, BULK = bulk vessels, CARGO = general cargo vessels, DREDGE = dredge vessels, OFSV = offshore support vessels, PASS = passenger vessels, TANK = tankers)

Table 25 Summary of vessel visits to Bunbury Port from source locations during 2011 (others are excluded due to lack of information on source)

Source	Number of visits	Percentage of visits (%)
International	**254**	**62.5**
Singapore	59	23.3
Japan	42	16.6
China	38	15.0
Indonesia	23	9.1
Malaysia	12	4.7
Taiwan	11	4.3
United Arab Emirates	11	4.3
South Korea	10	4.0
India	9	3.6
Hong Kong	7	2.8
Thailand	5	2.0
Vietnam	5	2.0
Philippines	5	2.0
Bangladesh	3	1.2
Qatar	3	1.2
South Africa	2	0.8
Denmark	1	0.4
Brunei	1	0.4
New Zealand	1	0.4
Sri Lanka	1	0.4
Oman	1	0.4
Mozambique	1	0.4
USA	1	0.4
Papua New Guinea	1	0.4
Domestic	**151**	**37.3**
Interstate	**50**	
Adelaide	19	38.0
Bing Bong	1	2.0
Botany Bay	1	2.0
Brisbane	2	4.0
Darwin	1	2.0
Geelong	2	4.0
Melbourne	6	12.0
Newcastle	2	4.0
Port Kembla	2	4.0
Port Pirie	1	2.0
Portland	13	26.0

Source	Number of visits	Percentage of visits (%)
Intrastate	**101**	
Albany	5	5.0
Cape Cuvier	1	1.0
Dampier	6	5.9
Esperance	6	5.94
Fremantle	21	20.8
Geraldton	11	10.9
Kwinana	49	48.5
Port Hedland	2	2.0
Other	**1**	**0.2**

12.1.5 Sociopolitical risk

Vessels visiting Bunbury Port were registered from 35 different flag states and of these, nearly a third (i.e. 11 or 31.4%) were listed as FOC states (Figure 86, see 'A'). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 56.5% of all visits to Bunbury port (Figure 86, see 'B'). The greatest proportion of FOC vessels came from Panama (42.8%) and the Marshall Islands (22.7%) (Figure 86C).

Of the 35 flag states, only 10 (27.4% of total visits) have ratified the IMO BWM. However, further analysis revealed that 5 of these 10 were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 21.8% of total visits.

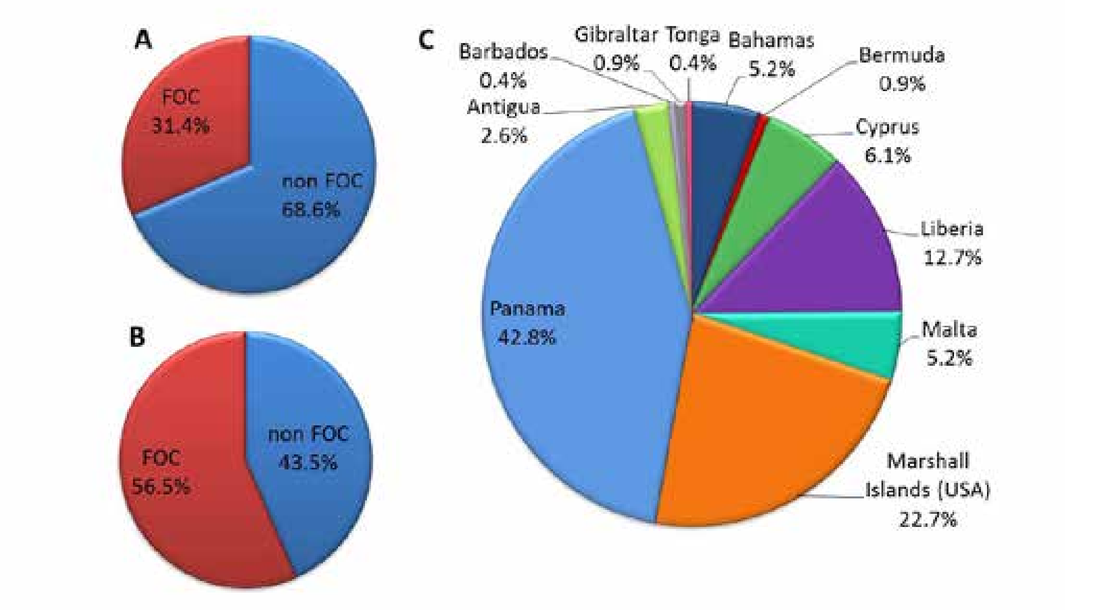


Figure 86 Percentage of FOC and non-FOC states entering Bunbury Port (A) in 2011. Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Bunbury (B). FOC states shown by country of registry and frequency of vessel visits (%) (C)

The overall inoculation risk to Bunbury Port was low, as the majority of vessels were classed as low risk, only visited once, and stayed for a short time. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Additionally, over half of the vessels visiting Bunbury Port were registered from countries considered to be FOCs and only a quarter of the total numbers of vessels were from flag states that had ratified the IMO BWM convention. This could indicate a propensity toward compromised environmental standards and vessel cleanliness, increasing the risk that an IMP might be present on the hull. The greatest inoculation risk to Bunbury Port was from a dredge with a high risk rating that stayed for 22 days.

12.1.6 Infection and establishment likelihood

There were 42 IMP species present at LPOC locations, of which 35 (83%) had temperature and salinity tolerances compatible with Bunbury Port environs. All 35 compatible species were located at one or more of the international sources for vessels (Figure 87). For domestic LPOCs there were seven species located interstate and three species located intrastate. *Caulerpa taxifolia* and *Crassostrea gigas* were present at the most locations (20 and 19 respectively: international and domestic combined). The next most common species were *Carcinus maenas* (13 locations) and *Balanus improvisus* (12 locations).

The macroalgae *C. taxifolia* occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe (Meinesz *et al.* 2001). *C. gigas* (oyster) is a species that could thrive in Bunbury and if it entered the 'wild', it could pose a significant threat to native oyster and mussel populations by outcompeting them. *C. maenas* (crab) is well known for its negative impacts on native biodiversity, and this species is one of the few invasive species demonstrated to have a significant economic impact upon fisheries (Lafferty & Kuris 1996; Lovell *et al.* 2007). *B. improvisus* (barnacle) is a common biofouler and once introduced into a new area this species can dominate and outcompete native species for available habitat (Qvarfordt *et al.* 2006).

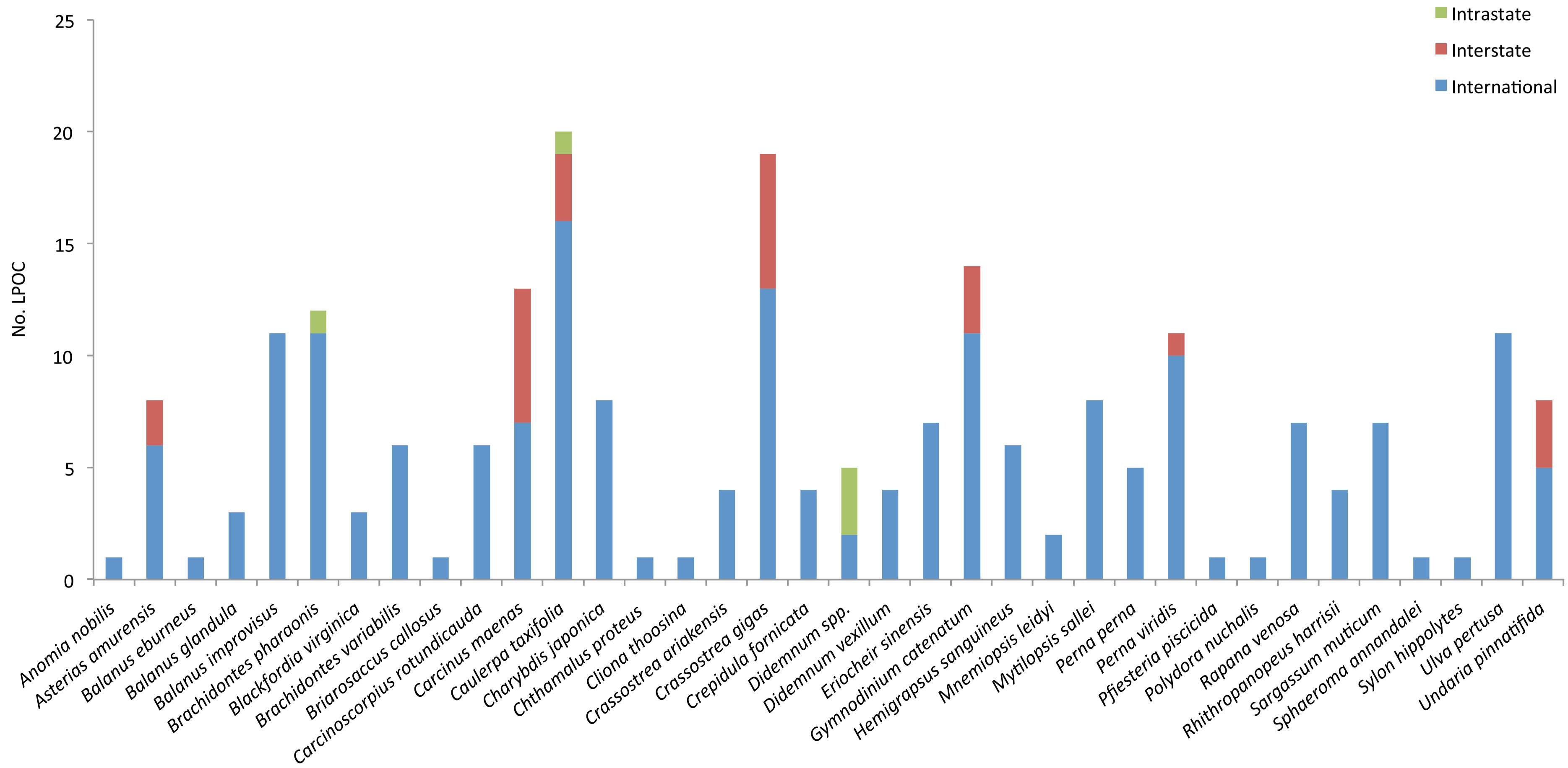


Figure 87 IMP species compatible with Bunbury Port and the number of LPOCs (international, interstate and intrastate) at which they occur

There were 22 different international LPOCs that contained an IMP with either a high or moderate risk rating that was compatible with Bunbury Port's environment. USA had the greatest number of IMPs with 29 species, 16 of which were classed as high risk. Japan and Thailand had the next greatest numbers of IMPs, 21 and 17 respectively. Japan had 14 species with a high risk rating and 7 species with a moderate risk rating. Thailand had 12 species with a high risk rating and 5 species with a moderate risk rating (Figure 88).

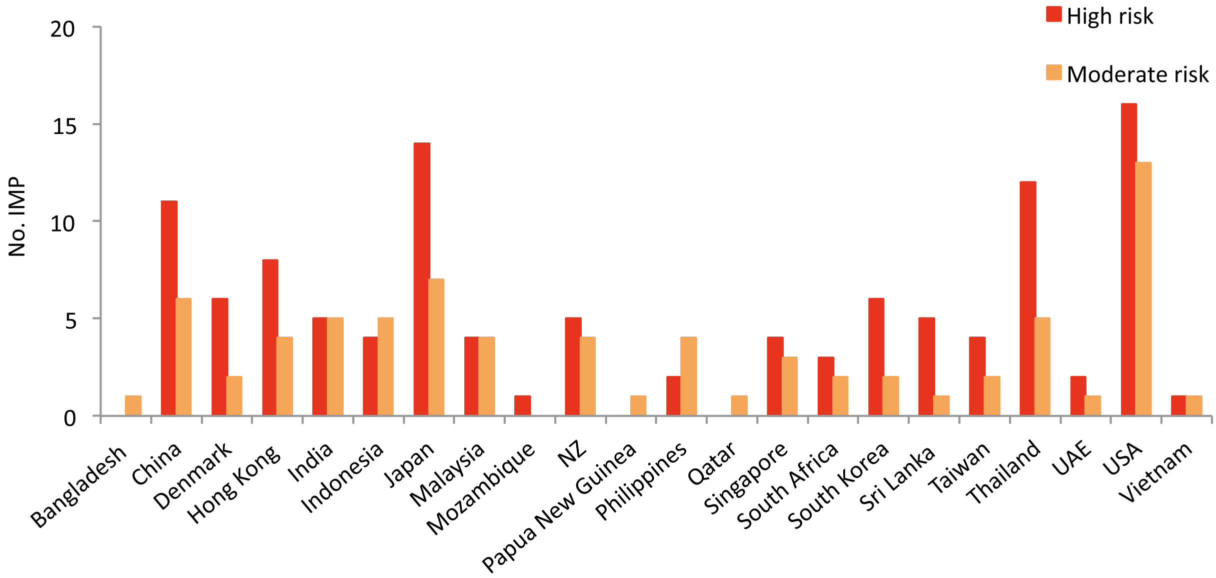


Figure 88 IMP species with a moderate or high risk rating, present at international LPOCs, that were compatible with Bunbury Port environs

When the cumulative effect of the number of vessel visits from an international LPOC and the number of compatible IMP present at that LPOC is considered, the greatest infection and establishment risk to the Bunbury Port was from Japan (Figure 89). China and Singapore also represented considerable infection and establishment risks. LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 89. Selected IMPs from Japan that posed a risk to Bunbury Port are shown pictorially in Figure 90.

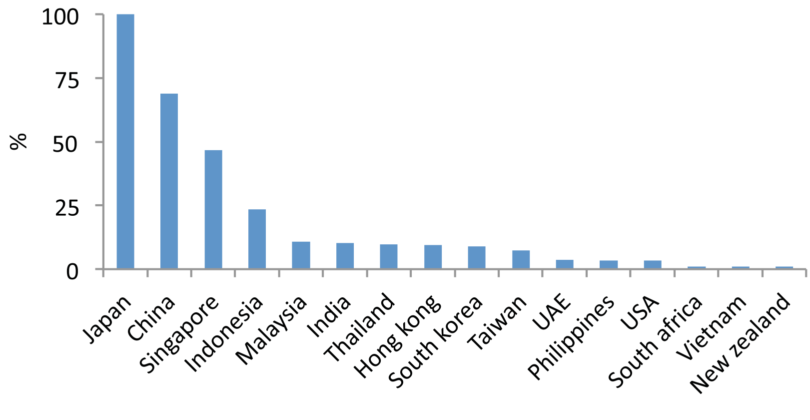


Figure 89 Ranking of the infection and establishment risk posed to Bunbury Port by international LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Japan 100%)

Figure 90 Map showing the proximity of Japan (red circle) to Bunbury Port (yellow star) and the selected IMPs that pose the greatest risk to Bunbury Port

IMP species were recorded at 11 domestic source locations (LPOC), 7 of which were interstate and 4 intrastate (Table 26, Figure 91). Victorian sources had the most high risk IMPs. The ports of Geelong and Melbourne both had three species with a high risk and Portland had two species with a high risk (Table 26). When the cumulative effect of the number of vessels visits from a domestic LPOC and the number of compatible IMP present at that LPOC is considered, Port Adelaide represented the greatest domestic infection and establishment risk to Bunbury Port (Figure 91). Portland and Kwinana also posed considerable domestic infection and establishment risks to Bunbury Port. Domestic locations for which the inoculation relative risk was negligible are not shown in Figure 91. The domestic IMP species that posed the greatest likelihood of introduction and establishment to Bunbury Port are *Asterias amurensis* (seastar from Victoria), *Carcinus maenas* (crab from South Australia, New South Wales and Victoria), *Undaria pinnatifida* (algae from Victoria and New South Wales).

Table 26 Number of high and moderate risk IMPs present at domestic (interstate and intrastate) LPOCs

LPOC	High risk	Moderate risk
Interstate		
Botany Bay (New South Wales)	1	3
Port Kembla (New South Wales)	1	1
Brisbane (Queensland)	1#	1
Adelaide (South Australia)	1	3
Geelong (Victoria)	3	1
Melbourne (Victoria)	3	1
Portland (Victoria)	2	2

LPOC	High risk	Moderate risk
Intrastate		
Dampier	0	1
Fremantle	0	1
Geraldton	0	1
Kwinana	0	1

# Indicates the species *Perna viridis*: although listed on marine invasive databases as present in Brisbane, the authors acknowledge that the species is not currently detected in the Brisbane Port environment (NIMPIS website)

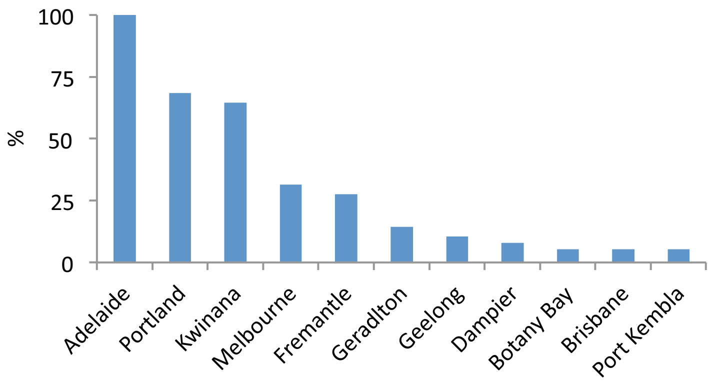


Figure 91 Ranking of the infection and establishment risk posed to the Bunbury Port by domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Adelaide 100%)

There were 14 IMP species that presented the greatest likelihood of infection and establishment to Bunbury Port, from international and domestic sources. Four of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining 10 species, although not listed in the top 100 worst, still posed a significant threat to Bunbury Port for one or more of the following: the environment, sociocultural values, economic value or human health. Brief information on these species is provided in Table 27. For further information, images and references for these species please see Appendix 2.

Table 27 The impact rank and examples of impacts for the 14 species which presented the greatest likelihood of infection and establishment to Bunbury Port

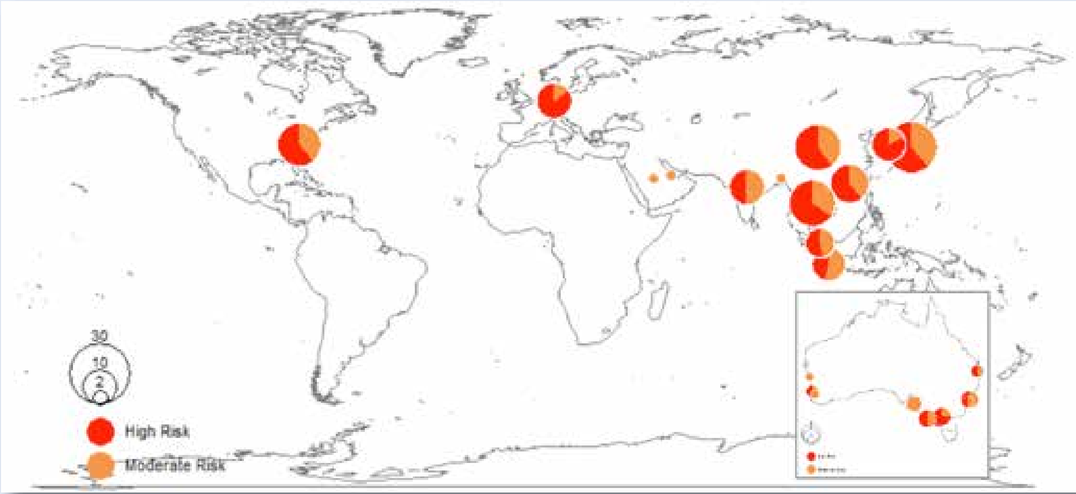
IMP species	Impact rank (M = medium, H = high)	Impacts
Asterias amurensis (sea star)	H	This is a voracious predator, known to outcompete native and commercial fish species. The Tasmanian scallop industry has reported losses of AU$1 million to their fishery as a result of the introduction of this sea star.
Carcinus maenas (crab)	H	This voracious predator is known to negatively impact population size and structure of many species especially shellfish and crabs. In the US, financial losses to the shellfish industry have been reported at USD$22.6 million and this is predicted to rise significantly.
Eriocheir sinensis (crab)	H	Large economic costs following the introduction of this species have been reported (EUR€80 million). These costs arise from ongoing management requirements to stabilise river banks damaged by the crabs, losses to commercial fisheries (crab predation), installation of barriers and ramps to prevent further crab migration and population control methods.

IMP species	Impact rank (M = medium, H = high)	Impacts
Undaria pinnatifida (algae)	H	This extremely fast-growing algae has two forms of efficient reproduction that result in a competitive advantage over native species for space.
Balanus improvisus (barnacle)	H	This is a fast-growing species that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.
Crepidula fornicata (limpet)	H	This limpet is known to increase sedimentation rates, creating muddy anoxic conditions that negatively impact endofauna, outcompete and negatively impact the density of other species and negatively modify benthic communities.
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi River region in the USA, M. sallei has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic/pelagic system, affected the food web structure and productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes and reducing efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder, it can pose a hazard for shellfish poisoning (paralytic shellfish poison toxins).
Charybdis japonica (crab)	H	This highly aggressive crab and opportunistic omnivore consumes mostly bivalves, crustaceans and polychaetes. This crab can outcompete native species for space and food. It can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Hemigrapsus sanguineus (crab)	H	This is an aggressive crab that can outcompete and displace native crabs and other native species thus altering ecosystem functioning.
Rhithropanopeus harrisii (crab)	H	This crab can compete with native crabs and benthic feeding fishes for food, alter food webs, foul water intake pipes, cause economic losses to gill net fisheries by spoiling fish caught in the fill nets and can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Didemnum vexillum (colonial ascidian)	H	This species has the inherit ability to drastically overwhelm and overgrow almost any substrate and sessile community. It is known to have completely altered ecosystems, impacted both lower and higher trophic levels, overgrown cobblestones, seagrass beds, mussel and oyster valves, barnacles and even other ascidians. In New Zealand, aquaculture industries have spent over NZ$804,000 in an attempt to eradicate this species that regularly smothers their mussel lines.
Sargassum muticum (algae)	H	This algae is known to outcompete native species (e.g. algae and seagrass) for space and through exclusion (i.e. shading), it can heavily foul marine equipment, clog intake pipes, increase the rate of sedimentation as it slows the water flow (dense stands) and reduce the social amenity of an area (floating mats and through decay).
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication.

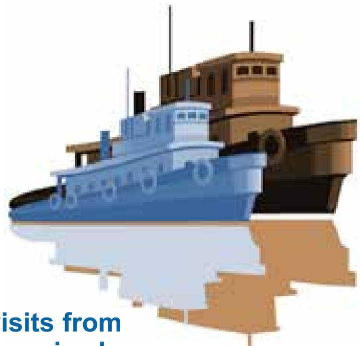
13.0 Albany Port

ALBANY PORT AT A GLANCE

Asia is the greatest source of high and moderate risk IMPs to Albany

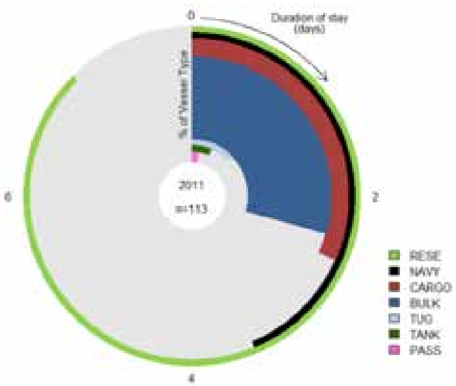


85% of inbound IMPs are compatible with Albany Ports environs

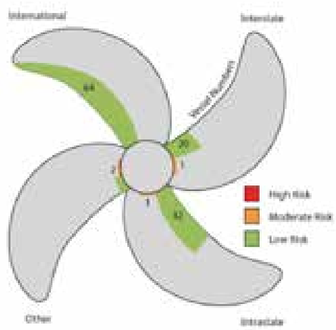


48 visits from recognized flags

65 visits from flags of convenience



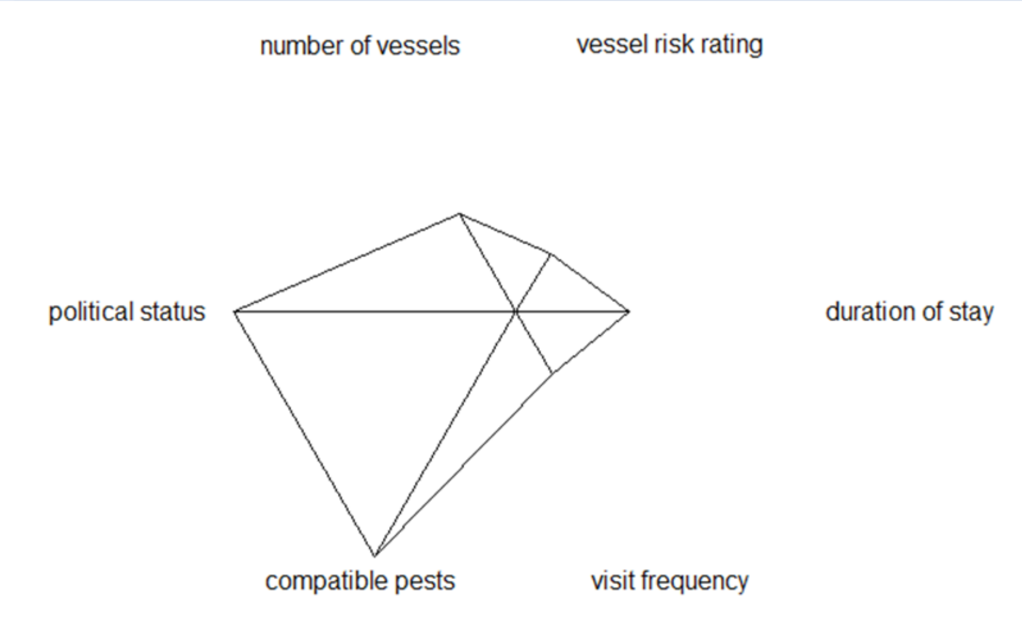
Research vessels stay the longest but bulk vessels are more common



Majority of vessels are from international LPOCs and are low risk

Albany Port

The drivers for Albany Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Albany Port. The length of the point indicates the degree to which that factor contributes to the risk.



The majority of vessels entering Albany (from all sources) had a low risk rating. There were no vessels with a high risk rating recorded in the 2011 data. Over half of the vessels visiting Albany were registered from countries considered FOCs and only 15% of the total vessel visits were from flag states that had ratified the IMO BWM convention. There was a very high compatibility (85%) between the potential incoming marine pests and the environment of Albany Port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOC that posed the greatest risk to Albany Port was Japan. Japan also has 5 species listed in the top 100 worst invasive species worldwide, all compatible with the environment of Albany Port. These include: *Asterias amurensis* (northern pacific sea star), *Carcinus maenas*, (European shore crab), *Caulerpa taxifolia* (algae: invasive strain), *Eriocheir sinensis* (Chinese mitten crab) and *Undaria pinnatifida* (wakame). Adelaide Port posed the greatest domestic risk to Albany Port based on the number of vessels arriving from there and the number of potentially compatible pests.

13.1 Albany Port description

Albany is located in WA's Great Southern region approximately 418 km south-east of the state capital, Perth. It was the first site of European settlement in WA, colonised in 1826. The population is now just over 33,000 (Census QuickStats 2011). The climate is Mediterranean, typified by warm, dry summers and cool, wet winters.

Albany Port is located on the northern shore of Princess Royal Harbour (Figure 92). It is predominantly a bulk products port, the main export trade being grain (43% in 2011) and woodchips (45% in 2011) (Albany Port Authority 2012; Albany Port Authority website). The port currently has four operational berths with a combined total length of 825 m, a tug marina and seven anchorage positions.

Figure 92 Albany Port infrastructure and locality map

13.1.1 Environment

The Albany marine area has the widest habitat diversity on the south coast (Wells 1990). The sea floor of King George Sound consists mainly of sand, seagrasses, rocky areas and artificial hard structures, such as shipwrecks and navigational markers. Oyster Harbour has large areas of sand and seagrass, smaller areas of rocks, and numerous artificial hard structures within the boating marina and navigational markers. Princess Royal Harbour contains large areas of shallow sandflats, seagrass, several shipwrecks, rocks, jetties, mud, and artificial hard surfaces within the Princess Royal Sailing Club, navigational markers, and the Port of Albany.

Environmental values used for the analysis were water a temperature range of 11.5 °C to 21.0°C and a salinity range of 33.0 – 34.8ppt. These values were based on data used in the Global Ballast Water Management Programme (GloBallast).

13.1.2 Current knowledge of introduced marine pests

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

A National System survey of the Albany marine area (King George Sound, Princess Royal Harbour and Oyster Harbour) for IMP species was conducted in 2007. The only species recorded from Albany on the target list was the polychaete *Sabella spallanzanii* and the marine alga *Codium fragile* ssp. *tomentosoides* (now *C. fragile* ssp. *fragile*). *Sabella spallanzanii* was previously known from the area, but the single specimen of *C. fragile* ssp. *fragile* was a new record. Following the finding of *C. fragile* ssp. *fragile* in Princess Royal Harbour, an extensive survey specifically targeting this species was conducted in June 2008. Additional individuals of *C. fragile* ssp. *fragile* have since been confirmed as being established outside the initial survey area and in the broader Albany region.

13.1.3 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the Methods section.

13.1.4 Inoculation likelihood

Albany Port received a total of 113 vessel visits based on the 2011 data examined. Bulk carriers were the dominant vessel type entering Albany Port (69.0%). General cargo vessels and passenger vessels were the next most abundant types of vessels (15.0% and 8.8% respectively) (Figure 93). Seventy-seven vessels (85.5%) only visited the port once (Figure 94). Twelve (13.3%) visited 2 – 5 times and one vessel (1.1%) visited 6 times (Figure 94). There were no vessels that visited more than ten times.

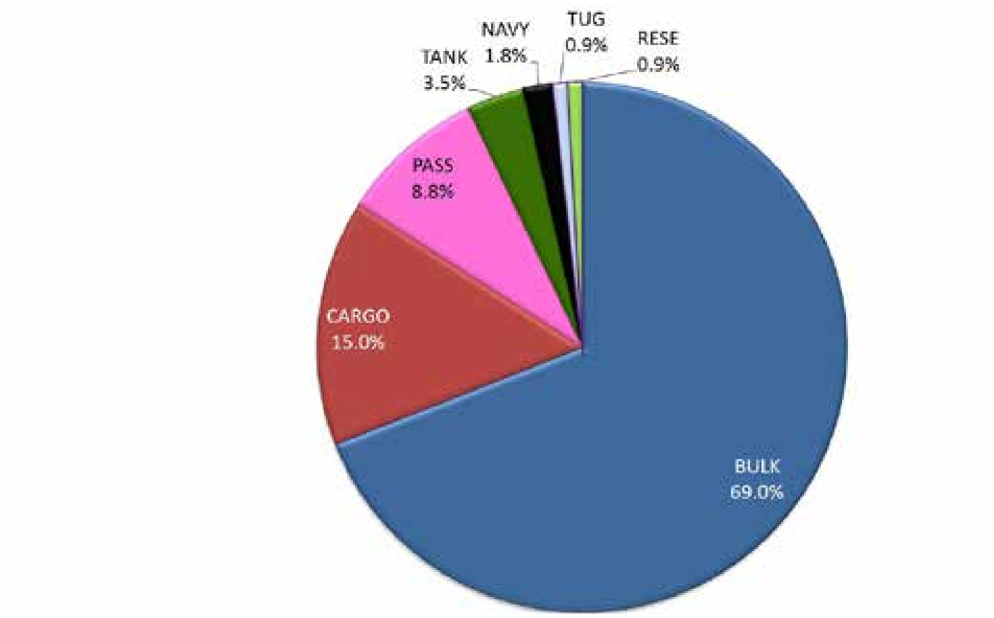


Figure 93 Summary of vessel types entering Albany Port in 2011. (BULK = bulk vessels, CARGO = general cargo vessels, NAVY = navy vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

Bulk carriers and general cargo vessels, both with a low risk rating, stayed the longest (average of 2.4 and 2.5 days respectively) (Figure 95). Research vessels, with a moderate risk rating, had the longest duration of stay at seven days. A Navy vessel, the only vessel with a high risk rating, had an average stay of 3.5 days.

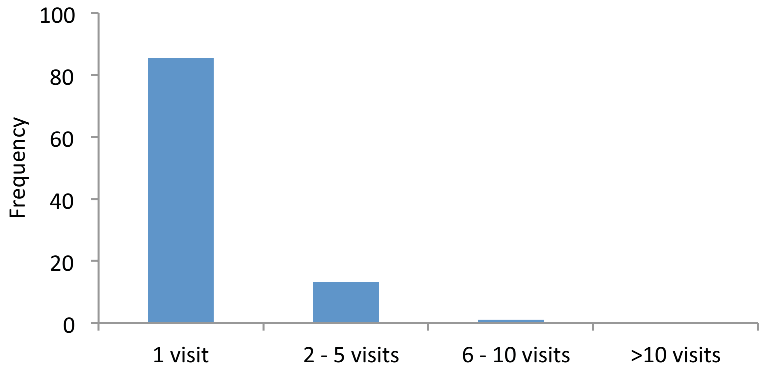


Figure 94 Frequency of repeat vessel visits to Albany Port in 2011

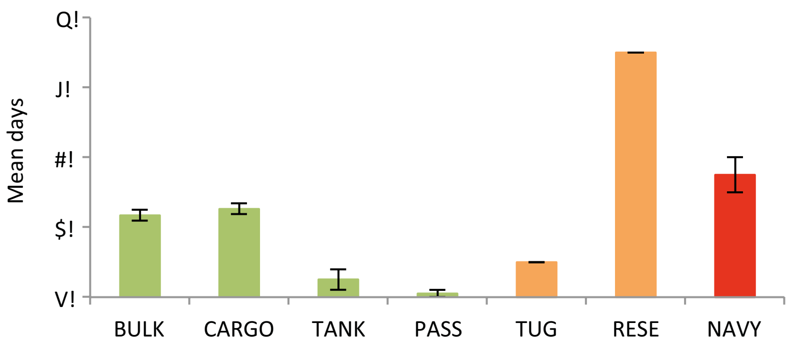


Figure 95 Mean residency time (days ± SE) for the different vessel types visiting Albany in 2011 and their risk rating (green = low risk, orange = moderate risk and red = high risk). (BULK = bulk vessels, CARGO = general cargo vessels, NAVY = navy vessels, PASS = passenger vessels, TANK = tankers, TUG = tugs)

The majority of vessel visits (64 out of 113, or 56.6%) to Albany were from an international source and all were from vessels with a low risk rating: bulk carriers (48 visits or 75.0%), general cargo (15 visits or 23.4%) and tankers (1 visit or 1.6%) (Figure 96). These international vessel visits were from 13 countries. Twenty-five visits (i.e. 39.1% of the total international visits) were from Japan, followed by 13 visits from Singapore (20.3%) and 6 visits from China (9.4%) (Table 28).

Domestic visits (47) accounted for 41.6% of the remaining visits. This included 14 visits from seven different interstate locations (Table 28). Adelaide was the greatest source of interstate vessel visits with 8 visits (57.1% of the total interstate visits) and the remaining 6 locations each contributed only one visit (7.1%). The interstate vessel types included four with a low risk rating, and one with a moderate risk rating (Figure 96). Bulk vessels, with a low risk rating, were the most common at eight visits (57.1%). Three of the remaining vessel types, general cargo vessels, passenger vessels and tankers, also all had a low risk rating and visited between one (7.1%) and three times (21.4%). A tug (1 visit or 7.1%) was the only vessel with a moderate risk rating from an interstate location visiting Albany port.

Intrastate visits (33) were from five different locations (Table 28). Esperance, with 10 visits (30.3% of total intrastate visits) was the greatest source of intrastate vessels, followed by the ports of Kwinana and Bunbury at 8 visits (24.2%) and 7 visits (21.2%) respectively. The intrastate vessel types included three with a low risk and one with a moderate risk rating (Figure 96). Bulk vessels, with a low risk rating, comprised the majority of vessels (22 visits or 66.7%). There were two other vessel types with a low risk rating, passenger vessels (9 visits or 27.3%) and general cargo vessels (1 visit or 3.0%) (Figure 96). The research vessel (1 visit or 3.0%) was the only vessel with a moderate risk rating visiting Albany port from an intrastate location. The LPOCs for the high risk navy vessels (2 visits) were unknown and therefore referred to as ‘other’.

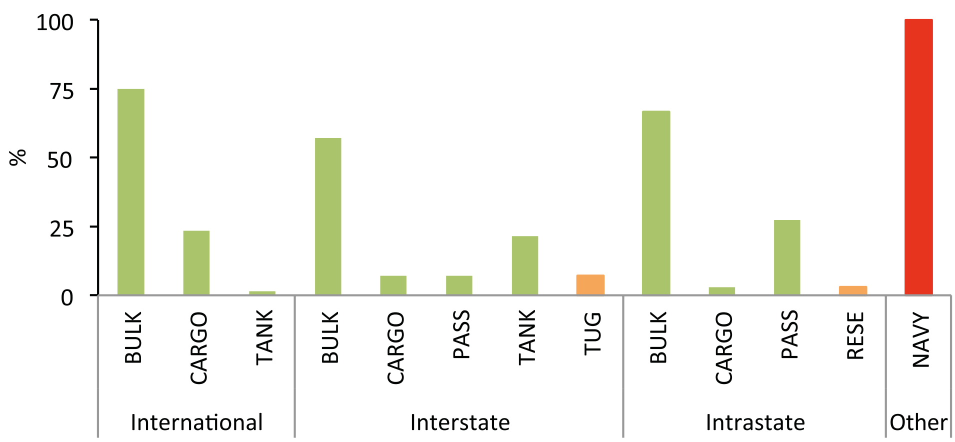


Figure 96 Percentage of vessels arriving into Albany in 2011 from international, interstate and intrastate sources by vessel type and risk rating (green = low risk, orange = moderate risk and red = high risk). (BULK = bulk vessels, CARGO = general cargo vessels, NAVY = navy vessels, PASS = passenger vessels, RESE = research vessels, TANK = tankers, TUG = tugs)

Table 28 Summary of vessel visits to Albany Port from source locations

Source	Number of visits	Percentage of visits (%)
International	**64**	**56.6**
Bangladesh	1	1.6
China	6	9.4
Germany	1	1.6
Hong Kong	1	1.6
India	4	6.3
Indonesia	5	7.8
Japan	25	39.1
Qatar	1	1.6
Saudi Arabia	2	3.1
Singapore	13	20.3
South Korea	2	3.1
Thailand	2	3.1
West USA	1	1.6
Domestic		**41.6**
Interstate	**14**	
Adelaide	8	57.1
Botany Bay	1	7.1
Brisbane	1	7.1
Geelong	1	7.1
Melbourne	1	7.1
Port Kembla	1	7.1
Portland	1	7.1
Intrastate	**33**	
Bunbury	7	21.2
Esperance	10	30.3
Fremantle	4	12.1
Geraldton	4	12.1
Kwinana	8	24.2
Other	**2**	**1.8**

13.1.5 Sociopolitical risk

Vessels visiting Albany were registered from 24 different flag states and of these, 8 (33.3%) were FOC states (Figure 97, see 'A'). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 57.5% of all visits to Albany (Figure 97, see 'B'). The greatest proportion of FOC vessels came from the countries of Panama (50.8%), Malta and the Marshall Islands (both 10.8%) (Figure 97, see 'C').

Of the 24 flag states, only 6 (15% of total visits) have ratified the IMO BWM. However, further analysis revealed that two of these six were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 11.8% of total visits.

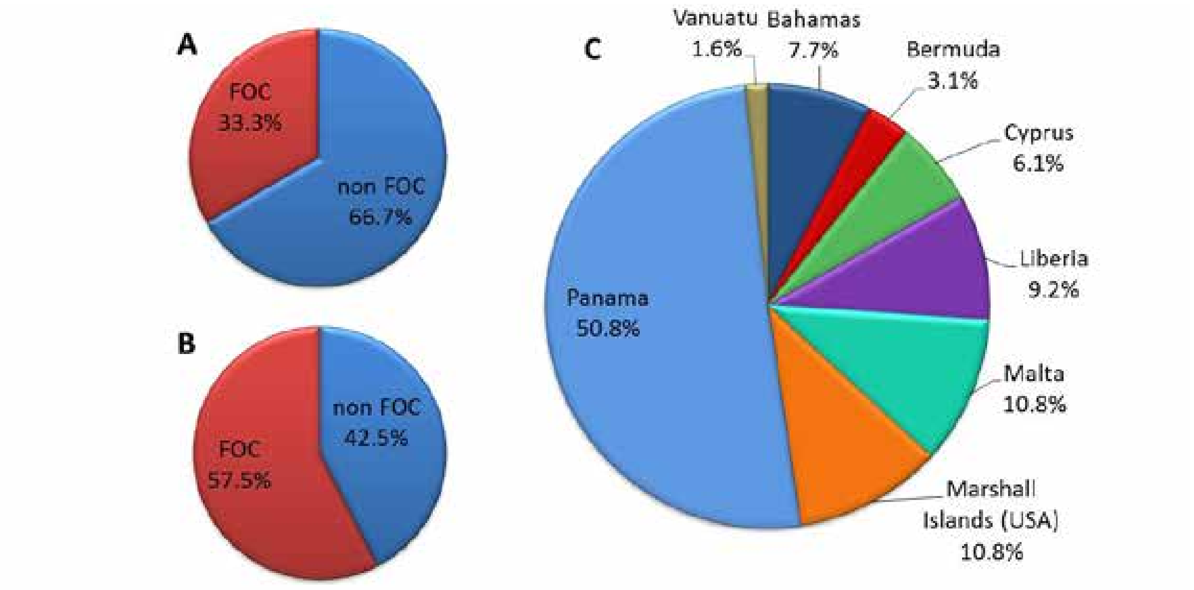


Figure 97 Percentage of FOC and non-FOC states entering Albany Port (A). Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Albany (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Albany Port was low as the majority of vessels had a low risk rating, only visited once and stayed for short periods. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Additionally, over half of the vessels visiting Albany Port were registered from countries considered to be FOCs and very few of the total number of vessels were from flag states that had ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull. The greatest inoculation risk to Albany port was from a navy vessel with a high risk rating, and a research vessel with a moderate risk rating that stayed the longest, at 7 days.

13.1.6 Infection and establishment likelihood

There were 34 IMP species present at LPOC locations, 29 of which (85%) had temperature and salinity tolerances compatible with Albany Port environs. All 29 compatible species were located at one or more of the international sources for vessels (Figure 98). For domestic LPOCs there were six species located interstate and three species located intrastate. *Crassostrea gigas* and *Caulerpa taxifolia* were present in the most sources (14: international and domestic combined). The next most common species were *Gymnodinium catenatum* (12 locations) and *Carcinus maenas* (10 locations).

C. gigas (oyster) is a species that could thrive in Albany and if it entered the 'wild', could pose a significant threat to native oyster and mussel populations. Previous attempts to introduce *C. gigas* into Albany may actually have released 'stock' into the wild. As such, the authors recommend an analysis of the 'wild' oyster populations in this region as vessels from Albany are likely to move to other WA ports. The macroalgae *C. taxifolia* occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe. *G. catenatum* (dinoflagellate) is not regarded as a vessel biofouling species, however it may be transported as a cyst on equipment such as ropes and cages or in sediment present on a vessel. *C. maenas* (crab) is well known for its negative impacts on native biodiversity, and this species is one of the few invasive species demonstrated to have a significant economic impact upon fisheries (Grosholz *et al.* 2000; McGaw *et al.* 2011).

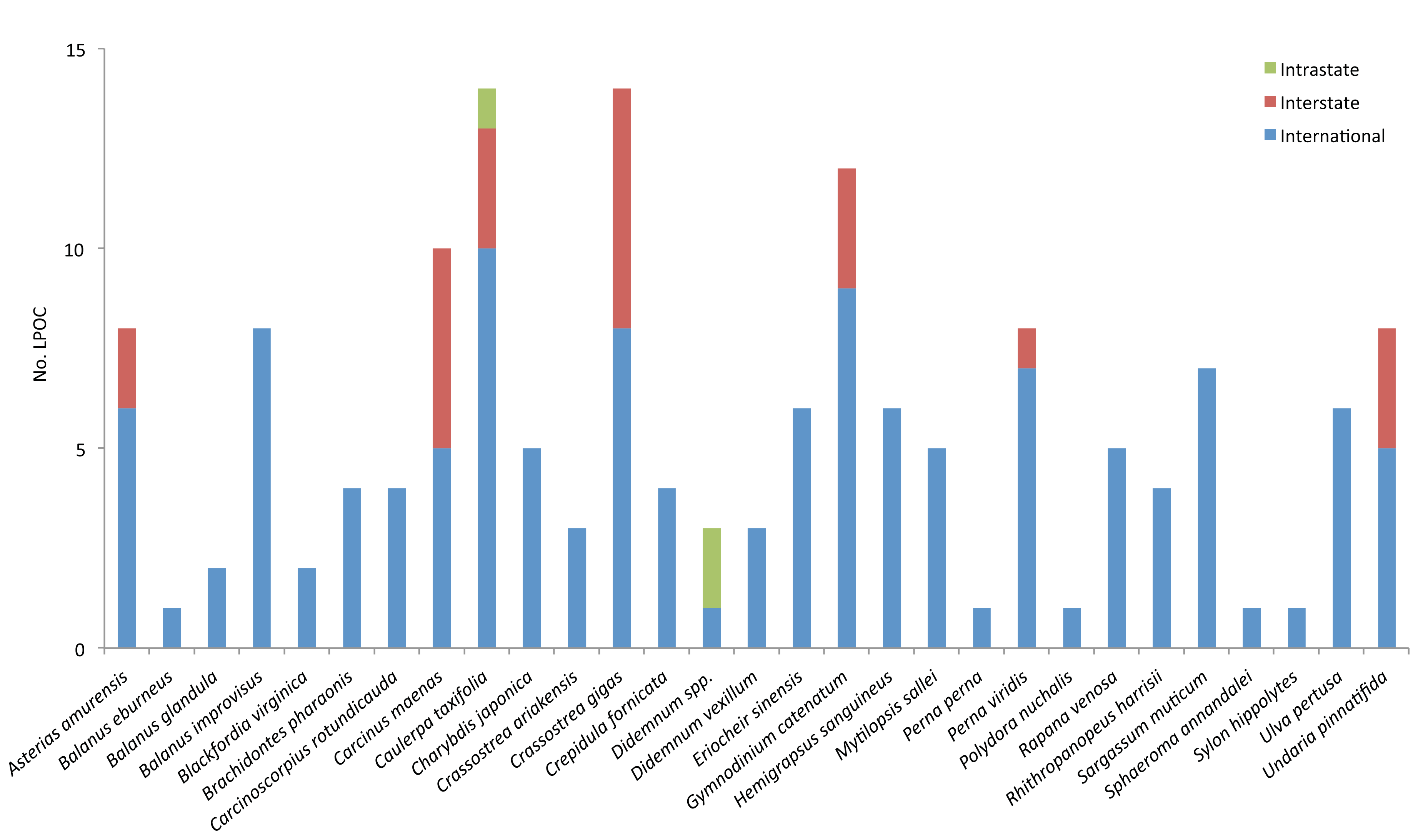


Figure 98 IMP species compatible with Albany Port and the number of LPOCs (international, interstate and intrastate) at which they occur

There were 13 different international LPOCs that contained an IMP with either a high risk or moderate risk that was compatible with Albany Port's environment. Japan had the greatest number of IMPs with 21 species, 14 of which 14 were classed as high risk. China and Thailand had the next greatest number of IMPs at 17 each, of which 11 and 12 respectively had a high risk (Figure 99).

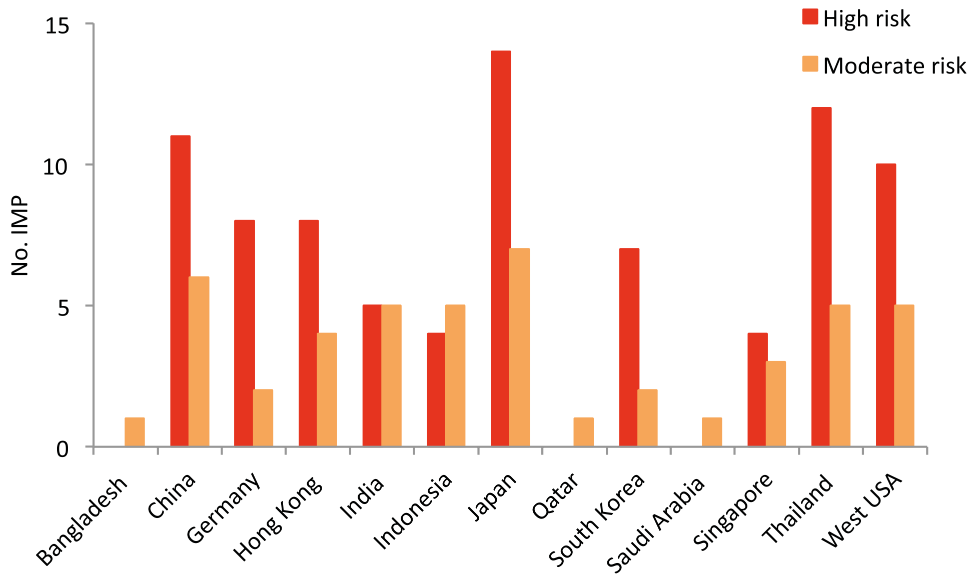


Figure 99 IMP species with a moderate or high risk rating, present at international LPOCs, that were compatible with Albany Port environs

When the cumulative effect of the number of vessel visits from an international LPOC and the number of compatible IMP present at that LPOC is considered, the greatest infection and establishment risk to Albany Port was from Japan (Figure 100). LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 100. Selected IMPs from Japan that pose a risk to Albany Port are shown pictorially in (Figure 101).

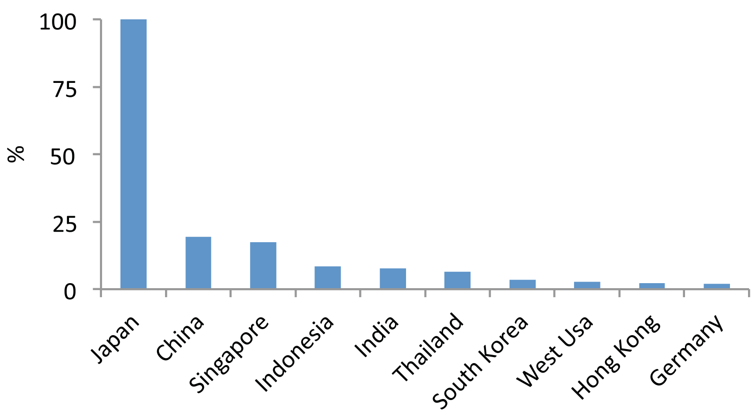


Figure 100 Ranking of the infection and establishment risk posed to Albany Port by international LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Japan 100%)

Figure 101 Map showing the proximity of Japan (red circle) to Albany Port (yellow star) and the selected IMPs that pose the greatest risk to Albany Port

IMP species were recorded at 10 domestic LPOCs, 7 of which were interstate and 3 intrastate (Table 29, Figure 102). Victoria had the greatest number of source locations with high risk IMPs; the ports of Geelong and Melbourne both had three high risk species and Portland had two high risk species (Table 29). When the cumulative number of vessel visits from a domestic LPOC and the number of compatible IMP present at that LPOC is considered, Port Adelaide represented the greatest domestic infection and establishment risk to Albany Port (Figure 102). Domestic LPOCs that had negligible infection and establishment risks (i.e. <1%) are not shown in Figure 102. The domestic pest species that pose the greatest risk to Albany port include *Asterias amurensis* (seastar from Victoria), *Carcinus maenas* (crab from New South Wales and Victoria) and *Undaria pinnatifida* (algae: Victoria).

Table 29 Number of compatible high and moderate risk IMPs present at domestic (interstate and intrastate) LPOCs

LPOC domestic	High risk	Moderate risk
Interstate		
Botany Bay (New South Wales)	1	2
Port Kembla (New South Wales)	1	1
Brisbane (Queensland)	1	1
Port Adelaide (South Australia)	0	2
Geelong (Victoria)	3	1
Melbourne (Victoria)	3	1
Portland (Victoria)	2	1
Intrastate		
Fremantle	0	1
Geraldton	0	1
Kwinana	0	1

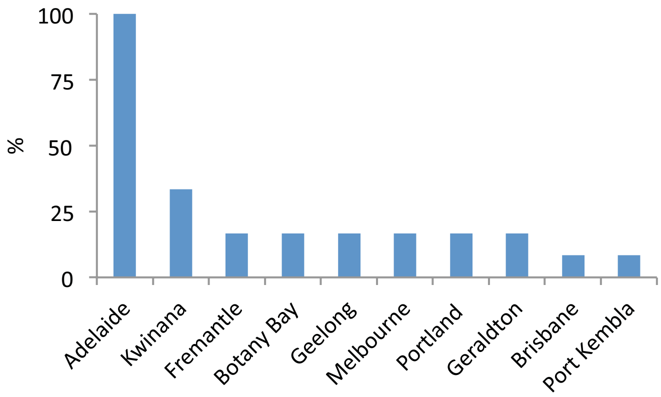


Figure 102 Ranking of the infection and establishment risk posed to Albany Port by domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. Adelaide 100%)

There were 15 species from international and domestic sources that presented the greatest likelihood of infection and establishment to Albany Port. Five of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), *Caulerpa taxifolia* (clone strain of the macroalgae), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining 10 species, although not listed in the top 100 worst, still posed a significant threat to Albany Port for one or more of the following: the environment, economic value, sociocultural values or human health. Brief information on these species is provided in Table 30. For further information, images and references for these species please see Appendix 2.

Table 30 The impact rank and examples of impacts for the 15 species which presented the greatest likelihood of infection and establishment to Albany Port

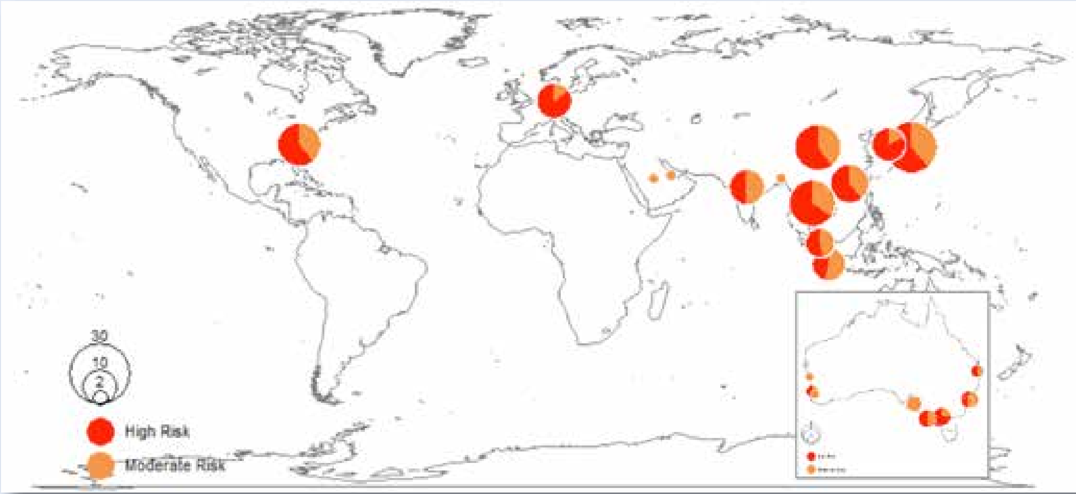
IMP species	Impact rank (M or H)	Impacts
Asterias amurensis (sea star)	H	This voracious predator is known to outcompete native and commercial fish species. The Tasmanian scallop industry has reported losses of AU$1 million to their fishery as a result of the introduction of this sea star.
Caulerpa taxifolia (algae, clone strain)	M	Invasive algae that has the potential to grow rapidly, alter marine habitats and affect biodiversity. It can potentially invade seagrass beds and modify organic and inorganic components of the sediment.
Carcinus maenas (crab)	H	This voracious predator is known to negatively impact population size and structure of many species, especially shellfish and crabs. In the US, financial losses to the shellfish industry have been reported at USD$22.6 million and this is predicted to rise significantly.
Eriocheir sinensis (crab)	H	Large economic costs following the introduction of this species have been reported (EUR€80 million). These costs arise from ongoing management requirements to stabilise river banks damaged by the crabs, losses to commercial fisheries (crab predation), installation of barriers and ramps to prevent further crab migration and population control methods.
Undaria pinnatifida (algae)	H	This is an extremely fast-growing algae with two forms of efficient reproduction that result in a competitive advantage over native species for space.

IMP species	Impact rank (M or H)	Impacts
Balanus improvisus (barnacle)	H	This is a fast-growing species that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.
Crepidula fornicata (limpet)	H	This limpet is known to increase sedimentation rates, creating muddy anoxic conditions that negatively impact endofauna, outcompete and negatively impact the density of other species and negatively modify benthic communities.
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi River region in the USA, *M. sallei* has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic/pelagic system, affected the food web structure and productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes and reducing efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder, it can pose a hazard for shellfish poisoning (paralytic shellfish poison toxins).
Charybdis japonica (crab)	H	This is a highly aggressive crab and opportunistic omnivore, consuming mostly bivalves, crustaceans and polychaetes. This crab can outcompete native species for space and food. It can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Hemigrapsus sanguineus (crab)	H	This is an aggressive crab that can outcompete and displace native crabs and other native species thus altering ecosystem functioning.
Rhithropanopeus harrisii (crab)	H	This crab can compete with native crabs and benthic feeding fishes for food, alter food webs, foul water intake pipes, cause economic losses to gill net fisheries by spoiling fish caught in the fill nets and can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Didemnum vexillum (colonial ascidian)	H	This species has the inherit ability to drastically overwhelm and overgrow almost any substrate and sessile community. It is known to have completely altered ecosystems, impacted both lower and higher trophic levels, overgrown cobblestones, seagrass beds, mussel and oyster valves, barnacles and even other ascidians. In New Zealand, aquaculture industries have spent over NZ$804,000 in an attempt to eradicate this species that regularly smothers their mussel lines.
Sargassum muticum (algae)	H	This algae is known to outcompete native species (e.g. algae and seagrass) for space and through exclusion (i.e. shading) it can heavily foul marine equipment, clog intake pipes, increase the rate of sedimentation as it slows the water flow (dense stands) and reduce the social amenity of an area (floating mats and through decay).
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients resulting in eutrophication.

14.0 Esperance Port

ESPERANCE PORT AT A GLANCE

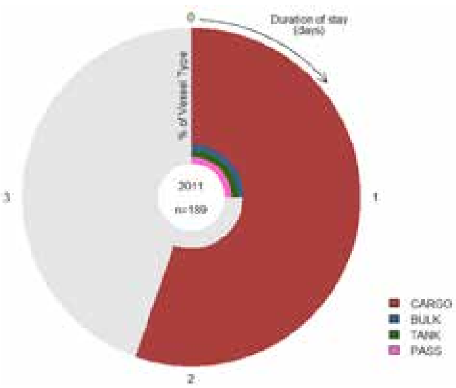
Asia is the greatest source of high and moderate risk IMPs to Esperance



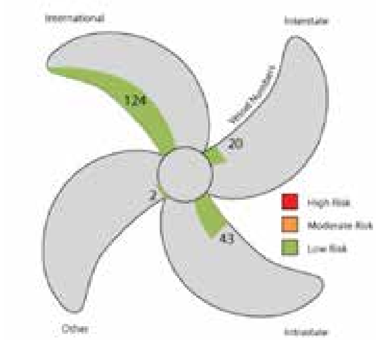
92% of inbound IMPs are compatible with Esperance Port environs

90 visits from recognized flags

99 visits from flags of convenience



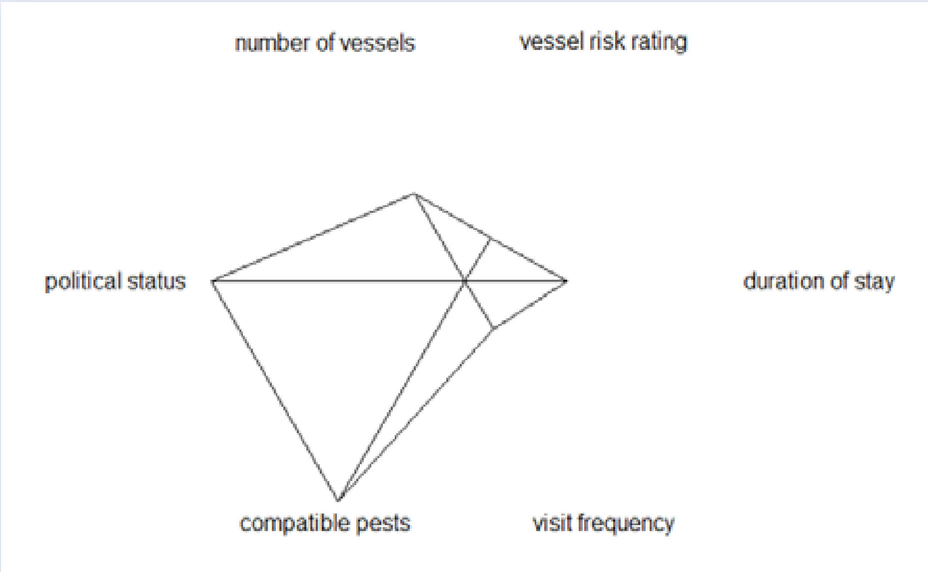
Cargo vessels stay the longest and are the most common



Majority of vessels are from international LPOCs and are low risk

Esperance Port

The drivers for Esperance Port's risk are: number of vessels, the overall vessel risk rating, the average duration of stay, the visit frequency, the number of compatible pests and the sociopolitical status (political status) of the vessels arriving at Esperance Port. The length of the point indicates the degree to which that factor contributes to the risk.



The majority of vessels entering Esperance Port (from all sources) had a low risk rating and were form an international source. There were no vessels with a high risk rating recorded in the 2011 data. Over half of the vessels visiting Esperance Port were registered from countries considered to be FOCs and very few of the total number of vessels were from flag states that had ratified the IMO BWM convention. There was a very high compatibility (92%) between the potential incoming marine pests and the environment of Esperance Port. Based on the number of incoming vessels and the number of potentially compatible pests, the international LPOC that posed the greatest risk to Esperance Port was China. China also has 3 species listed in the top 100 worst invasive species worldwide, all compatible with the environment of Esperance Port. These include: *Asterias amurensis* (northern pacific sea star), *Eriocheir sinensis* (Chinese mitten crab) and *Undaria pinnatifida* (wakame). Kwinana, Port Adelaide and Portland Port all pose a domestic risk to Esperance Port based on the number of vessels from there and the number of potentially compatible pests.

14.1 Esperance Port description

Esperance Port is located approximately 600 km south-east of Perth. It is WA's easternmost south coast port and is approximately 700 km from the South Australian border. Port waters are considered to be the area within a 10 nautical mile (M) radius of the western breakwater of Bandy Creek, and encompass: the main port facilities of two land-backed wharves and a dolphin-style berth; the small marina at Bandy Creek; a recreational harbour; and the 600 m long decommissioned tanker jetty (Figure 103).

The port is predominantly an export point for the mining industry and in the 2011/12 financial year almost 11 million tonnes, primarily of iron ore, were exported through the port (Esperance Port Sea and Land 2012). Exports tend to reflect international commodity prices, with previous years seeing greater exports of nickel and lead.

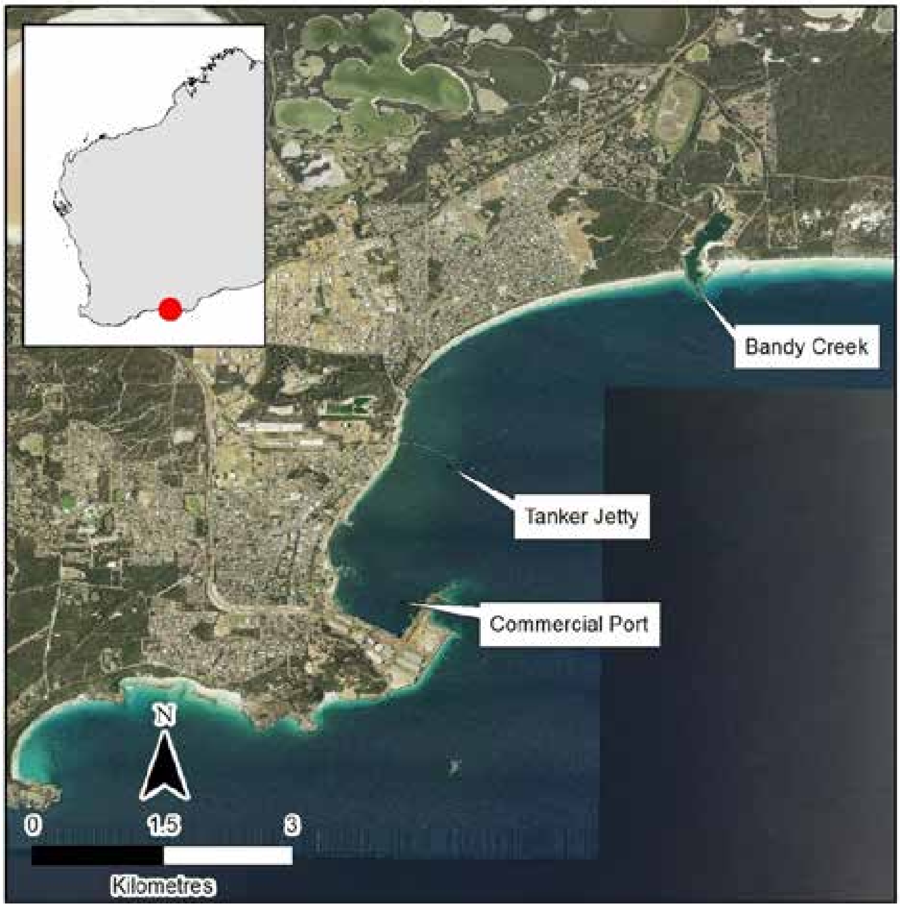


Figure 103 Esperance Port (Commercial Port) infrastructure and location map

14.1.1 Environment

The marine environment in the region of Esperance is classed as warm temperate and the water temperatures range between 13 °C and 22 °C (Kendrick *et al.* 2005). The tidal range is relatively small (1.1 m) and the coastline is instead dominated by swell and seawater movements. The commercial port itself is relatively protected from oceanic conditions, being on the leeside of Dempster Head and several breakwaters.

The coastline is comprised of granite headlands, interspersed with sandy coves and beaches. Subtidal substrates are comparable to the coastline and are predominantly unconsolidated sands, with considerable areas of seagrass and some areas of exposed granite and algal communities.

The only substantial freshwater input into the port waters is via Bandy Creek, which periodically causes the marina waters to become brackish. This input has no appreciable effect on the environment outside the Bandy Creek Marina, but has the potential to dramatically alter the fouling communities inside the marina.

Environmental values used for the analysis were a water temperature range of 11.5 °C to 16.0°C and a salinity range of 28.0 – 34.8 ppt. These values were based on data used in the Global Ballast Water Management Programme (GloBallast).

14.1.2 Current knowledge of introduced marine pests

Two surveys for IMP species are recorded for the port of Esperance and its surrounds. The first was carried out in 2002 (Campbell 2003a) and the second, more targeted survey was conducted in 2007 (McDonald & Travers 2008). Fifteen of the species detected by Campbell (2003a) are considered introduced by Huisman *et al.* (2008) and the results of the McDonald & Travers (2008) survey did not find any additional IMP species. A list of the confirmed introduced species found in Esperance waters is provided in Table 31.

Table 31 Confirmed introduced species in Esperance Port and surrounding waters

Taxonomic group	Species	Taxonomic group	Species
Bryozoans	*Bugula neritina*	Crustaceans	*Paracerceis sculpta*
	Bugula stolonifera		*Sphaeroma serratum*
	Conopeum seurati	Ascidians	*Ascidiella aspersa*
	Schizoporella errata		*Botryllus schlosseri*
	Schizoporella unicornis		*Ciona intestinalis*
Barnacles	*Amphibalanus amphitrite*		*Styela plicata*
	Megabalanus tintinnabulum	Polychaetes	*Sabella spallanzanii*

14.2 Results and discussion

From a biosecurity perspective the risk to any region is based on multiple factors. These factors include inoculation likelihood, infection and establishment likelihood and the sociopolitical risk. These are explained fully in the *Methods* section.

14.2.1 Inoculation likelihood

Esperance Port received a total of 189 vessel visits based on the 2011 data examined. General cargo carriers were the dominant vessel type entering Esperance Port (98.5%) in 2011. Only three other types of vessels accounted for the remaining 1.5%; passenger vessels, tankers and bulk vessels (Figure 104). The majority of vessels only visited the port once in 2011 (147 or 89.6%) (Figure 105). Sixteen (9.8%) visited 2 – 5 times and one vessel visited 6 times (0.6%). All vessels recorded for Esperance Port in 2011 had a low risk rating and stayed between 1 and 2.2 days (Figure 106).

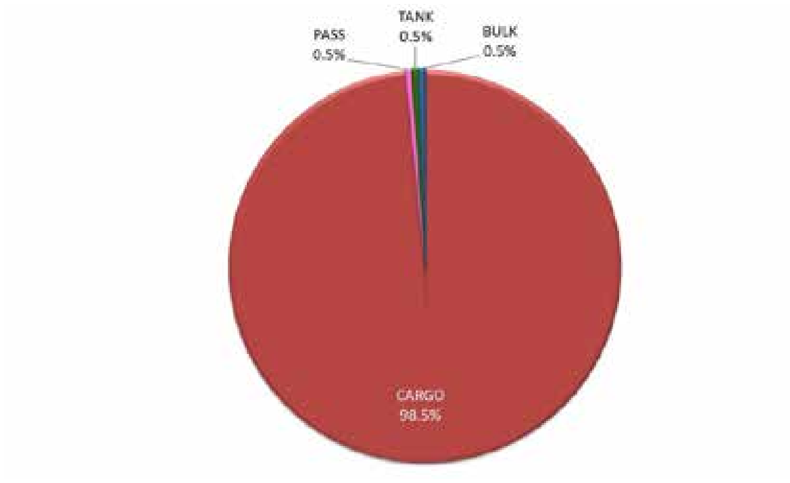


Figure 104 Summary of vessel types entering Esperance Port in 2011. (BULK = bulk vessels, CARGO = general cargo vessels, PASS = passenger vessels, TANK = tankers)

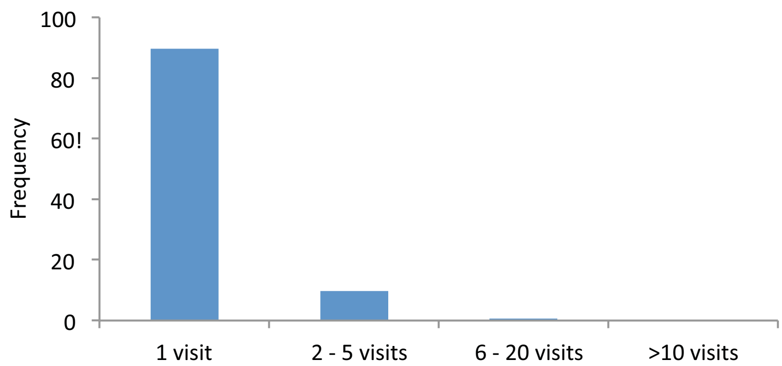


Figure 105 Frequency of repeat vessel visits to Esperance Port

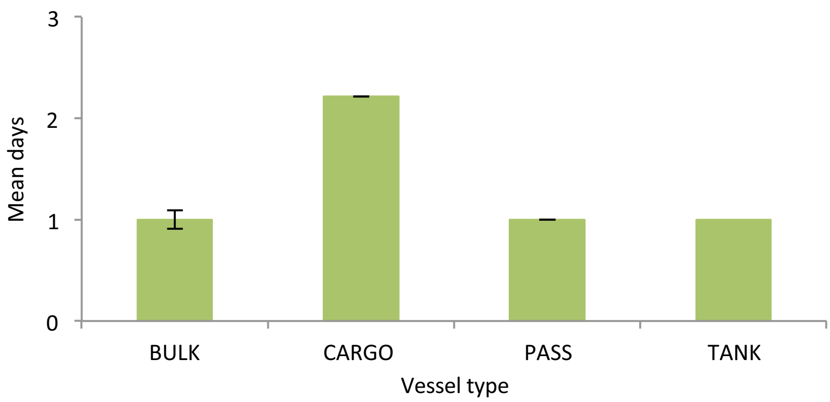


Figure 106 Mean residency time (days ± SE) for the different vessel types visiting Esperance in 2011 and their risk rating (green = low risk). (BULK = bulk vessels, CARGO = general cargo vessels, PASS = passenger vessels, TANK = tankers)

The majority of vessel visits (124 out of 189, or 65.6%) to Esperance Port were from international sources (LPOCs) (Table 32). These international vessel visits were from 15 countries, of which 44 visits (i.e. 35.5% of the total international visits) were from China. The next most common sources were Singapore (19.4%), Indonesia (12.1%) and Japan (8.9%).

Domestic visits (63) accounted for 33.3% of the remaining visits. This included 20 visits from 11 different interstate locations (LPOCs) (Table 32). The interstate locations each contributed between one and four visits (5 – 20% of the total interstate visits). Intrastate visits, of which there were 43, were from six different locations. Kwinana, with 13 visits (i.e. 30.2% of the total intrastate visits) and Albany with 10 visits (23.3%) were the most common intrastate sources. There were two visits for which no source location was provided.

Table 32 Summary of vessel visits to Esperance Port from source locations

Source	Number of visits	Percentage of visits (%)
International	**124**	**65.6**
China	44	35.5
East USA	1	0.8
Hong Kong	5	4.0
India	3	2.4
Indonesia	15	12.1
Japan	11	8.9
Malaysia	4	3.2
New Zealand	2	1.6
Panama	1	0.8
Qatar	1	0.8
Saudi Arabia	1	0.8
Singapore	24	19.4
South Korea	5	4.0
Taiwan	5	4.0
Thailand	2	1.6
Domestic	**43**	**33.3**
Interstate	**20**	
Adelaide	4	20.0
Bell Bay	1	5.0
Geelong	2	10.0
Gladstone	1	5.0
Newcastle	1	5.0
Port Giles	1	5.0
Port Kembla	1	5.0
Port Lincoln	3	15.0
Port Pirie	2	10.0
Portland	3	15.0
Wallaroo	1	5.0
Intrastate	**43**	
Albany	10	23.3
Bunbury	6	14.0
Esperance	5	11.6
Fremantle	4	9.3
Geraldton	5	11.6
Kwinana	13	30.2
Other	**2**	**1.1**

14.2.2 Sociopolitical risk

Vessels visiting Esperance Port were registered from 27 different flag states and of these, 7 (25.9%) were listed as FOC states (Figure 107, see 'A'). The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. Vessels from these FOC states represented 52.4% of all visits to Esperance (Figure 107, see 'B'). The greatest proportion of FOC vessels came from Panama (48.5%, Figure 107, see 'C').

Of the 27 flag states, only6 (17.5% of total visits) have ratified the IMO BWM. However, further analysis revealed that two of these six were from FOC states. FOC states often ratify conventions but fail to have either the financial capacity or political will to enforce or implement the ratification. This potentially reduces the number of flag states that will adhere to the IMO BWM convention to 3.7% of total visits.

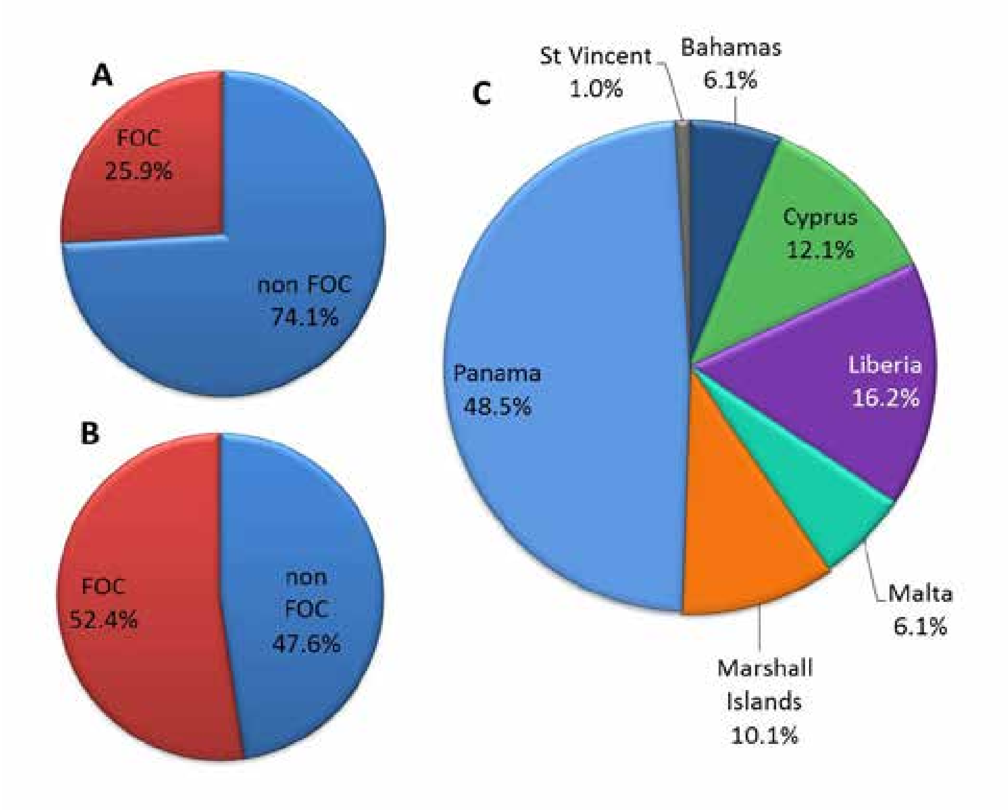


Figure 107 Percentage of FOC and non-FOC states entering Esperance Port (A). Percentage of vessel visits (%) by registry of FOC and non-FOC state entering Esperance Port (B). FOC states shown by country of registry and percentage (C)

The overall inoculation risk to Esperance Port was low as most vessels had a low risk rating, only visited once and stayed for a short time. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Additionally, over half of the vessels visiting Esperance port were registered from countries considered to be FOCs and very few of the total number of vessels were from flag states that had ratified the IMO BWM convention. This could indicate a greater propensity toward compromised environmental standards and hence vessel cleanliness, increasing the risk that an IMP might be present on the hull.

14.2.3 Infection and establishment likelihood

There were 39 IMP species present at LPOC locations of which 36 (92%) had temperature and salinity tolerances compatible with Esperance Port environs. All 36 compatible species were located at one or more of the international sources for vessels (Figure 108). For domestic LPOCs there were six species located interstate and three species located intrastate. *Crassostrea gigas* was from the most sources (15: international and domestic combined) (Figure 108). The next most common species were *Gymnodinium catenatum* and *Caulerpa taxifolia* (13 locations each) (Figure 108).

C. gigas (oyster) is a species that could thrive in Esperance and if it entered the 'wild', it could pose a significant threat to native oyster and mussel populations. *G. catenatum* (dinoflagellate) is not regarded as a vessel biofouling species, however it may be transported as a cyst on equipment such as ropes and cages or in sediment present on a vessel. The macroalgae *C. taxifolia* occurs as a native species in many parts of WA, however the invasive strain has been reported as a problem elsewhere around the globe.

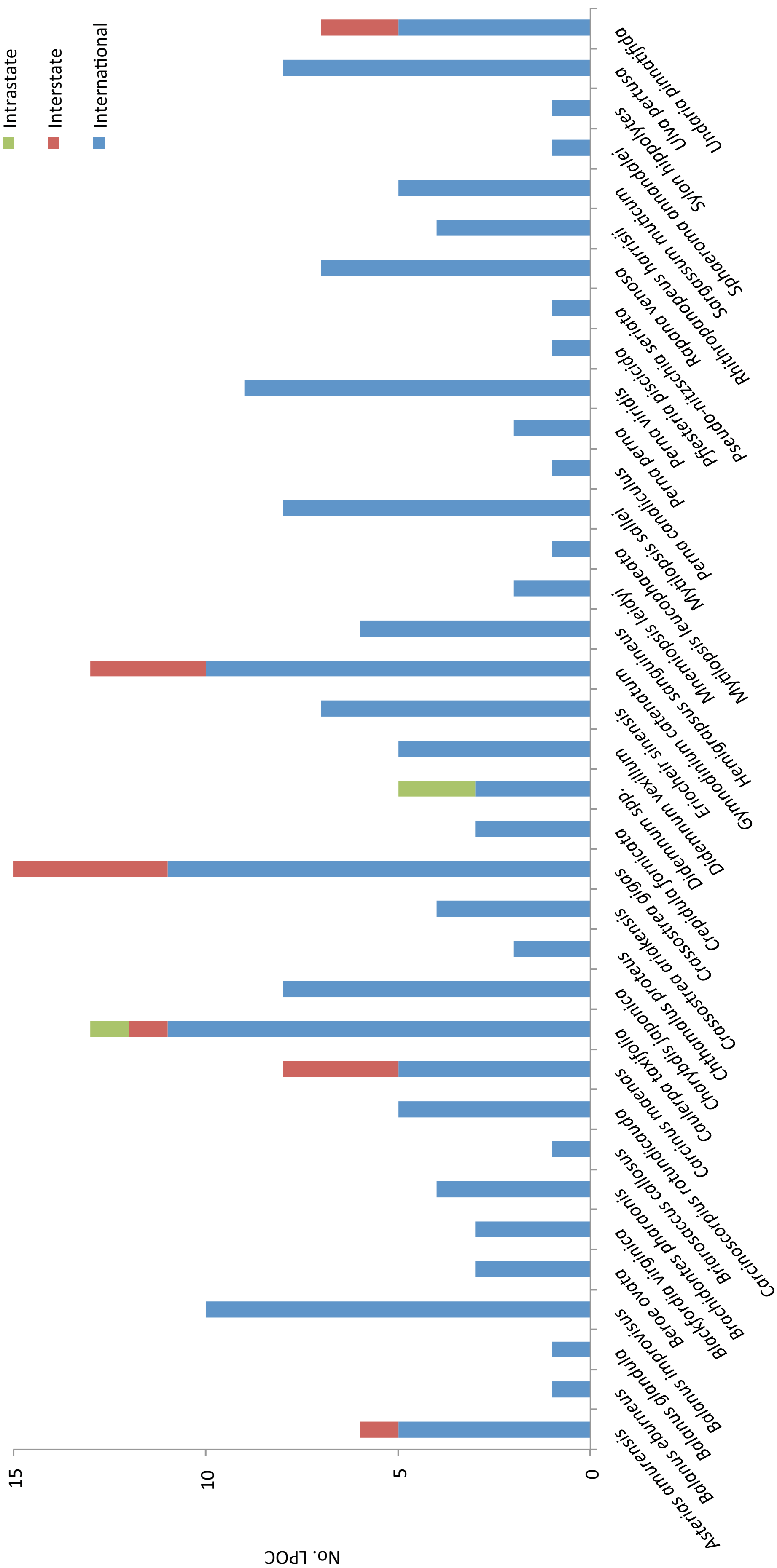


Figure 108 IMP species compatible with Esperance Port and the number of LPOCs (international, interstate and intrastate) at which they occur

There were 15 different international LPOCs that contained an IMP with either a high or moderate risk rating that was compatible with Esperance Port's environment. USA (east coast) had the greatest number of IMPs with 23 species, 12 of which had a high risk rating. Japan and China had the next greatest number of IMPs, with 14 and 11 high risk species, respectively (Figure 109).

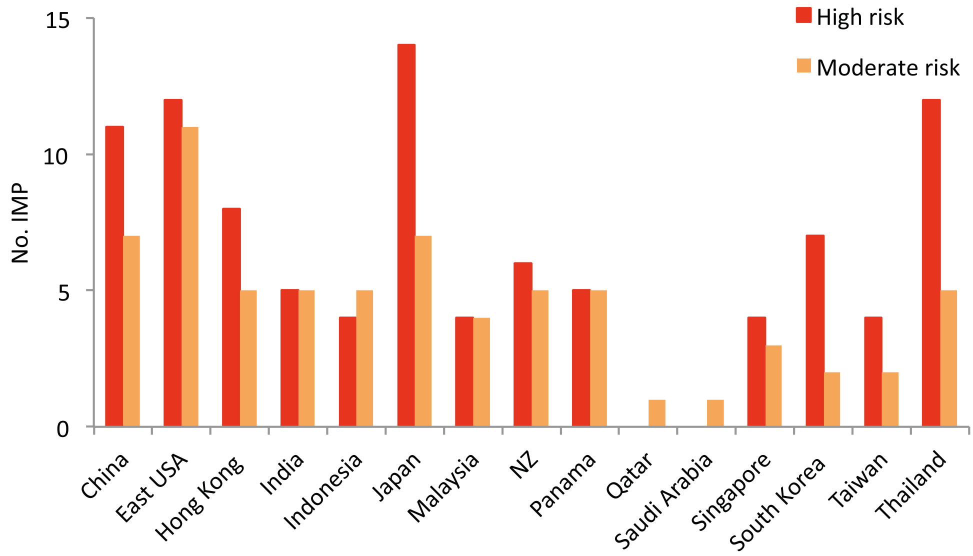


Figure 109 IMP species with a moderate or high risk rating, present at international LPOCs that were compatible with Esperance Port environs

When the cumulative effect of the number of vessel visits from an international LPOC and the number of compatible IMP present at that LPOC is considered, the greatest infection and establishment risk to Esperance Port was from China (Figure 110). LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 110. Selected IMPs from China that pose a risk to Esperance Port are shown pictorially in Figure 111.

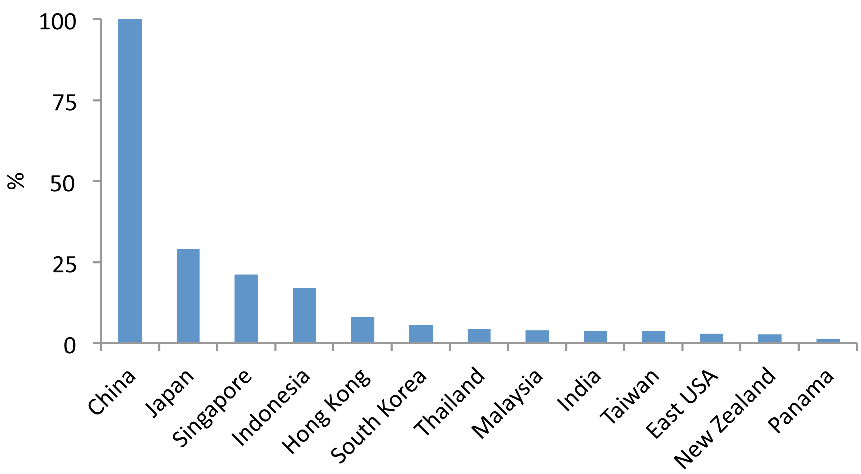


Figure 110 Ranking of the infection and establishment risk posed to Esperance Port by international LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (i.e. China 100%)

Figure 111 Map showing the proximity of China (red circle) to Esperance Port (yellow star) and the selected IMPs that pose the greatest risk to Esperance Port

IMP species were recorded at eight domestic LPOCs, five of which were interstate and three of which were intrastate (Table 33, Figure 112). Victorian sources had the greatest number of IMPs with a high risk. The port of Geelong had three species with a high risk and Portland had two species with a high risk (Table 33). When the cumulative effect of the number of vessels visits from a domestic LPOC and the number of compatible IMPs located at that LPOC is considered, Kwinana, Port Adelaide and Portland represented the greatest domestic infection and establishment risks to Esperance Port (Figure 112). Domestic LPOCs that had negligible relative infection and establishment risks (i.e. <1%) are not shown in Figure 112. Geelong also represented a considerable infection and establishment risk to Esperance Port. The domestic pest species that pose the greatest risk to Esperance Port included *Undaria pinnatifida* (algae from Victoria), *Carcinus maenas* (crab from Victoria and New South Wales) and *Asterias amurensis* (seastar from Victoria).

Table 33 Number of high and moderate risk IMPS present at Domestic (interstate and intrastate) LPOCs

LPOC domestic	High risk	Moderate risk
Interstate		
Port Kembla (New South Wales)	1	1
Adelaide (South Australia)	0	3
Port Lincoln (South Australia)	0	1
Geelong (Victoria)	3	1
Portland (Victoria)	2	1
Intrastate		
Fremantle	0	1
Geraldton	0	1
Kwinana	0	1

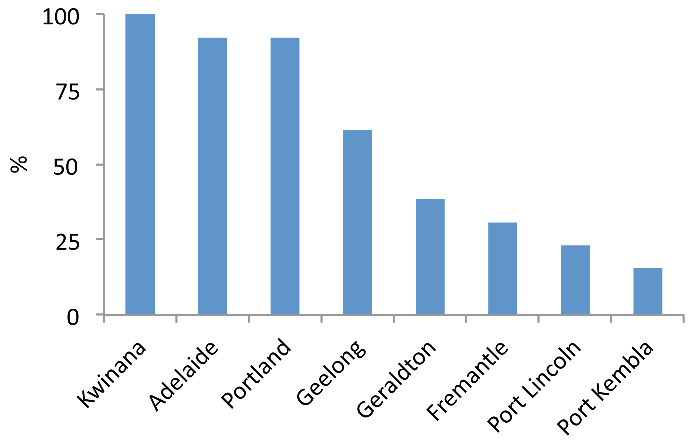


Figure 112 Ranking of the infection and establishment risk posed to Esperance Port by domestic LPOCs. Each LPOC value is a relative percentage of the largest LPOC value (i.e. Kwinana 100%).

There were 11 species from international and domestic sources that presented the greatest likelihood of infection establishment to Esperance Port. Three of the species, *Asterias amurensis* (sea star), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000). The remaining 8 species, although not listed in the top 100 worst, still pose a significant threat to Esperance Port for one or more of the following: the environment, sociocultural values, economic value or human health. Brief information on these species is provided in Table 34. For further information, images and references for these species please see Appendix 2.

Table 34 The impact rank and examples of impacts for the 11 species which presented the greatest likelihood of infection and establishment to Esperance Port

IMP species	Impact rank (M = medium, H = high)	Impacts
Asterias amurensis (sea star)	H	This is a voracious predator, known to outcompete native and commercial fish species. The Tasmanian scallop industry has reported losses of AU$1 million to their fishery as a result of the introduction of this sea star.
Eriocheir sinensis (crab)	H	Large economic costs following the introduction of this species have been reported (EUR€80 million). These costs arise from ongoing management requirements to stabilise river banks damaged by the crabs, losses to commercial fisheries (crab predation), installation of barriers and ramps to prevent further crab migration and population control methods.
Undaria pinnatifida (algae)	H	This is an extremely fast-growing algae with two forms of efficient reproduction that result in a competitive advantage over native species for space.
Balanus improvisus (barnacle)	H	This is a fast-growing species that can outcompete native species for space and foul aquaculture species and infrastructure resulting in higher maintenance costs.

IMP species	Impact rank (M = medium, H = high)	Impacts
Brachidontes pharaonis (mussel)	H	There is no impact information available for Brachidontes pharaonis (mussel) and the taxonomic status of the species is complex, as such the species is currently considered cryptogenic.
Mytilopsis sallei (mussel)	H	In the Great Lakes and Mississippi River region in the USA, *M. sallei* has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic/pelagic system, affected the food web structure and productivity at higher trophic levels.
Perna viridis (mussel)	H	This mussel can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure. Economic impacts arise from the mussels blocking water intake pipes and reducing efficiency of mechanical structures through heavy fouling. As this mussel is a filter feeder it can pose a hazard for shellfish poisoning (paralytic shellfish poison toxins).
Charybdis japonica (crab)	H	This is a highly aggressive crab and opportunistic omnivore, consuming mostly bivalves, crustaceans and polychaetes. This crab can outcompete native species for space and food. It can carry strains of the extremely virulent white spot baculovirus that can cause disease in other crustaceans.
Hemigrapsus sanguineus (crab)	H	This is an aggressive crab that can outcompete and displace native crabs and other native species thus altering ecosystem functioning.
Sargassum muticum (algae)	H	This algae is known to outcompete native species (e.g. algae and seagrass) for space and through exclusion (i.e. shading), it can heavily foul marine equipment, clog intake pipes, increase the rate of sedimentation as it slows the water flow (dense stands) and reduce the social amenity of an area (floating mats and through decay).
Ulva pertusa (algae)	H	Information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication.

15.0 Key findings by individual port

15.1 Wyndham Port

The overall inoculation risk to Wyndham Port was assessed as low to moderate. All vessels were rated as low risk, based on their operating and structural properties and included the following types: bulk carriers, cargo carriers, fisheries vessels, passenger vessels and tankers. Repeat visits from vessels made up over half of the total visits to Wyndham Port and some vessels stayed for a moderate length of time. Flag of vessel registry was identified as a key risk, as almost three-quarters of the vessels visiting Wyndham Port were registered from countries considered to be FOCs. There was a very high compatibility (82%) between the potential incoming marine pests and the environment of Wyndham Port. The greatest infection and establishment risk to Wyndham Port was Indonesia. Broome Port posed the greatest domestic infection and establishment risk to Wyndham Port. There were nine species identified as posing the greatest likelihood of infecting and establishing in Wyndham Port. These included *Caulerpa taxifolia* (clone strain of the macroalgae) which is listed in the top 100 worst invasive species worldwide. The remaining eight species are *Balanus improvisus* (barnacle), *Crassostrea gigas* (oyster), *Carcinoscorpius rotundicauda* (horseshoe crab), *Charybdis japonica* (crab), *Ulva pertusa* (algae), *Gymnodinium catenatum* and *Didemnum perlucidum* (colonial ascidian).

15.2 Broome Port

The overall inoculation risk to Broome Port was moderate, as a large percentage of the vessels visiting had a moderate risk rating, they stayed for extended periods and were repeat visitors. The vessel types with a moderate risk rating included barges, commercial fishing vessels, research vessels and tugs. Repeat visits made up over 60% of the total visits to Broome Port. A small percentage of the vessels entering Broome Port were registered from countries considered to be FOCs. No analysis of the likelihood of infection and establishment was possible from the available data.

15.3 Port Hedland Port

The overall inoculation risk to Port Hedland Port was low to moderate. Based on their operating and structural profiles, the majority of vessels were rated as low risk, and included the following vessel types: bulk carriers, cargo carriers, passenger vessels and tankers. Vessels stayed only for short periods but a moderate number of these vessels were repeat visitors. Flag of registry was identified as a key risk, as almost two-thirds of the vessels visiting Port Hedland Port were registered from countries considered to be FOCs. There was a moderate level of compatibility (47%) between the potential incoming marine pests and the environment of Port Hedland Port. The greatest infection and establishment risk to Port Hedland Port was from China. Dampier Port posed the greatest domestic risk. There were six species identified as posing the greatest likelihood of infecting and establishing in Port Hedland Port. One of these species, *Carcinus maenas* (crab), is listed in the top 100 worst invasive species worldwide. The remaining five species are *Undaria pinnatifida* (algae), *Balanus improvisus* (barnacle), *Brachidontes pharaonis* (mussel), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel) and *Hemigrapsus sanguineus* (crab).

15.4 Dampier Port

The overall inoculation risk to Dampier Port was assessed as moderate to high. Based on their operating and structural profiles, the majority of vessels were classed as moderate risk and included the following vessel types: barges, commercial fishery vessels, research vessels and tugs. These vessels stayed for extended periods and over half visited repeatedly. A quarter of the vessels visiting were registered from countries considered to be FOCs. There was a high compatibility (74%) between the potential incoming marine pests and the environment of Dampier Port. The greatest infection and establishment risk to Dampier Port were the international locations of China and Japan. Geelong Port posed the greatest domestic risk. There were 12 species identified as posing the greatest likelihood of infecting and establishing in Dampier Port. Three of these species, *Carcinus maenas* (crab), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae), are listed in the top 100 worst invasive species worldwide. The remaining nine species are *Balanus improvisus* (barnacle), *Crepidula fornicata* (limpet), *Brachidontes pharaonis* (mussel), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel), *Hemigrapsus sanguineus* (crab), *Rhithropanopeus harrisii* (crab), *Sargassum muticum* (algae) and *Ulva pertusa* (algae).

15.5 Useless Loop Port

The overall inoculation risk to Useless Loop Port was low as all vessels had a low risk rating (bulk carriers, cargo carriers and tankers), visited only once and stayed for short durations. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Flag of registry was identified as a key risk, as almost two-thirds of the vessels visiting Useless Loop Port were registered from countries considered to be FOCs. There was a moderate level of compatibility (66%) between the potential incoming marine pests and the environment of Useless Loop Port. The greatest infection and establishment risk to Useless Loop Port were the international locations of Japan and Malaysia, while Port Adelaide posed the greatest domestic risk. There were 10 species identified as posing the greatest likelihood of infecting and establishing in Useless Loop Port. Three of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide. The remaining seven species are *Balanus improvisus* (barnacle), *Brachidontes pharaonis* (mussel), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel), *Hemigrapsus sanguineus* (crab), *Rhithropanopeus harrisii* (crab) and *Ulva pertusa* (algae).

15.6 Geraldton Port

The overall inoculation risk to Geraldton Port was low, as the majority of vessels had a low risk rating, visited only once and stayed for short durations. These vessel types included bulk carriers, cargo carriers, offshore support vessels, passenger vessels and tankers. The fact that the majority were low risk does not negate the biosecurity risk these vessels may pose, as all vessels are susceptible to biofouling. Flag of registry was identified as a key risk as over half of the vessels visiting Geraldton Port were registered from countries considered to be FOCs. There was a very high compatibility (80%) between the potential incoming marine pests and the environment of Geraldton Port. The greatest infection and establishment risk to Geraldton Port was China. Fremantle and Kwinana Ports posed the greatest domestic risk. There were 12 species identified as posing the greatest likelihood of infecting and establishing in Geraldton Port. Four of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide. The remaining eight species are *Balanus improvisus* (barnacle), *Brachidontes pharaonis* (mussel), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel), *Charybdis japonica* (crab), *Hemigrapsus sanguineus* (crab), *Sargassum muticum* (algae) and *Ulva pertusa* (algae).

15.7 Fremantle Port

The overall inoculation risk to Fremantle Port was assessed as moderate to high. Based on their operating and structural profiles, the majority of vessels had a moderate or high risk rating, and included the following vessels types: barges, commercial fishing vessels, research vessels, tugs, dredges, mobile offshore drilling units and navy vessels. These moderate and high risk vessels stayed for extended durations. Flag of registry was identified as a risk as just under half of the vessels visiting Fremantle Port were registered from countries considered to be FOCs. There was a high compatibility (79%) between the potential incoming marine pests and the environment of Fremantle Port. The greatest infection and establishment risks to Fremantle Port were from the international locations of Singapore and Indonesia. Port Adelaide posed the greatest domestic risk. There were 12 species identified as posing the greatest likelihood of infecting and establishing in Fremantle Port. Four of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), *Caulerpa taxifolia* (clone strain macroalgae) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide. The remaining eight species are *Undaria pinnatifida* (algae), *Balanus improvisus* (barnacle), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel), *Crassostrea gigas* (oyster), *Carcinoscorpius rotundicauda* (horseshoe crab), *Charybdis japonica* (crab), *Ulva pertusa* (algae) and *Didemnum perlucidum* (colonial ascidian). Please note that *D. perlucidum* is already known to occur in Fremantle Port and surrounding waters.

15.8 Bunbury Port

The overall inoculation risk to Bunbury Port was low, as the majority of vessels had a low risk rating, visited only once and stayed for a short time. These vessel types included bulk carriers, cargo carriers, offshore support vessels, passenger vessels and tankers. The fact that the majority of vessels were low risk does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Flag of registry was identified as a risk as over half of the vessels visiting Bunbury Port were registered from countries considered to be FOCs. There was a very high compatibility (83%) between the potential incoming marine pests and the environment of Bunbury Port. The greatest infection and establishment risk to Bunbury Port was from Japan while Port Adelaide posed the greatest domestic risk. There were 14 IMP species identified as posing the greatest likelihood of infecting and establishing in Bunbury Port. Four of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide. The remaining eight species are *Balanus improvisus* (barnacle), *Crepidula fornicata* (limpet), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel), *Charybdis japonica* (crab), *Hemigrapsus sanguineus* (crab), *Rhithropanopeus harrisii* (crab), *Didemnum vexillum* (colonial ascidian), *Sargassum muticum* (algae) and *Ulva pertusa* (algae).

15.9 Albany Port

The overall inoculation risk to Albany Port was low, as the majority of vessels had a low risk rating (bulk carriers, cargo carriers, tankers and passenger vessels), visited only once and stayed for short durations. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Flag of registry was identified as a risk as over half of the vessels visiting Albany Port were registered from countries considered to be FOCs. There was a very high compatibility (85%) between the potential incoming marine pests and the environment of Albany Port. The greatest infection and establishment risk to Albany Port was from Japan. Port Adelaide posed the greatest domestic risk. There were 15 species identified as posing the greatest likelihood of infecting and establishing in Albany Port. Five of the species, *Asterias amurensis* (sea star), *Carcinus maenas* (crab), *Caulerpa taxifolia* (clone strain of the macroalgae), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide. The remaining 10 species are *Balanus improvisus* (barnacle), *Crepidula fornicata* (limpet), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel), *Charybdis japonica* (crab), *Hemigrapsus sanguineus* (crab), *Rhithropanopeus harrisii* (crab), *Didemnum vexillum* (colonial ascidian), *Sargassum muticum* (algae) and *Ulva pertusa* (algae).

15.10 Esperance Port

The overall inoculation risk to Esperance Port was low, as all vessels were rated as low risk (bulk carriers, cargo carriers, passenger vessels and tankers), visited only once and stayed for a short time. However, this does not negate the biosecurity risk these vessels may pose as all vessels are susceptible to biofouling. Flag of registry was identified as a risk as over half of the vessels visiting Esperance Port were registered from countries considered to be FOCs. There was a very high compatibility (92%) between the potential incoming marine pests and the environment of Esperance Port. The greatest infection and establishment risk to Esperance Port was from China. Kwinana, Port Adelaide and Portland Port all posed the greatest domestic risk to Esperance Port. There were 11 species identified as posing the greatest likelihood of infecting and establishing in Esperance Port. Three of the species, *Asterias amurensis* (sea star), *Eriocheir sinensis* (crab) and *Undaria pinnatifida* (algae) are listed in the top 100 worst invasive species worldwide. The remaining 8 species are *Balanus improvisus* (barnacle), *Brachidontes pharaonis* (mussel), *Mytilopsis sallei* (mussel), *Perna viridis* (mussel), *Charybdis japonica* (crab), *Hemigrapsus sanguineus* (crab), *Sargassum muticum* (algae) and *Ulva pertusa* (algae).

16.0 Limitations and gaps

The authors acknowledge that available pest species distribution information is limited. All locations examined may not monitor for, or record marine pest species. Further at many locations examined the species in question may not be classed as pests and not readily identified in searches. As there was no way to account for this, it was assumed that if a species was not recorded for a location then the species did not exist at that location. Conversely if a species was recorded at a site within a country then the species was deemed to exist (or have the potential to exist) across the whole country.

It is acknowledged that there are many contributing factors that need to be met for a vessel to become infected with a marine pest species. However, for the purpose of this analysis the authors assumed that every vessel from a location with a listed IMP was infected.

Temperature and salinity were the only environmental parameters used in this analysis. Temperature and salinity data was readily available for all locations examined and has been used in other similar analyses (see Clarke *et al.* 2004). It is acknowledged that other environmental parameters may provide additional rigour to this type of analysis however this data was not consistently and readily available.

17.0 Conclusions

Western Australia's (WA) coastline is extensive spanning over 20 781 linear km and offering a wide variety in habitats from tropical to temperate. Given the diversity of habitats available conditions would be suitable for introduced marine pests (IMPs) to survive, grow and reproduce somewhere in the State. To date WA has remained free of any serious marine pest incursions and there have been no documented impacts of IMPs on WA's marine environment. However there remains a real threat to its environment, social amenity and economy from a serious IMP incursion. Vessels are the key vector for IMP translocation around the world, as IMPs can be transported as hull fouling or within ballast water. According to Lloyds shipping data there were just under 53 000 commercial shipping visits to WA in the three year period from 2010-2012. It is this significant number of vectors entering our marine waters that make WA susceptible to an IMP incursion.

Determining the likelihood of an IMP introduction from vessels to a location can inform future planning at the WA bioregional or port level. This document analysed the likelihood of a marine pest inoculating, infecting and establishing in WA's aquatic resources from commercial shipping at the bioregional and port level. It identified the following key risks and future management outcomes:

1. Increased understanding of the risks posed to recipient ports from vessel and donor ports:

    1.1 This analysis identified where (i.e. last port of call (LPOC)) the greatest risk to a WA port came from. This knowledge would allow managers to identify high risk locations based on the perceived vessel inoculation risks. The identification that certain regions around the globe may pose a greater risk than others to a recipient WA port would enable port managers to better manage potential biosecurity risks. For example vessels from high risk ports could be allocated to particular berths which are monitored for IMPs. Furthermore monitoring of these high risk berths with the highest risk of IMP introduction could potentially reduce sampling costs and increase the likelihood of detection.

    1.2 This analysis identified the IMP most likely to infect a recipient port and in doing so provided a 'watch list' that is port-specific. A further application of this information could be to tailor monitoring techniques to detect the most likely IMPs. This may reduce redundant sampling and hence costs and at the same time increase detection sensitivity. For example if China was identified as presenting the highest infection and establishment risk to Port Hedland Port and the main compatible IMPs from China were crabs, monitoring techniques employed could predominantly target crab species.

    1.3 This analysis highlighted the potential risk posed to a port from the management standards of vessels. The assumption was that if the state of registry was a flag of convenience (FOC), the overall vessel management standards may be lower, thus the vessel may have a greater likelihood of translocating an IMP. This information could be used to further inform vessel risk assessments.

2. Results from this analysis could be used to inform the process for managing vessel movements around WA.

    2.1 In particular knowing where the greatest risk of inoculation to a specific WA port is coming from, internationally, interstate or intrastate could flag vessels from that location as potential targets for inspection and assessment.

2.2 This analysis has given some understanding of the connectivity between ports: For example, an IMP might be initially brought into a WA port via international commercial shipping, but the IMP is further dispersed to other WA ports via intrastate commercial vessel movements.

17.1 Recommendations

It was evident from the data provided to the Department that there is little consistency across the ports as to what information is collected relating to a vessel's visit. For this current analysis, a minimum of seven pieces of vessel related information were required:

1. vessel name
2. Lloyd's number or flag state
3. date of arrival
4. time of arrival
5. date of departure
6. time of departure
7. LPOC.

The authors noted that some ports do not collect LPOC data. It is acknowledged that this data may not be relevant to the day-to-day functioning of a port; however it is vital if any analysis of the biosecurity risk of potential IMPs coming into the port is to be undertaken. It is therefore strongly recommended that LPOC information be routinely gathered by all ports. Collecting this information would allow for a regular assessment of the likelihood of infection and establishment of an IMP to a port, and identify potential IMPs most likely to pose a risk to the port. This data could also be used by the ports to identify vessels from LPOCs that pose a significant inoculation, infection and establishment risk which they could potentially manage through berthing and mooring practices.

For future analysis, the inclusion of a vessel's next port of call (NPOC) would assist in developing a better understanding of the connectivity between ports in WA. This would provide the potential to predict future routes of IMP translocations between WA ports or bioregions that could then be managed by implementing management strategies, such as vessel inspections, prior to the vessel departing the 'infected' port.

The significant expansion of port developments in WA, particularly evident in the North Coast bioregion, will affect the numbers and types of commercial vessels coming into WA and hence the risk posed by IMPs. It is therefore suggested that this analysis be repeated initially at a minimum of every 4 – 5years in order to more accurately reflect the likelihoods of inoculation, infection and establishment of marine pests to the WA aquatic resources bioregions and ports.

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Appendix 1. DoF IMP list (as of 22 August 2012)

This list was used for the analysis. It shows the values allocated for the different risks (environment, economy, sociopolitical and human health) and the overall rating and impact rank for each IMP species.

Species	Risk				Overall rating	Impact rank
	Environ-ment	Economy	Socio-political	Human health		
Charybdis japonica	3	5		5	13	H
Sargassum muticum	5	5	3		13	H
Eriocheir sinensis	3	3	3	3	12	H
Perna perna	3	1	3	5	12	H
Perna viridis	3	1	3	5	12	H
Balanus improvisus	3	5		3	11	H
Asterias amurensis	5	3	1		9	H
Balanus eburneus	5	1		3	9	H
Crassostrea virginica	3	3		3	9	H
Didemnum vexillum	5	3	1		9	H
Mytilopsis sallei	3	5	1		9	H
Ulva pertusa	3	3	3		9	H
Carcinus maenas	5	3			8	H
Mytilopsis leucophaeata	3	5			8	H
Cliona thoosina	3	3	1		7	H
Brachidontes pharaonis	3	3			6	H
Crepidula fornicata	3	3			6	H
Hemigrapsus sanguineus	3	3			6	H
Rhithropanopeus harrisi	3	3			6	H
Undaria pinnatifida	5	1			6	H
Crassostrea ariakensis	1	1		3	5	M
Mnemiopsis leidyi	1	3	1		5	M
Blackfordia virginica	1	1	1	1	4	M
Caulerpa taxifolia (aquarium strain)	1	3			4	M
Crassostrea gigas	3	1			4	M
Didemnum spp. *(perlucidum)*	3	1			4	M
Gymnodinium catenatum	1			3	4	M
Rapana venosa	3	1			4	M
Solidobalanus fallax	3	1			4	M
Sphaeroma annandalei	3	1			4	M
Anomia nobilis	3				3	M
Balanus glandula	3				3	M
Beroe ovata	1	1	1		3	M
Briarosaccus callosus	3				3	M
Callinectes sapidus	3				3	M
Carcinoscorpius rotundicauda			3		3	M

Species	Risk				Overall rating	Impact rank
	Environ-ment	Economy	Socio-political	Human health		
Chthamalus proteus	3				3	M
Perna canaliculus	3				3	M
Pfiesteria piscicida	1	1		1	3	M
Polydora nuchalis	3				3	M
Pseudo-nitzschia seriata	1	1	1		3	M
Sylon hippolytes	3				3	M
Anadara demiri	1	1			2	L
Anguillicola crassus	1	1			2	L
Avrainvillea amadelpha	1	1			2	L
Chaetoceros concavicornis	1	1			2	L
Chaetoceros convolutus	1	1			2	L
Chattonella antiqua	1	1			2	L
Dinophysis norvegica	1	1			2	L
Hemigrapsus takanoi/penicillatus	1	1			2	L
Loxothylacus panopaei	1	1			2	L
Marenzelleria spp.	1	1			2	L
Mytella charruana	1	1			2	L
Pseudochattonella farcimen	1	1			2	L
Pseudodiaptomus marinus	1	1			2	L
Sabella spallanzanii	1	1			2	L
Siganus luridus	1	1			2	L
Siganus rivulatus	1	1			2	L
Tridentiger barbatus	1	1			2	L
Tridentiger bifasciatus	1	1			2	L
Acartia tonsa	1				1	L
Alexandrium catenella	1				1	L
Alexandrium minutum	1				1	L
Alexandrium monilatum	1				1	L
Alexandrium tamarense	1				1	L
Ampelisca abdita	1				1	L
Bonnemaisonia hamifera	1				1	L
Caulerpa racemosa var. cylindracea	1				1	L
Codium fragile fragile	1				1	L
Corbula (Potamocorbula) amurensis	1				1	L
Corethron criophilum	1				1	L
Crangonyx floridanus	1				1	L
Dikerogammarus villosus	1				1	L
Ensis directus	1				1	L
Fucus evanescens	1				1	L
Gammarus tigrinus	1				1	L

Species	Risk				Overall rating	Impact rank
	Environ-ment	Economy	Socio-political	Human health		
Gelliodes fibrosa	1				1	L
Geukensia demissa	1				1	L
Grateloupia doryphora	1				1	L
Grateloupia turuturu	1				1	L
Hydroides dianthus	1				1	L
Maoricolpus roseus	1				1	L
Musculista senhousia	1				1	L
Mya arenaria				1	1	L
Neogobius melanostomus	1				1	L
Pachygrapsus fakaravensis	1				1	L
Tortanus dextrilobatus	1				1	L
Varicorbula (Corbula) gibba	1				1	L
Womersleyella setacea	1				1	L

Appendix 2. Species information

Asterias amurensis Northern Pacific Seastar

Listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000)

Synonyms: *Allasterias rathbuni nortonens*, *Allasterias rathbuni* var. *anom, Allasterias rathbuni* var. *nort*, *Asterias amurensis f. acervispinis*, *Asterias amurensis f. flabellifera*, *Asterias amurensis f. gracilispinis*, *Asterias amurensis f. latissima*, *Asterias amurensis f. robusta*, *Asterias anomala, Asterias nortonensis, Asterias rubens, Asterias pectinata* and *Parasterias albertensis*.

Figure 113 Photograph of *A. amurensis* by Wikimedia Commons, available from Wikipedia

Asterias amurensis is a relatively large seastar, growing to a maximum size of 40 – 50 cm in diameter. It has a small central disc and five distinct arms that taper to pointed, often upturned, tips. Small jagged-edged spines occur irregularly over the entire body. On the underside of the animal, spines line the groove in which the tube feet lie. These tube feet join at the mouth in a fan-like shape. The underside is yellow in colour, however the upper surface may have some purple or red pigmentation (Figure 113).

The seastar *A. amurensis* is a voracious feeder, preferring mussels, scallops and clams, although it will eat almost anything it can find, including dead fish and fish waste (Ross *et al.* 2002; 2003). In its native range of Japan during boom times, this seastar has been known to negatively impact commercial shellfish industries resulting in losses in the AUS$ millions (Goggin 1998). In Australia, *A. amurensis* has been shown to have a significant negative impact on bivalve populations, especially those that live on or near the sediment surface (Ross *et al.* 2003).

A. amurensis was first collected in Tasmania in 1986. Subsequently, specimens have been collected in Port Phillip Bay (Victoria), the population size of which was 150 million in 2000 (Parry & Cohen 2001). Attempts at eradicating *A. amurensis* from Port Phillip Bay, even when in low densities, have, to date, been unsuccessful (Dommisse & Hough 2004). The seastar has been reported to have resulted in an AUS$1million loss to the Tasmanian scallop industry in 2000 (Dommisse and Hough 2002).

Balanus improvisus Ivory Barnacle

Synonym: *Amphibalanus improvisus*

Figure 114 *Balanus improvisus*, photograph courtesy of Robert Hilliard, Intermarine

Balanus improvisus is a barnacle with a white, conical to cylindrical shaped shell (depending on the extent of crowding) characterised by smooth plates (NIMPIS 2012) (Figure 114). A mature shell has a diameter of up to 17 mm and a height of up to 10 mm. The shell also has a thin, diamond-shaped and slightly toothed opening. *B. improvisus* is a filter/suspension feeder, consuming zooplankton and phytoplankton from the water column.

The barnacle has a cosmopolitan distribution and is found in temperate and tropical parts of the Atlantic Ocean, the Arctic Ocean, the Baltic Sea, the North Sea, the Mediterranean Sea and the Black Sea (Chan 2013). It is a biofouling species and has been recorded as causing biofouling on vessels in Australian waters (J. McDonald pers. comm.).

In a new area, this species can dominate and outcompete native species for available habitat, alter food webs and foul aquaculture species (mussels and oysters) and water intake pipes (Leppäkoski 1999; Olenin & Leppäkoski 1999; Kotta *et al.* 2006).

Brachidontes pharaonis

Synonyms: *B. variabilis, B. ustulatus* and *B. semistriatus*

There is much confusion surrounding the correct nomenclature of this species and its synonyms. However, *Brachidontes pharaonis* is the currently accepted species name.

Figure 115 *Brachidontes pharaonis*, photograph by Marine Biosecurity Research & Monitoring

Brachidontes pharaonis is a small (40 mm) brown-black coloured mussel (Figure 115). *B. pharaonis* is a long recognised component of the Australian mytilid community; however as the species complex is taxonomically challenging, the Western Australian Museum (Kirkendale & Cosgrove-Wilke 2013) suggests that:

> *To reflect the uncertainty regarding the taxonomic status of this species complex, which may contain species that will be considered introduced, as well as species within that may be regarded as native following close research, it is recommended that* B. pharaonis *(and synonymized taxa) be considered cryptogenic at present. Cryptogenic status calls for a clear and urgent need for additional (and in this case ideally genetic) work, to determine type localities and clarify identity of component taxa.*

Carcinus maenas European Green Shore Crab

Listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000)

Synonyms: *Cancer granaries, Cancer granulatus, Cancer maenas, Cancer pygmeus, Cancer rhomboidalis, Cancer viridis, Carcinus granulatus* and *Megalopa montagui*

Figure 116 Photograph of *Carcinus maenas* (European Green Shore Crab) by Luis Miguel Bugallo Sánchez, available from Wikipedia

The European Green Shore Crab, *Carcinus maenas*, is a small crab that grows to a carapace width of between 60 mm and 80 mm (Figure 116). They are typically dark green to brown in colour but can often vary, having a pale orange underside or a dominant red colouring when moulting is delayed during reproductive phases.

C. maenas is a voracious predator, consuming predominantly molluscs and bivalves, but also a range of other organisms including crustaceans, annelids, fish and algae. Its impacts have been noted to affect both population size and structure of many species in non-native regions, for example native clams and crab species (Grosholz *et al.* 2000; McGaw *et al.* 2011).

It has had significant economic impacts on fisheries, with its greatest documented impact being upon bivalve and mollusc commercial fisheries. Predation alone is thought to have created a USD$22.6 million per year loss to the shellfish industry on the east coast of the USA and that loss is projected to increase (Lovell *et al.* 2007). Lafferty & Kuris (1996) estimated that the potential total economic value threatened by the invasive green crab could potentially reach USD$43.7 million.

Specimens have also been recorded in Port Phillip Bay and South Australia. *C. maenas* is also present in Tasmania (for approximately 20 years) where it has been found to significantly negatively affect commercial bivalve species (*Fulvia tenuicostata* and *Katelysia rhytiphoraI*) (Ross *et al.* 2004). Genetic testing indicates that the Tasmanian populations originated from southern Australia, most likely transported via shipping vectors (Bagley & Geller 2000). A single, mature male specimen was also recorded at Blackwall Reach in the Swan River, WA, in 1965 (Zeilder 1997). Extensive sampling in the Swan River and adjacent water bodies by the DoF in 2007 failed to find any *C. maenas* (McDonald & Wells 2009). Additional sampling by the department in 2011 and 2012 along the lower Swan River, including four sites at Blackwall Reach, also failed to capture any *C. maenas*.

Caulerpa taxifolia (invasive strain)

Listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000)

Synonym: *Fucus taxifolius*

Figure 117 *Caulerpa taxifolia*, photograph by Rachel Woodfield, Merkel & Associates, Inc. Bugwood.org

Caulerpa taxifolia is a green alga endemic to tropical and subtropical regions around the world, including parts of WA (Figure 117). This endemic species is recorded to have a distribution running north from the Montebello Islands, WA, around to Queensland (Huisman 2000). However, there is a clone species that was developed for the aquarium trade. This species is the invasive strain. For the purpose of this report, the term *C. taxifolia* will be used to refer to the invasive strain.

Caulerpa taxifolia is a fast-growing marine alga that has colonised various areas outside its natural range. *C. taxifolia* was first identified outside its natural range near Monaco in the Mediterranean Sea in 1984. By the end of 2000, the alga had covered approximately 131 km^2 of seafloor in the Mediterranean (Meinesz *et al.* 2001). It has since colonised thousands of hectares in the Mediterranean from France to Croatia (although some populations have experienced dieback in recent years) and it has also colonised two locations in California.

The invasive nature of *C. taxifolia* has raised concerns as it has the potential to grow rapidly, alter marine habitats and affect biodiversity. It can potentially invade seagrass beds (Ceccherelli & Cinelli 1999), modify organic and inorganic components of the sediment (Chisholm & Moulin 2003) and threaten biodiversity (Meinesz *et al.* 2001).

C. taxifolia has been identified in New South Wales and South Australia. The *C. taxifolia* incursion of West Lakes in Adelaide is one of only two successful eradications of IMPs in Australia. The entire 4 km length of the water body was isolated from Port River and turned from a marine to a freshwater environment by diverting a creek into a stormwater system. Although this method killed the alga in the lake, the population in Port River remained viable and has continued to spread.

Carcinoscorpius rotundicauda Mangrove Horseshoe Crab

Figure 118 Photograph of *Carcinoscorpius rotundicauda* (mangrove horseshoe crab) by Wikimedia Commons, available from Wikipedia

This species occurs only in Asia around the Indo-West Pacific region where the climate is tropical or subtropical (Chiu & Morton 2003). These horseshoe crabs can be found throughout the south-east Asia region in shallow waters with soft, sandy bottoms or extensive mud flats (Lim *et al.* 2001). The mangrove horseshoe crab is bentho-pelagic, spending most of its life close to or at the bottom of brackish, swampy water habitats, such as mangroves (Lim *et al.* 2001) (Figure 118). Despite its name, this animal is not a crab, it is more closely related to the arachnids.

While listed by the Australian Government Department of Agriculture as a species of concern and likely to do harm, there is no clear evidence of this species posing a pest risk. The only documented detection of this species as introduced was one instance in New Zealand in 1910 (Ahyong & Wilkens 2011). While acknowledging the data needs updating, this species is currently listed on the IUCN Red List of Threatened Species (IUCN 2013).

Crassostrea gigas **Pacific Oyster**

Synonyms: *Ostrea gigas, Ostrea laperousi, Ostrea talienwhanensis* and *Crassostrea angulate*

Figure 119 Photograph of *Crassostrea gigas*, by David Monniaux, available from Wikipedia

Crassostrea gigas is an oyster that can reach up to 20 – 30 cm. Their shells are very sharp, with large, irregular radial folds, and the two halves are unequal in size (Figure 119). The oyster is a suspension/filter feeder that cements itself to hard substrata.

C. gigas has the potential to smother marine life, exclude species, hybridise with other oyster species and alter ecosystems and destroy habitats, including their social amenity (Eno *et al.* 1997; AMCS Bulletin 1998).

C. gigas has been deliberately introduced to locations – virtually worldwide – as an aquaculture species. Numerous attempts have been made to introduce this species in Australia and there are currently populations in Tasmania, Victoria, South Australia and New South Wales. In New South Wales, the oyster was introduced into the seed production area of Port Stephens. However, in 1985 the species was declared a noxious fish by the New South Wales Agriculture and Fisheries Department as it was found to be outgrowing the native rock oyster *Saccostrea glomerata* (syn *S. commercialis*). This led to eradication attempts, all of which were unsuccessful. *C. gigas* is now a cultivated species in New South Wales and Tasmania. In Tasmania, the industry is estimated to have a 'farm gate' value of AUS$24 million (Oysters Tasmania 2013).

Charybdis japonica **Asian Paddle Crab**

Synonyms: *Charybdis peitchihiliensis, Charybdis sowerbyi* and *Goniosoma japonica*

Figure 120 Photograph of *Charybdis japonica*, the Asian paddle crab, by Wikimedia Commons, available from Wikipedia

Charybdis japonica is a highly aggressive crab that typically grows up to a carapace width of 12 cm (Figure 120). *C. japonica* is an opportunistic omnivore, consuming mostly bivalves, crustaceans and polychaetes. Fowler (2011) found that they have a preference for smaller sessile or slow-moving invertebrate prey, but have also been recorded to be a significant predator of juvenile flounder in Japan (Sudo *et al.* 2008). Factors such as extended larval duration, rapid growth to maturity, high fecundity, aggressive nature, broad diet and large environmental tolerances have been attributed to *C. japonica*'s successful invasion into New Zealand (Fowler 2011).

C. japonica is a known carrier of the White Spot Syndrome Virus (WSSV) a highly lethal and contagious virus known to infect prawns, crabs and lobsters, thus threatening both crustacean fisheries and farming industries (Maeda *et al.* 1998). The virus caused the collapse of the Chinese shrimp farming industry in 1993 and crippled the shrimp farming industries of Mexico and South America.

In 2000, a recreational fisher found a single mature male in the Port River, Adelaide, using a hoop net. Subsequent surveys of the region in 2001, 2007 and 2009 did not find any additional specimens and there have been no other subsequent reports (Wiltshire 2010). *C. japonica* has been detected in two estuaries in WA. In late 2010, a single male specimen of *C. japonica* was discovered in the Peel Harvey Estuary and in 2012, three specimens were detected in the Swan River (Bridgwood & Hourston 2010; Fletcher and Santoro 2013). All detections were from recreational fishers undertaking crabbing. Despite repeat extensive surveys in both locations, no further specimens have been captured.

Crepidula fornicata American Slipper Limpet

Synonyms: *Crepidula densata, Crepidula maculate, Crepidula mexicana, Crepidula nautiloides, Crepidula roseae, Crepidula violacea, Crepidula virginica, Crypta nautarum* and *Patella fornicata*

Figure 121 Photograph of *Crepidula fornicata* the American slipper limpet by Wikimedia Commons, available from Wikipedia

Crepidula fornicata has a smooth, calcareous, glossy shell with a small, depressed spire and a large, final whorl that can grow up to 50 mm long and 25 mm high (Figure 121). The colour of the shell varies from yellow to red-brown with dark streaks and there is no operculum. The shells tend to occur in groups, with multiple animals stacked one on top of the other creating curved chains. *C. fornicata* is a suspension feeder.

C. fornicata is known to increase sedimentation rates, creating muddy, anoxic conditions that negatively impact endofauna, outcompete and negatively impact other species (e.g. coralline algae, scallop) and negatively modify the composition and structure of benthic communities (Grall & Hall-Spencer 2003; Le Pape *et al.* 2004; Blanchard 2009).

In the Bay of Mont Saint Michel, (France), where the limpet was previously accidentally introduced, it was found to have increased by 50% (approximately 9000 t y-1) in eight years (Blanchard 2009).

Didemnum perlucidum

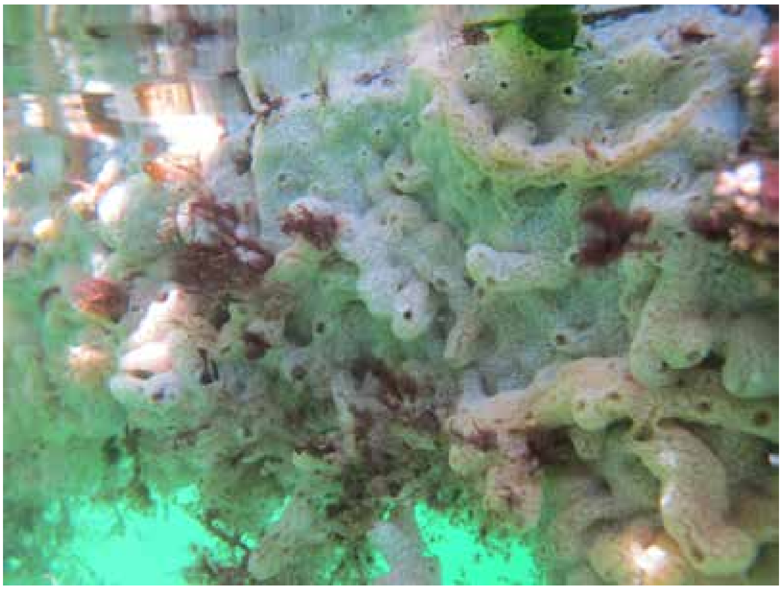

Figure 122 Photograph of *Didemnum perlucidum* by the Marine Biosecurity Research and Monitoring Group, DoF

Didemnum perlucidum is classified as a tropical colonial ascidian which grows on multiple substrates (Figure 122) (Rocha & Monniot 1995). In the Caribbean, where this ascidian is considered native, it grows in low densities and is associated with coral reefs and mangroves (Rocha *et al.* 2009, Kremer *et al.* 2010). In introduced locations, *D. perlucidum* is commonly associated with disturbed habitats (e.g. marinas, harbours and aquaculture facilities) (Kremer *et al.* 2010) where it can heavily foul artificial substrates including buoys, ropes, pylons and vessels (HARC 2012). In these environments, this ascidian is usually observed growing on other organisms such as polychaete tubes, algae, corals, barnacles and solitary ascidians and is frequently associated with other introduced ascidians (e.g. *Styela plicata*) (Kremer *et al.* 2010, Kremer & Rocha 2011).

D. perlucidum has also been described as a common fouler in shellfish farms, where it can heavily grow over mussels such as *Perna perna* (Rocha *et al.* 2009), *Mytilus edulis* (Glen Dibbin 2012 pers. comm.) and *Pinctada* oysters (Baptista *et al.* 2007). Interestingly, in Brazil, *D. perlucidum* was reported as one of the most common foulers on oysters (Baptista *et al.* 2007) but not on cultivated mussels (Rocha *et al.* 2009). The ability of *D. perlucidum* to heavily foul certain cultured bivalves and the actual effect on farm productivity requires further investigation.

D. perlucidum has been detected at various locations around WA, from Cygnet Bay to Busselton (Figure 123).

Figure 123 WA distribution of *Didemnum perlucidum* as at 3 April 2013

The Department's current position on *D. perlucidum* is a follows:

> On 16/12/2013 02:46 PM, Victoria Aitken wrote:
>
> The position currently on *Didemnum perlucidum* is this:
>
> Until recently the Department treated *D. perlucidum* like any pest listed on the Western Australian Prevention List for Introduced Marine Pests (2013). Inclusion on this list means that certain management responses should be followed by vessel operators when a pest is found - including reporting all suspected and confirmed detections to the Department as soon as possible.
>
> Unfortunately, *D. perlucidum* is now confirmed in several locations around the coast of WA. As a consequence, the Department has revised the policy and the management response for this species and is now to manage this pest only for high value asset areas. These areas are considered to be State marine parks, lands and waters adjacent to A class reserves, pearling and aquaculture facilities, and ports.
>
> Thus, the Department proposes to provide the following advice for all stakeholders:
>
> - *D. perlucidum* remains listed as a marine pest and suspected and confirmed detections should still be reported so its distribution can be tracked.
> - If moving vessels or immersible equipment into, or adjacent to, high value assets areas as mentioned above, stakeholders are requested to comply with any specific Departmental management advice regarding *D. perlucidum*. Actions may include ensuring vessels, or immersible equipment, are clean before entering these areas.
>
> Furthermore, proponents with marine pest conditions within a Ministerial Statement under the Environmental Protection Act 1986 will still be required to undertake actions as per their relevant Statement.
>
> The Department recommends to the Office of the Environmental Protection Authority the following specific response actions for *D. perlucidum* found within project areas:
>
> - Establish the extent of the species within the project (i.e. through a delimiting survey); and
> - Report any suspected or confirmed detections of the species.
>
> Further action is likely only to be required if infested vessels and equipment are planning to be moved into or near high value asset areas, as mentioned above. If clarity is required, stakeholders will be able to seek guidance from the Department.
>
> Regards,
>
> Victoria Aitken
>
> Biosecurity Section Leader | Aquatic Environment Branch | Department of Fisheries
>
> T +61 8 9482 7385 | M +61 (0)419 913 946 | victoria.aitken@fish.wa.gov.au

Didemnum vexillum

Synonyms: *Didemnum vestum*, *Didemnum carnulentum*, *Didemnum lutarium*, *Didemnum lahillei*, *Didemnum helgolandicum*, *Didemnum pardum* and *Didemnum moseleyi*

Figure 124 Photograph of *Didemnum vexillum* by the United States Geological Society, available from Wikipedia

Didemnum vexillum is a fast-growing colonial ascidian that consists of many microscopic individuals called zooids that are fixed in a sheet-like matrix. The colony has the ability to grow in sheets over any surface type and can form long, rope-like extensions (Figure 124). Colonies can vary in colour, including tan, cream, yellow, orange, pinkish or white.

D. vexillum has the inherit ability to drastically overwhelm and overgrow almost any substrate and sessile community. It has completely altered ecosystems, impacted both lower and higher trophic levels, overgrown cobblestones, seagrass beds, mussel and oyster valves, barnacles and even other ascidians (Lengyel *et al.* 2009; Morris *et al.* 2009; Carman & Grunden 2010). In New Zealand, aquaculture industries have spent over NZ$804,000 in attempts to eradicate *D.vexillum* that regularly smothers their mussel lines. Its ability to overgrow almost any type of surface means that it can interfere with almost any surface that is in the water including fishing equipment and aquaculture infrastructure. It is also commonly associated with artificial habitats in harbours including wharves and pylons.

Eriocheir sinensis **Chinese Mitten Crab**

Listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000)

Synonyms: *Grapsus nankin*, *Grapsus nankin, Eriochirus sinensis*, *Eriocheir japonicas* and *Eriocheir leptognathus*

Figure 125 Photograph of *Eriocheir sinensis* by Ron Offermans, available from Wikipedia

Eriocheir sinensis is a light brown to olive green coloured crab with a square shaped carapace measuring up to 100 mm in width (Figure 125). This crab has distinct, hairy, mitt-like appendages which give the 'mitten' crab its name. These mittens are especially well-developed in males. Claws are equal in size with white tips and mittens. This crab tolerates a broad range of environmental parameters from freshwater to marine.

E. sinensis is an opportunistic omnivore, with a diet mostly consisting of algae and detritus, however it is also known to consume benthic worms, clams, snails, freshwater shrimps, water insects, dead fish and fish eggs (Galil *et al.* 2011; Rudnick *et al.* 2003).

This crab's impacts mostly arise from its migrating, feeding and burrowing behaviours (Dittel & Epifanio 2009). For example, in Germany the economic costs of *E. sinensis* is estimated to be over EUR€80 million, since it was introduced in 1912. These costs arise from ongoing management to stabilise river bank erosion caused by the crabs, losses in commercial fisheries (e.g. through predation of fishes' food, damage to nets and ropes), the need to install catchment gear (e.g. barriers and ramps) and costs of maintenance aimed at controlling the population (including gear management) (Gollasch 2011). In California and the UK, there are significant costs associated with the removal of crabs from power plants and water stations because they block the screening and cooling systems (Attrill & Thomas 1996; Veldhuizen 1999). *E. sinensis* has been known to compete for resources with freshwater fish and invertebrates, placing additional pressures among native populations (Herborg *et al.* 2003).

Gymnodinium catenatum

Figure 126 Image of *Gymnodinium catenatum* by Minami Himemiya, available from Wikipedia

Gymnodinium catenatum is a microalgae (dinoflagellate) that occurs as a single cell or as a chain of cells up to 63 cells long (Figure 126). This species can form toxic blooms, which is its primary impact. The toxins *G. catenatum* produces can cause Paralytic Shellfish Poisoning (PSP) in humans, which results from consuming shellfish that have eaten this dinoflagellate. PSP can be fatal and in Mexico, between approximately 1990 and 2000, there were 32 deaths from 460 recorded poisonings (Band-Schmidt *et al.* 2004). Marine animals (e.g. turtles and fish) and fisheries (e.g. shrimp) can also be negatively affected by PSP outbreaks (Sierra-Beltrán *et al.* 1998; Alonso-Rodríguez & Páez-Osuna 2003).

In addition to the health costs of PSP, there are commercial losses resulting from shellfish farm closures and preventative screening of stock. In Australia, the direct costs from PSP contamination of shellfish exceeds AUS$1 million per year, i.e. through toxin and plankton monitoring (CAB International 2013a). In southern Tasmania (e.g. Huon Estuary) some areas are so heavily affected that oyster and/or mussel production is no longer commercially viable due to the risk of extended periods of closure (CAB International 2013a).

Hemigrapsus sanguineus Asian Shore Crab

Synonyms: *Heterograpsus maculatus, Heterograpsus sanguineus* and *Brachynotus sanguineus*

Figure 127 Photograph of *Hemigrapsus sanguineus*. Photograph Wikimedia commons available from Wikipedia

Hemigrapsus sanguineus is a small crab with a smooth square carapace of up to 44 mm wide (Figure 127). The crab varies in colour from brown-orange to green-purple, usually with red spots on its claws, and adult males have a fleshy membrane on the inner base of the dactyl.

Within ten years of being first detected in New Jersey, North America, *H. sanguineus* had spread rapidly from North Carolina to Massachusetts and become one of the most abundant intertidal crab species along the western rocky intertidal coastline (McDermott 1998). In New Jersey, average crab densities were 120 crabs per m^2 in 2006 (Kraemer *et al.* 2007) and in some locations, densities are up to 320 – 350 crabs per m^2 (Kraemer *et al.* 2007; McDermott 1998). Given the right conditions, *H. sanguineus*' shear mass of numbers can overwhelm many native species and has been blamed for displacing native xanthid and mud crabs from the mid-Atlantic coastlines (Gerard *et al.* 1999).

H. sanguineus is an aggressive crab that can outcompete and displace native species (Brousseau & Baglivo 2005; Galil *et al.* 2011; Lohrer & Whitlatch 2002). Studies have shown that it can alter the population dynamics of invertebrate species and it is thought to be responsible for altering the ecosystem's function via the displacement of several important native species (Gerard *et al.* 1999; Griffin & Byers 2009).

Mytilopsis sallei Black Striped Mussel

Synonyms: *Congeria gundlachi, Congeria sallei, Congeria rossmasessleri, Dreissena domingensis, Dreissena gundlachi, Dreissena morchiana, Dreissena pfeiferi, Dreissena riisei, Dreissena roosmassleri, Dreissenia domingensis, Dreissenia gundlachii, Dreissenia moerchiana, Dreissenia pfeifferi, Dreissenia rossmaessleri, Dreissenia sallei, Mytilopsis allyneana, Mytilus domningensis, Mytilus morchianus, Mytilus rossmassleri, Mytilus sallei, Tichogonia domingensis, Tichogonia gundlachi, Tichogonia moerchiana, Tichogonia pfiefferi, Tichogonia riisei, Tichogonia rossmassleri* and *Tichogonia sallei*

Figure 128 *Mytilopsis sallei* shells, photograph by Helen Cribb, Northern Territory Government

Mytilopsis sallei is a small, smooth-shelled mussel with thin, unequal sized shells. The shell colouration varies from pale to dark brown/black sometimes with dark coloured zig-zags or striped markings (Figure 128). *M. sallei* is a fast-growing, gregarious mussel species, forming dense clusters. The size range of the mussel varies from 8 mm to 25 mm long. Mussels are suspension feeders, consuming mainly plankton and other suspended particulate organic matter. *M. sallei* can also survive in heavily polluted conditions and quickly populate disturbed areas, often settling on artificial structures.

By forming dense, mono-specific groups, *M. sallei* is able to exclude most other species resulting in a reduction in biodiversity. In the Great Lakes and Mississippi River region in the USA, *M. sallei* has caused physical damage to vessels and artificial structures through fouling and by changing a pelagic-dominated system to a benthic-pelagic system, affecting the food web structure and productivity at higher trophic levels (Fahnensteil *et al.* 1995; Tan & Morton 2006).

The presence of *M. sallei* in Darwin Harbour in 1999 constitutes the first known record of a species from the Dreissenidae family in Australia, and the only successful eradication of an invasive marine pest in Australia to date (Willan *et al.* 2000). In March 1999, during a port of Darwin survey for adventive marine species, divers found dense clusters of *M. sallei* in Cullen Bay Marina, the largest of three marinas within Darwin Harbour. All three marinas had a system of lock gates separating the waters of the marina from the sea. This detection posed a threat to the pearl farming and aquaculture industries, as well as to both recreational and commercial fisheries because of the mussels' propensity for heavy fouling (Bax *et al.* 2002;

Willan *et al.* 2000). In April 1999, the three affected marinas were closed and quarantined by the Northern Territory Government. Cullen Bay Marina was treated with a total of 163 040 kg of liquid sodium hypochlorite (resulting in a 12% chlorine solution) and 4325 kg powdered copper sulphate (resulting in 0.8 mg litre-1 copper solution). Tipperary Waters and Francis Bay Marina were treated with equivalent amounts of the same solutions. Fouled vessels outside the marina were recalled to the nearest marina prior to treatment or lifted from the water. The chemical treatments were effective in killing *M. sallei* in all three marinas. However, there was considerable, but not complete, mortality of other marine life (Willan *et al.* 2000). The last living individual of *M. sallei* was detected 18 April 1999. Regular post-eradication surveys have been carried out with no further identification of *M. sallei*.

Perna viridis *Asian Green Mussel*

Synonyms: *Chloromya viridisI, Mytilus (Chloromya) smaragdinusI, Mytilus (Chloromya) viridisI, Mytillus opalus* and *Mytilus smaragdinus*

Figure 129 Photographs of juvenile through to adult stage of *Perna viridis*, photograph by Helen Cribb, Northern Territory Government

Perna viridis usually has a distinctive emerald green coloured shell, though this colour can vary from blue-green to brown (Figure 129). The shell of *P. viridis* is thin, with valves of equal size that are elongated and triangularly ovate in outline and can reach a maximum size of 230 mm. The mussel is known to settle in numbers of up to 60 000 per m^2 (NIMPIS 2013).

P. viridis can live in locations that are highly contaminated with industrial and human pollution. *P. viridis* is a filter-feeding organism and it can accumulate water contaminants including human pathogens and heavy metals that are present in the water column. This can pose a hazard through paralytic shellfish poisoning (PSP) to other organisms in the food chain as well as to humans who consume mussels from heavily polluted areas (Ong *et al.* 2009; NIMPIS 2013). *P. viridis* can potentially displace native bivalves and many other species, by dominating the benthic habitat and causing subsequent changes in trophic relationships, benthic ecology and community structure (Barber *et al.* 2005; Rajagopal *et al.* 2006).

Economic impacts arise from the mussel causing blockages in water systems, increasing corrosion rates and reducing efficiency through heavy fouling (Rajagopal *et al.* 1998). Costs can rise for vessel owners due to increased maintenance, decreased fuel efficiency and blocked or damaged internal pipes.

In 2009 and 2010, specimens of *P. viridis* were detected on naval vessels at HMAS Stirling on Garden Island, WA. To date, repeated surveys of the wharf facilities and ongoing monitoring using settlement arrays at HMAS Stirling have not detected any further specimens of *P. viridis*.

Rhithropanopeus harrisii White-Fingered Mud Crab

Synonyms: *Heteropanope tridentate, Heteropanope tridentate, Pilmnus harrisii, Pilmnus tridentatus* and *Rhithropanopeus harrisii* ssp. *tridentatus*

Figure 130 Photograph of *Rhithropanopeus harrisii* by Dirk Schories, www.guiamarina.com

Rhithropanopeus harrisii is a small brown to olive green coloured crab that reaches a maximum size of 26 mm. It has unequally sized and shaped claws that have a white tip (Figure 130). *R. harrisii* is a generalist scavenger that feeds on a range of animal and plant matter.

R. harrisii can compete with native crabs and benthic feeding fishes for food, alter food webs, foul water intake pipes, cause economic losses to gill net fisheries by spoiling fishes in the gill nets and is thought to have displaced native freshwater crayfish in Texas (reviewed in Roche & Torchin 2007). *R. harrisii* is also a carrier of strains of the white spot baculovirus, an extremely virulent virus that can cause disease in other crustaceans (Payen & Bonmai 1979).

Sargassum muticum

Synonym: *Sargassum kjellmanianum f. muticus*

Figure 131 Photograph of *Sargassum muticum* by Graça Gaspar, Wikipedia Commons, available from Wikipedia

Sargassum muticum is a large, brown marine alga. Structurally, it is comprised of a disc-shaped holdfast, which in turn gives rise to a single stipe upon which alternate branches (lamia) arise. Blades and air-filled vesicles grow off the lamia (Figure 131). It is usually 1 – 3 m in length, but can grow up to 16 m in length, and may form floating mats on the sea surface. It can grow up to 10 cm each day, and it also has a relatively long life span of 3 – 4 years.

S. muticum is known to have many biological and economic impacts, including outcompeting native species (e.g. algae and seagrass) for space and through exclusion (i.e. shading), it can heavily foul marine equipment, clog intake pipes, increase the rate of sedimentation as it slows the water flow (dense stands) and reduce the social amenity of an area (floating mats and through decay) (Eno *et al.* 1997; Critchley *et al.* 1986; Aguilar-Rosas *et al.* 2013).

Ulva pertusa

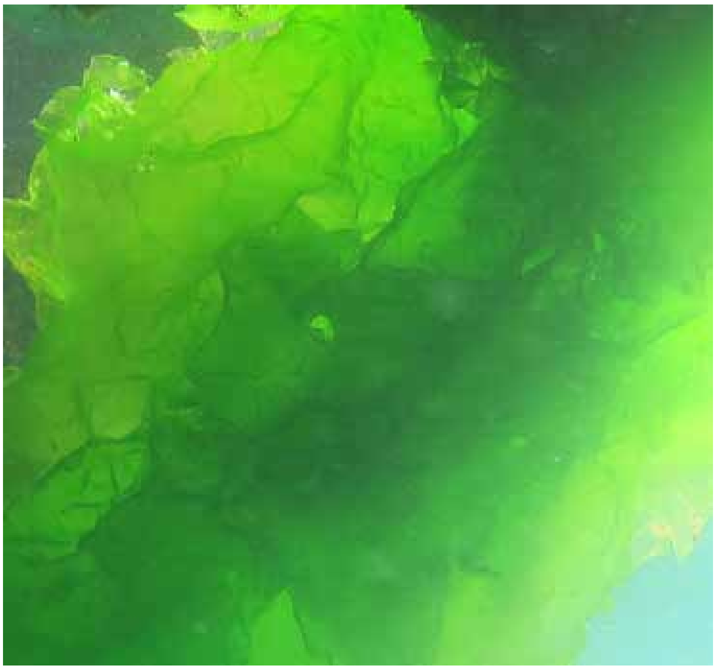

Figure 132: Photograph of *Ulva* sp. by the Marine Biosecurity Research and Monitoring group, DoF

Ulva pertusa is a marine, green alga with blades up to 20 cm long (maximum 40 cm). Like all Ulva species, the blades are bright green and glossy (Figure 132). As *U. pertusa* blades grow in length, they begin to develop perforations, particularly where the blade adjoins the holdfast, making it appear as though there are many blades. The species is most often found in the intertidal zone, but can also be found in the upper subtidal zone as an epiphyte (CAB International 2013b).

U. pertusa can become a dominant species in sheltered conditions where there is readily available nutrients and light (Seaweed Industry Association 2013). This species can be invasive due to its fast growth rate, high reproductive potential and broad environmental tolerances (CAB International 2013b). However, to date, information on negative impacts is limited, other than it may modify benthic communities purely by its presence and reduce social amenity when it decomposes and releases nutrients, resulting in eutrophication (CAB International 2013b). The species is used for human (nutritional additive) and animal consumption, as a fertiliser and as a biofilter in Asia (CAB International 2013b).

Undaria pinnatifida Wakame

Listed in the top 100 worst invasive species worldwide (Lowe *et al.* 2000)

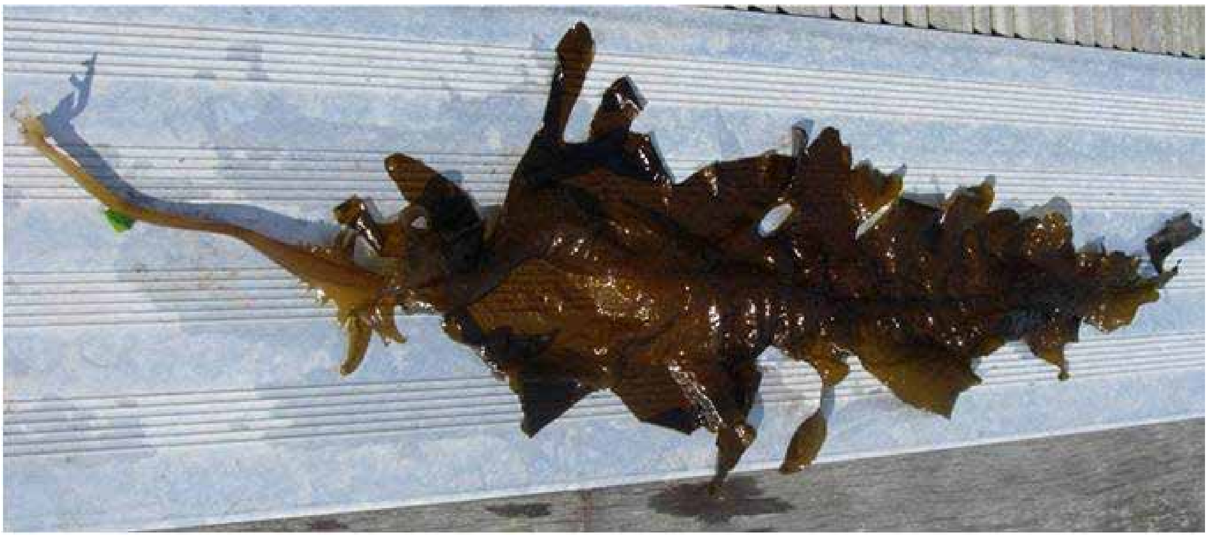

Figure 133 *Undaria pinnatifida*, photograph by Kathryn Birch

Undaria pinnatifida is a brown alga consisting of a holdfast, stipe (cylindrical stem) and flattened, branched blade with the stipe extending as an obvious mid-rib through the blade (Figure 133).

Worldwide, the major impact of *U. pinnatifida* is that it is opportunistic, especially in disturbed habitats. Due to its fast growth rate and dual form of establishment in its macro stage (i.e. sporophytes: spore producing plants) and microscopic stage (i.e. gamete producing stage), *U.pinnatifida* is extremely competitive and able to form large forests more quickly than most native species (Wotton *et al.* 2004). This is also highlighted by concerns regarding the ease at which *U. pinnatifida* is transported by shipping and recreation. This poses a significant risk to areas of high marine value in terms of both economic and conservation protection.

U. pinnatifida was first officially recorded in Tasmania in July 1988 on the east coast of the island near a bulk handling shipping terminus. It was assumed this was a result of dispersion from a ship's ballast water. Anecdotal evidence suggested it might have been present in Australian waters from as early as 1982 (Sanderson 1990). In 2002, *U. pinnatifida* was recorded 150 km north and 80 km south of the initial incursion site (Hewitt *et al.* 2005). The local spread across Tasmania and New Zealand is likely to be due to local translocation by fishing, recreational boating and aquaculture activities. Tasmania is currently farming *U. pinnatifida* with approximately 200 tonnes per year being sold for food and nutrition and pharmaceutical products (McHugh & King 2006). In Victoria, *U. pinnatifida* was found in Port Phillip Bay in July 1996 (Campbell & Burridge 1998). As yet, there has been no evidence of direct negative impact of *U. pinnatifida* on native species in Australia, however fouling of marine structures and aquaculture operations is a source of economic impact.