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Likelihood of Marine Pest introduction to the Indian Ocean Territories

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Acronyms and abbreviations

Department:	Department of Fisheries, Western Australia
DOA:	Department of Agriculture (federal)
IMP:	Introduced Marine Pest
IOTs:	Indian Ocean Territories
IMO:	International Maritime Organisation
MDET:	Monitoring Design Excel Template v2
MPMG:	Marine Pest Monitoring Guidelines v2
MPMM:	Marine Pest Monitoring Manual v2
MPSC:	Marine Pest Sectoral Committee, formerly National Introduced Marine Pest Coordination Group (NIMPCG)
National System:	National System for the Prevention and Management of Introduced Marine Pests
NIMPCG:	National Introduced Marine Pest Coordination Group (roles now assumed by the MPSC).
NODC:	National Oceanographic Data Center

1.0 Marine pest risk

The introduction of new species to environments in which they did not evolve has been widely recognised as one of the top five threats to marine ecosystem function and to biodiversity (Millennium Ecosystem Assessment, 2005). Many of these introduced organisms remain inconspicuous and innocuous, causing no known adverse effects. When introduced to a new environment a species has the potential to threaten human health, economic values and the environment, in the marine realm these species are referred to as marine pests. Introduced marine pests (IMPs) are a global problem, and in terms of potential to reduce global biodiversity, second only to habitat change and loss (Millennium Ecosystem Assessment, 2005).

It has been estimated that globally, 4,000 species of invertebrate, algae and other marine creatures are being transported around the world every day in ballast water. While not all vessels carry ballast water, the majority of vessels do have hull fouling. A relatively recent assessment of the relative contribution of vectors to the introduction and translocation of marine invasive species in Australia, reports that around 250 non-indigenous marine species have been identified in Australia, of which more than 75% have been introduced through biofouling (Bax *et al.* 2003).

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 in support of 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 (DoT, 2013). As such, Australia is particularly susceptible to the introduction of non-indigenous species from a range of shipping sectors, including commercial cargo and container ships, bulk carriers, commercial fishing vessels, oil and gas industry vessels (e.g. oil rigs), recreation boats and non-trading vessels (e.g. barges, dredges, defence vessels). Although the volume of traffic is less, the islands of the IOTs are just as reliant upon this maritime trade and just as much at risk from IMP introduction.

The impacts of IMPs are varied and substantial. They can predate on native and farmed species, out-compete natives for space and food, alter nutrient cycles and lead to a loss of diversity in local species. In addition to environmental consequences, IMPs have the potential to harm human health (e.g. through cholera, paralytic shellfish poisoning), negatively affect commercial fish and seafood species, negatively affect amenity and recreational activities and reduce the fuel efficiency for all vessel types (hull fouling organisms). With increasing human population and associated travel, transport and trade, the risk of pest species moving from one location to another is growing.

The primary aim of any biosecurity system is to reduce risk of IMP entering the country, whether it is through likelihood analyses or border and vessel standards. If prevention is not viable or doesn't work then early detection of IMPs is vital if there is to be any chance of eradication before it becomes established. To date, there has only been one IMP species that has been successfully eradicated from Australia, *i.e.* the black striped mussel, which was found in Darwin Harbour in 1999. This eradication program cost more than $2M, but the mussel presented a direct threat to the $225M pealing industry (value of production in 1998). If eradication is not an option then other management controls can be put in place, such as community education regarding boating habits and routines, quarantine areas and managing vessel movements between locations.

2.0 Indian Ocean Territories

The Australian Indian Ocean Territories has two distinct constituents; Christmas Island and the Cocos (Keeling) Islands. Not only are these two areas widely separated (*ca.* 1000 km) but also differ greatly in terms of their marine habitats and possible sources of IMPs. Due to the very small landmass of these islands, their isolated nature, their proximity to high risk sites in south-east Asia and their unique array of endemic fauna, they may be considered a high priority for protection from IMP incursions

2.1 Christmas Island

Christmas Island is a very small island (135 sq km), located 1500 km off the North West coast of Australia in the northern Indian Ocean. At only 400 km south of Java, the island is closer to Indonesia than the Australian mainland (Figure 1). Marine substrates of the Island are typically rock and reef, with very minimal areas of soft sediment. Nearshore areas are very narrow, with the bathymetry quickly descending to abyssal depths.

Despite being small, Christmas Island has a commercial port which is ranked 39th on the list of Australian ports most at risk of the introduction of new IMP species (NIMPCG, 2007). This is at a similar level to the other Western Australian ports of Esperance (37), Wyndham (41) and Broome (43). The only major port installation on Christmas Island is in Flying Fish Cove on the northern part of the island. The island's shipping facilities are contained within a very small area, with the entire port area being confined to a single 1km-long bay.

Figure 1 Map of Christmas Island showing key vessel nodes or IMP likelihood hotspots within the island.

There are also secondary port installations at Smith Point and at Nui Nui for use when conditions are unfavourable at Flying Fish Cove. Smith Point is exclusively a fuelling facility, and is used to both receive fuel shipments and refuel vessels. The Nui Nui facility is for cargo only, it comprises a set of mooring points and a crane and, as at Smith Point, there is no direct ship-shore interface. Weather conditions very rarely favour use of the Nui Nui facility, and it has only infrequently been used since it was built in 2004.

2.2 Cocos (Keeling) Islands

The Cocos (Keeling) Islands (Figure 2) are located 1300km southwest of the nearest landmass, Indonesia. They are a series of 27 islands, making up two atolls. As there is currently no industry on Cocos Islands that requires substantial amount of sea transport, shipping activity to this location is minimal. This port was ranked 86th out of 91 ports included in the national port rankings for the risk of IMP incursion (NIMPCG, 2007). The atoll structure of the islands provides a lagoon area of shallow sand and reef, but outside of the island barriers the bathymetry descends to *ca.* 5000 m as it does at Christmas Island.

Port structures on the Islands are limited to two small jetties projecting into the lagoon, one on each of West and Home Islands. Recreational yachts often anchor on the lagoon side of Direction Island, but there are no permanent moorings there.

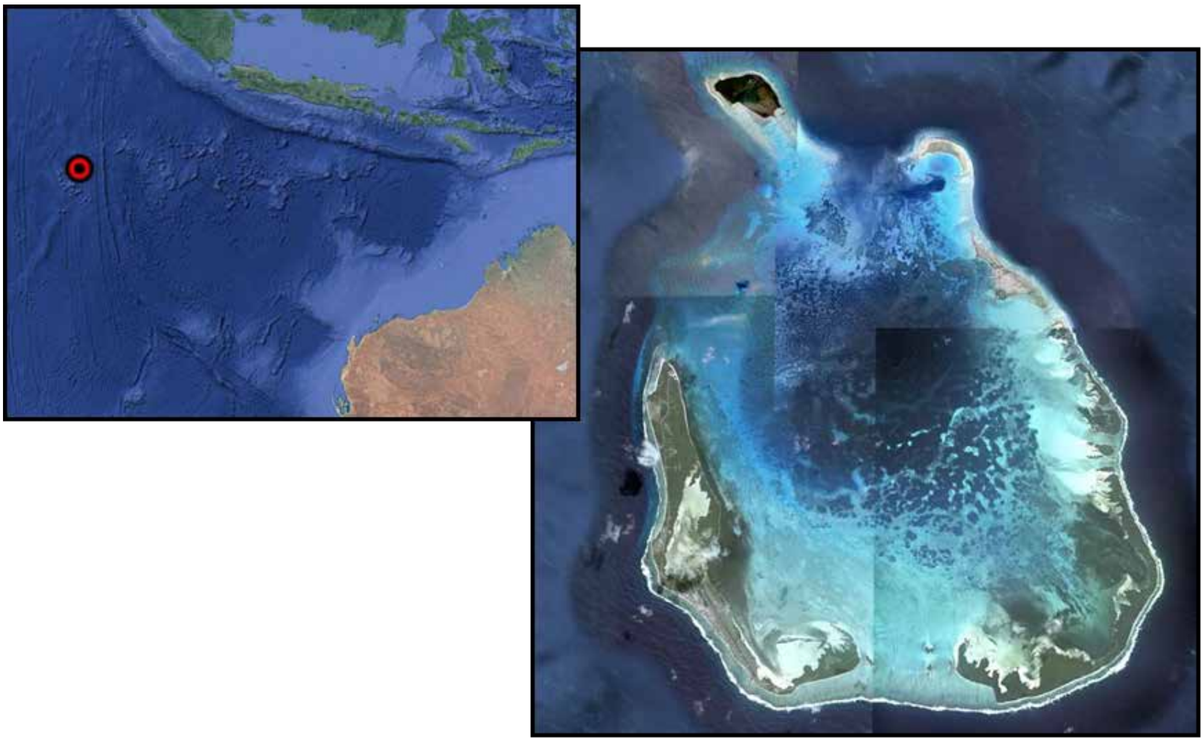

Figure 2 Map of Cocos (Keeling) Islands.

3.0 Current knowledge of Introduced Marine Pest species

Berry and Wells (2000) compiled the body of historical knowledge on the marine fauna of Christmas Island with that of their own surveys to produce a comprehensive checklist of the species present around the Island as well as an extensive list of published works on the Island's marine fauna. When this checklist was consulted, none of the current NIMPCG target faunal species were found to occur naturally, nor were any noted as having been introduced.

In 2004, a survey for IMP species was conducted for the various port structures on Christmas Island, which concluded that despite more than 100 years of operation, none of the targeted introduced pest species were present (GHD, 2004). The list of target species used by the 2004 IMP survey was that compiled by CRIMP of the introduced marine species (Hewitt & Martin, 2001).

Two recent IMP surveys have been conducted by the Department of Fisheries (Hourston, 2012 and 2013). The first survey did not detect any evidence of target IMP species, while the second found some specimens of a colonial ascidian displaying features consistent with a *Didemnum* species at Smith Point. It was, however, determined to be neither *D. vexillum* nor *D. perlucidum*. This species was not prevalent, did not display invasive characteristics and was observed at only one location.

The only species that was noted by GHD (2004) as a potential invasive species was the barnacle *Amphibalanus amphrite*. Huisman *et al.* (2008) regard this species as introduced into Australian waters and Hewitt (1998) considers it a significant fouling species. However, GHD (2004) identifies *A. amphrite* as cryptogenic and as such may or may not be introduced. During the 2010 and 2012 IMP surveys there was very little evidence of any barnacle species except for some empty shells attached to the Flying Fish Cove jetty pylons which were in too poor condition to be identifiable. This barnacle is not among the 55 high risk species identified by NIMPCG, nor is it on the target species list for this likelihood study.

Berry (1989) presents a synthesis of marine fauna of the Cocos (Keeling) Islands and notes only one species considered to be an introduced marine species by Huisman *et al.* (2008), *i.e. Megabalanus tintinnabulum*. The abundance and diversity of barnacles in general is recorded as being very low at Cocos and they are not a significant fouler in this environment. *Megabalanus tintinnabulum* is generally considered a cosmopolitan fouling species and is present at the majority of locations around the world that have any degree of shipping activity. Although an introduced marine species, this species is not currently on the target list for National System monitoring (NIMPCG, 2007), nor is it considered for this likelihood study.

4.0 Methods

This likelihood analysis examined commercial and recreational vessel data and the likelihood of a marine pest introduction from these vessels for Christmas Island Port and Cocos (Keeling) Islands. All vessel data available were sourced directly from the port managers. During the period spanned by the ports data, Christmas Island received 428 vessels, while Cocos received only 72. The Christmas Island data set was of sufficient size to be robustly analysed while the Cocos Islands data was not. For this reason, there are no detailed analyses presented for Cocos Islands, it could be assumed that this island would face comparable types of risks as that for Christmas Island, albeit at a lower pressure.

Although classed neither as commercial nor recreational, Suspected Illegal Immigration Vessels (SIEVs) were also intended to be considered for this examination of IMP risk given that the Indian Ocean Territories receive a significant number of these vessels. However, the arrivals data for these vessels is often only gleaned from anecdotal sources. Furthermore there is no documented or reported data on the biofouling risk these vessels represent. Due to these two factors these vessels could not be included in this analysis. It should be stressed however that given the locations from where these vessels are likely to have originated, the expected low level of vessel maintenance and in the absence of robust data to the contrary, these vessels would be classed as high risk.

From a biosecurity perspective the overall likelihood that a marine pest will be translocated from and to any region is based on multiple factors. For the purpose of this analysis, factors were grouped into:

- the inoculation likelihood, and
- the infection and establishment likelihood

Often components of the source data were used across both groups and linkages between groups were created from the outputs of one group to the inputs of the other.

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".

4.1 Inoculation likelihood

Inoculation likelihood assumes that the greater the number of vessel visits from a source location (that has 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 risks and movements for a Christmas Island port to determine the likelihood of inoculation for this location. The process used and the outputs generated are shown schematically in Figure 3 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.

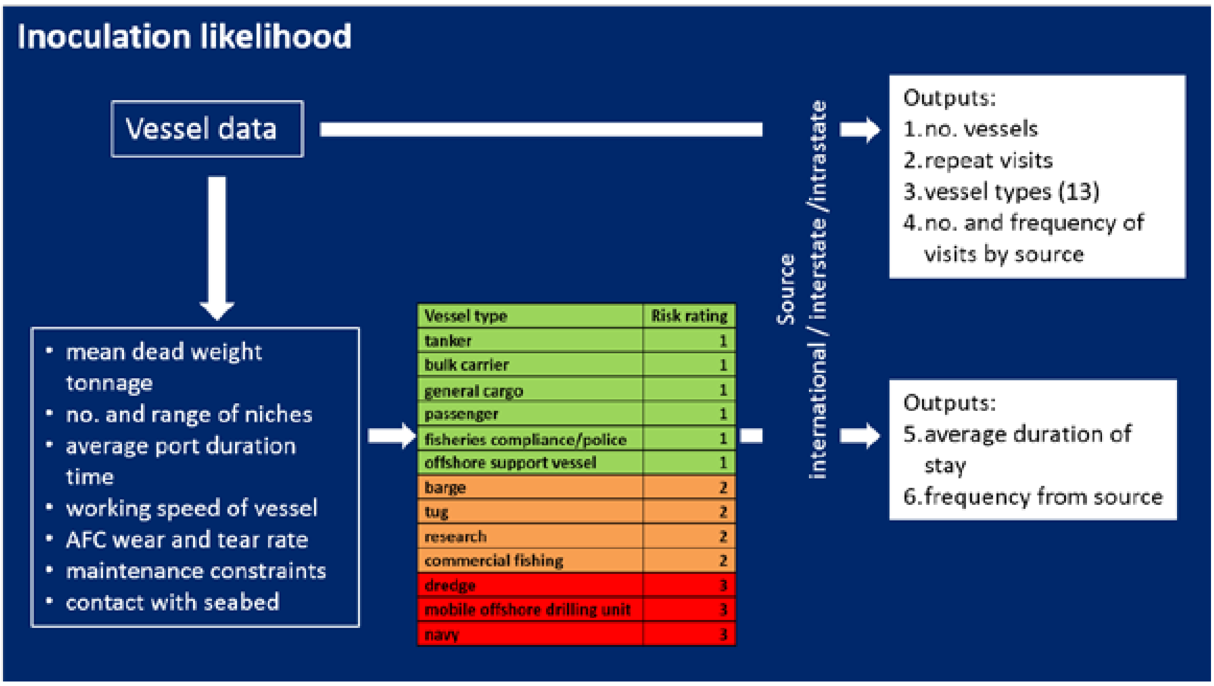

Figure 3 Schematic diagram for the process behind the analysis the inoculation likelihood.

Source data included the vessel name, the last port of call (LPOC) and the duration of stay within the Christmas Island port. Additional information was developed including whether the LPOC was international, interstate or intrastate. For international LPOCs the data were grouped into country, for domestic they were referred to by the port name. Vessels were grouped into one of 13 different vessel types using a number of salient characteristics, including the type of cargo and the vessels activity/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 and summarised the contribution (%) of the different vessel types visiting the Christmas Island port. In addition, the frequency of each vessel's visits to Christmas Island was quantified by interrogating the data by vessel name looking for repeat entries. 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 inoculation opportunity. Occurrences of vessel names were separated into four criteria based on the repetition of that vessel name. 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 following four categories were determined:

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

Vessel types may not consistently reflect a vessels size or activity (Ruiz *et al.* 2000), thus it is a widely used practice to further categorise vessel types into broad risk groups 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 2008; Hulme 2009; Hewitt *et al.* 2010). 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) = 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: greater duration of stay = greater risk/likelihood of transfer
4. Working speed of the vessel
   Assumption: the slower the vessel the greater likelihood that a pest can settle on the hull
5. Antifouling coat wear and tear rate
   Assumption: vessels that have an operating profile that causes increased wear and tear on 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 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 providing the overall level of risk for each type *i.e.* risk rating (Table 1). Naval vessels were initially assessed as a moderate risk using the above process. However, the authors considered that due to their unusual operating profiles, for example engagement of suspect illegal entry vessels (SIEV) and inability to provide last port of call (LPOC) data, a moderate risk score did not truly reflect their inherent risk. As such the risk category of naval vessels was increased to high.

Table 1 The factors and their asigned values used to determine the overall risk rating for each vessel type. 1 = low (green), 2 = moderate (orange) and 3 = high (red).

	Factors							
Vessel types	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

In order for a marine species to inoculate a port, the organism either needs to undergo a reproductive process or be dislodged from the vessel whilst in that a port. Intuitively this implies the longer a vessel stays in a port the greater the chances either process will happen and the port will become inoculated with an IMP from that vessel (Hewitt *et al.* 2010). The number of days a vessel type was in the port was derived from the arrival and departure dates and times provided in the port data. The duration of stay (mean ± SE of days) was 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 were also examined by their source location (LPOC: International/Interstate/Intrastate).

4.1.1 Socio-political risk

The authors considered the socio-political aspect of a vessels profile was another component worthy of investigation. This considers the flag of registry under which the vessel operates and whether that country of registry has signed the International Maritime Organisation (IMO) International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM). The assumption is that if a vessel is registered under a flag of convenience the overall standards to which it adheres may be lower, including environmental standards; hence they will have a greater propensity to harbour marine pests.

All commercial vessels have to be registered; however they can choose which country they register with *i.e.* flag state. Flag states vary greatly in the standards that a vessel needs to meet for registration and whether they have ratified and enforce international standards. Therefore the choice of flag state can be indicative of a behavioural risk from owners/operators (Knudsen and Hassler, 2011; International Maritime Organisation).

Certain flag states are termed Flags of Convenience (FOC), a term to describe flag states in which a vessel does not require a "genuine link" between the real owner of a vessel and the flag the vessel flies. This is in contrast to the guidelines of the International Transport Workers Federation (ITWF) and the United Nations Convention on the Law of the Sea (UNCLOS) (ITWF, 2014). The reasons for choosing a 'flag of convenience' (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 at least partially crewed by its citizens (ITWF, 2014).

The following 34 countries have been declared FOCs by the ITWF's Fair Practices Committee (a joint committee of ITWF seafarers' and dockers' unions):

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

Currently there is no convention pertaining to biofouling, thus consideration was only given to whether or not a country was a signatory to the IMO BWM as of 31st July 2013. The BWM was adopted in 2004 and as of June 2014 the convention has been ratified by 40 countries (*i.e.* 30.25 % 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 is no less than 35 % (Pughiuc, 2010).

The aim was to provide a detailed analysis of the potential risk to Christmas Island posed by vessels with potentially low standards. The process used and outputs generated are shown schematically in Figure 4 and included:

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.

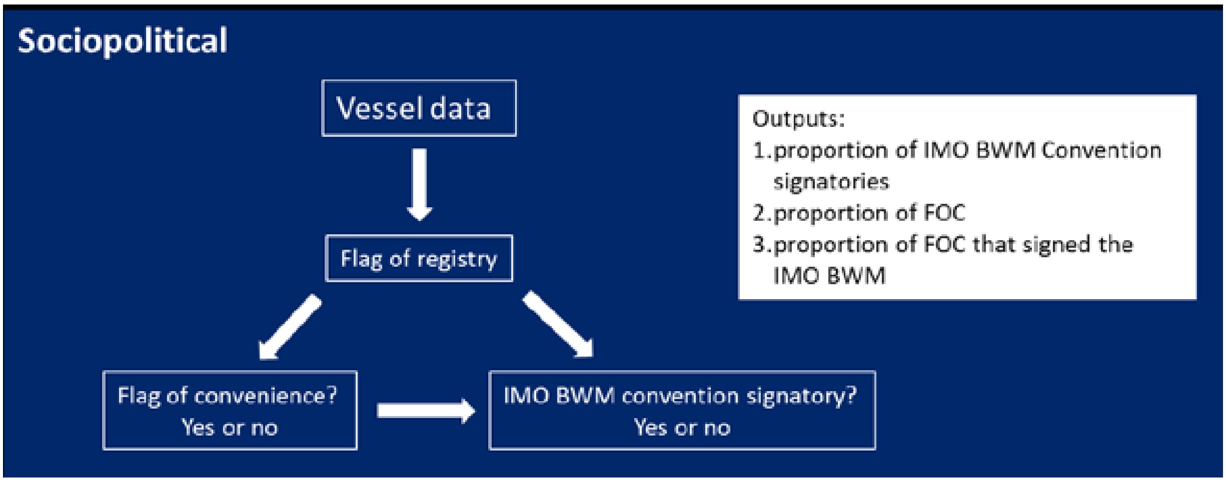

Figure 4 Schematic of the process and outputs used to analyse the socio-political aspect.

4.2 Infection and establishment likelihood

In order for a recipient port to be infected with a marine pest species there needs to be a vector and a viable source of IMP propagules at the previous port.

The aim was to provide each port with a description of the likelihood of infection by compatible marine pests, by identifying the most likely sources (LPOC) and most likely marine pest species. The process used and the outputs generated are shown schematically in Figure 5 and included:

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 Christmas Island port
4. LPOC with the greatest infection and establishment risk to each port.

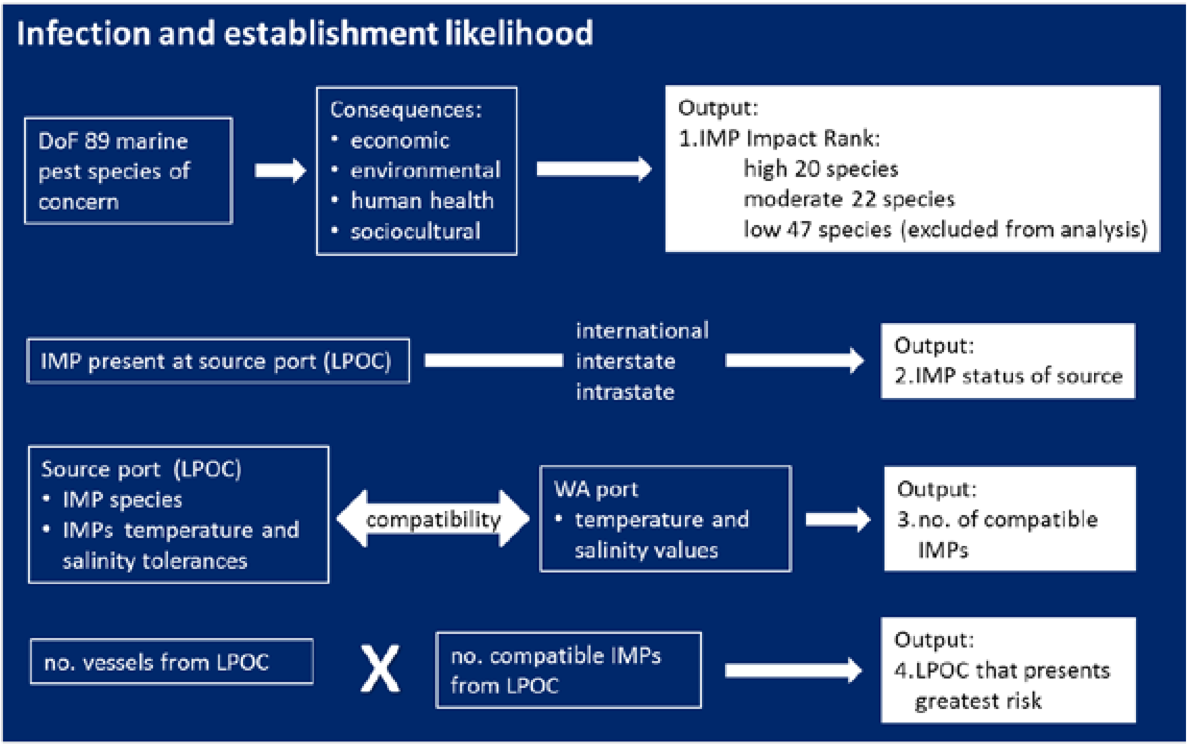

Figure 5 Schematic diagram of the process behind the analysis of the infection and establishment likelihood.

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.* (2010), with consideration from a Western Australian perspective. The impact rank of each species was assessed against four core consequences: environmental; economic; socio-cultural; and human health (see Hewitt *et al.* (2010) 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.* 2010 p 7). Economic consequence encompasses the "components within an ecosystem that provide a current or potential economic gain or loss" (Hewitt *et al.* 2010). Socio-cultural consequence encompasses the "values placed on a location in relation to human use for pleasure, aesthetic and generational values" (Hewitt *et al.* 2010). Human health consequence encompasses the value of a safe and healthy society shared equally across generations and socio-economic groups" (Hewitt *et al.* 2010). Hewitt *et al.* (2010) assigned a value of 1, 3 or 5 for each consequence to each species based on current knowledge for that species. For each species, the values across the four consequences were summed to give an overall rating value. For the most part we used the values as allocated by Hewitt and co-workers (2013) however we approached the analysis from a Western Australian perspective and so made adjustments where necessary as well as incorporating species not considered in Hewitt *et al.* (2010).

To derive the impact rank for the *DOF IMP list* we allocated a high risk to those species with an overall rating value of >5, a moderate risk to those species with an overall rating value of 3 – 5 and a low risk to those species with an overall rating value of ≤3. This resulted in categorising 20 high, 22 medium and 47 low risk species. Only the high and moderate ranked pests (n = 42) were used for further analysis (see Appendix 1).

Invasive species databases were interrogated for location data (country name) and temperature and salinity tolerance values for the 42 pest species being considered. Databases included:

1. National Introduced Marine Pest Information System (NIMPIS)
2. Delivering Alien Invasive Species Inventories for Europe (DAISIE)
3. Invasive Species Compendium (CABI)
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 and Sliwa 2003; Barry *et al.* 2008; Hewitt *et al.* 2010) it was assumed that if a pest species was present in a source country then the pest species was present in all ports of that country. The authors acknowledge that available pest species distribution information is likely to be 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 exist in that location.

Based on the LPOC vessel data, source locations for IMPs for each WA port were identified. International LPOC locations were assigned to a country following the above rationale, whereas 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 we assumed that when in the presence of an IMP the vessel was considered infected and may act as a transport vector for that species.

The next step identified those species that posed a threat to a Christmas Island specifically. To achieve this we used what we refer to as a species-specific environmental matching approach, based on the temperature and salinity. That is, we reduced the number of potential incoming species to those species whose temperature and salinity tolerances were compatible with the temperature and salinity values of the recipient WA port.

This method contrasts to other environmental matching methods in that it used 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 ports temperature and salinity values to another may potentially exclude compatible pest species. For example Portland Port (USA) has a temperature range of -2 to 14°C and Port Hedland Port (WA) has a temperature range of 20 to 32°C. A direct comparison between these ports would conclude that they are dissimilar and that a species from one would not be able to survive in the other (Figure 5). However the species-specific environmental matching method that we used showed that a marine pest, *Balanus improvisus* (temperature tolerance 0 - 35°C), known to exist in Portland Port would also be able to exist in Port Hedland as the temperature tolerances of the species span the conditions at both ports (Figure 6). Thus, there is a translocation risk for this species.

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 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 tolerance values, *i.e.* ± 3°C and ± 3ppt respectively. For pest species where temperature and salinity data was lacking it was assumed they could survive in Christmas Island Port (*i.e.* application of the precautionary principal). Temperature and salinity data for Christmas Island Port was acquired from Brewer *et al.* (2009) and the National Oceanographic Data Center (NODC). It was assumed if a species' tolerances were compatible with the temperature and salinity values of Christmas Island Port then the pest would be able to survive in the port. It was also assumed that there was suitable available habitat for the pest species to colonise, however, it is recognised that this later assumption is not always the case.

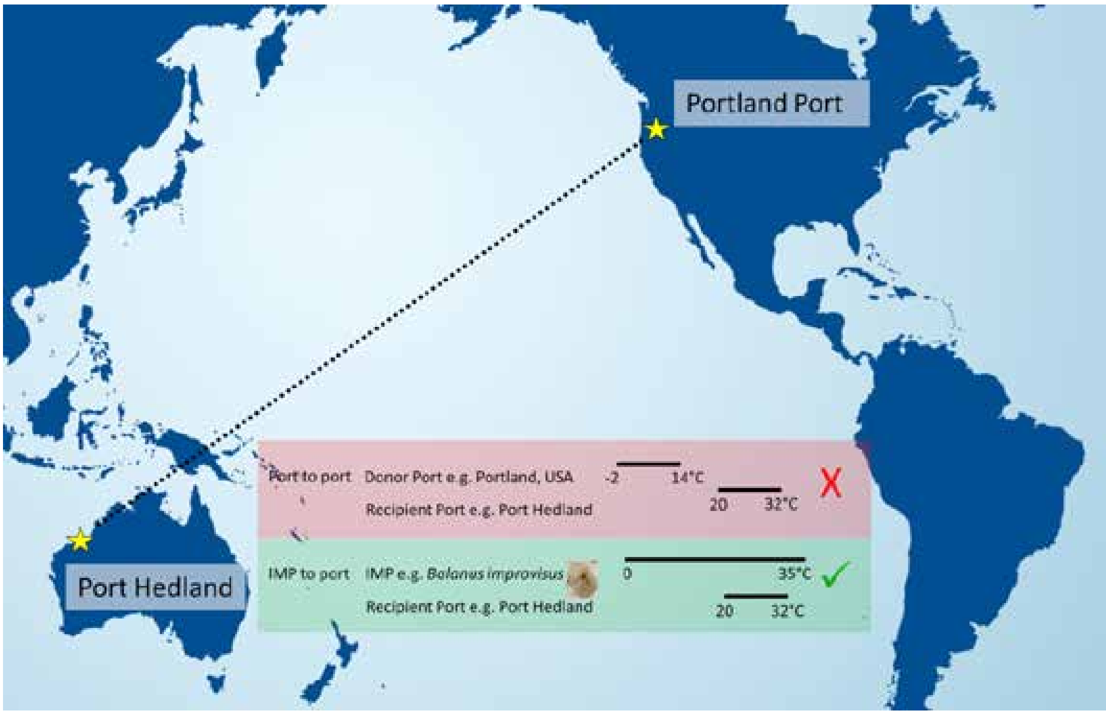

Figure 6 Example of the different results that can arise when 'port to port' and 'species-specific' comparisons are used

Compatible pest species and their frequency of occurrences were quantified internationally by country and domestically by port location. The compatible pests were also separated into high or moderate risk. The inoculation likelihood from a LPOC for Christmas Island Port was quantified by multiplying the number of vessels from a particular source with the number of pest species found that source.

5.0 Results and discussion

5.1 Vessel Inoculation likelihood

During 2011 Christmas Island received a total of 431 vessel visits. The dominant vessel type entering Christmas Island was cargo vessels, which comprised 40.6% of visits. Naval vessels were second at 37.6%, followed by bulk carriers at 8.8% and then recreational yachts at 7.7%. The remaining 4 vessel types were off-shore supply vessel, passenger vessels, research and tankers which collectively comprised just over 5% (Figure 7).

Total visits

There were 398 commercial visits to Christmas Island from 66 separate vessels. Thirty vessels (46%) only visited the port once. Nine (14%) visited between 2-5 times, nine vessels (14%) visited 6-10 times and 18 vessels or 28% of vessels visited greater than ten times (Figure 8). Thirty three recreational yachts visited Christmas Island during the 12 months of data; however no data was available on the frequency with which each of these yachts visited the island. Given the isolated location of the Island, it is likely that each yacht only visited the Islands only once within the year.

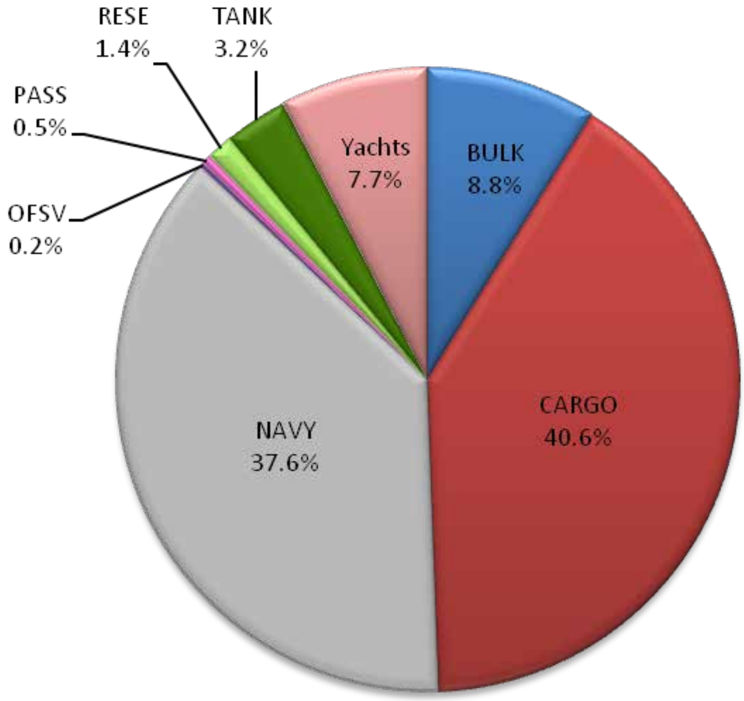

Figure 7 Summary of vessel types entering Christmas Island Port.

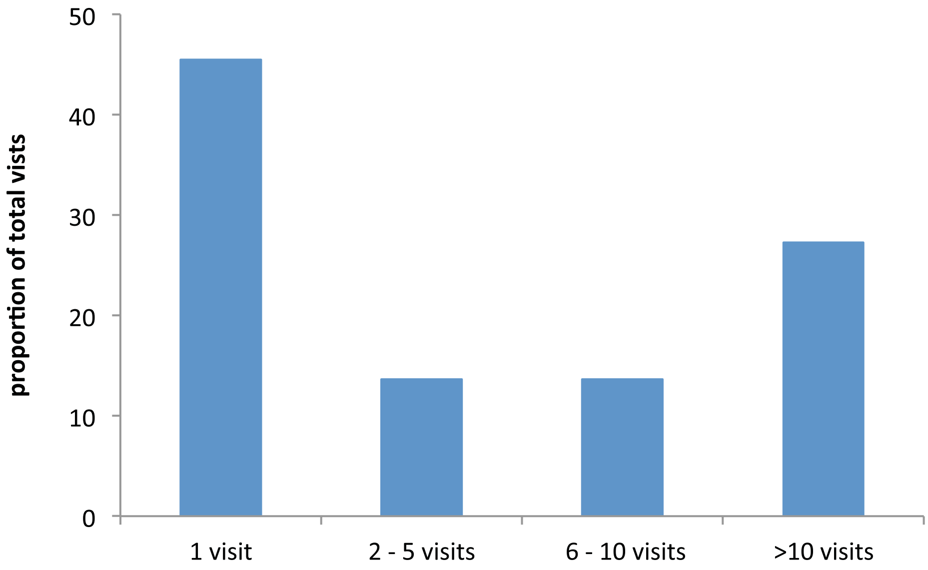

Figure 8 Commercial vessel visits broken down into single and categories of repeat visits.

Duration of stay

The greatest duration of stay was 6 days from a low risk cargo carrier. The average duration of stay for this vessel type was 1.5 days (ranging from 0.5 to 6 days). The remaining low risk vessels stayed an average of between 0.9 and 1 day. The highest recorded duration of stay for a moderate (research vessel) or high risk vessel (Naval vessel) was 1 day (Figure 9). NAVY were the only high risk vessel type recorded at Christmas Island, based on the data provided for the 2011 period. Duration of stay was not assessed for the 33 recreational yachts as there was no data available for the majority of these visits.

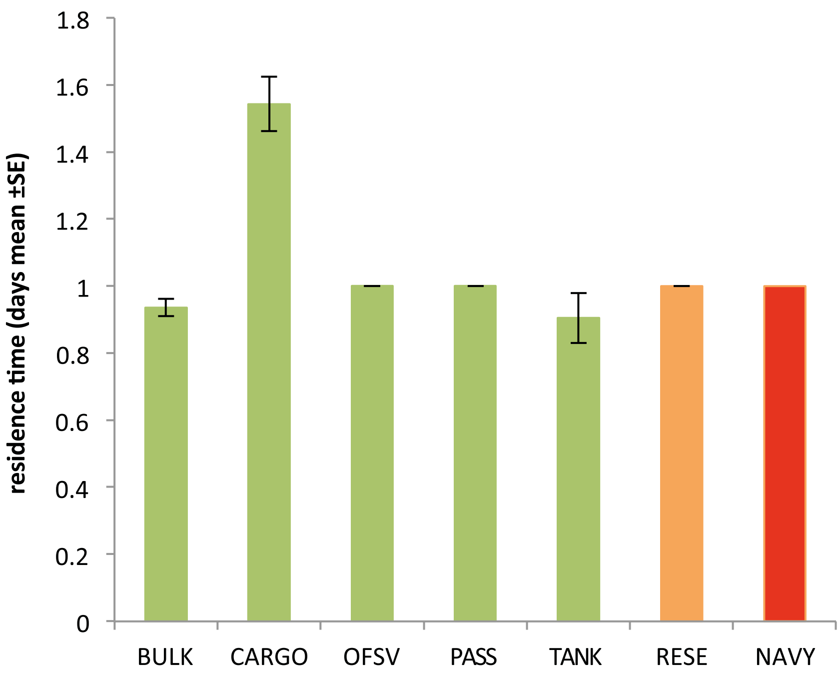

Figure 9 Mean residency time (days ± SE) for vessel types and risk (green low risk, orange moderate risk, red high risk) visiting Christmas Island.

Vessel source

The vast majority of commercial vessel visits from an international source were from low risk cargo carriers (156 visits; 78% of international visits), bulk carriers (37 visits; 18.5% of international visits) and tankers (8 visits; 4% of international visits) (Figure 10). There was one a single vessel visit from Interstate; a low risk cargo vessel (Figure 10).

Cargo vessels once again represented the majority of visits from intrastate sources (18 visits; 67% of intrastate visits). There were three other vessel types tankers (6 visits; 22% of intrastate visits) passenger vessels (2 visits 7.4% of intrastate vessel visits), and a single bulk carrier (4%) (Figure 10).

A number of vessels visiting Christmas Island had no last port of call (LPOC) data, these were Moderate risk vessels, comprised of 6 research vessels and a single offshore supply vessel (3.5% and 0.5% respectively (Figure 10) as well as High risk naval vessels which made up the remaining 96%.

Recreational yachts are classed as moderate risk vessels. The majority of recreational yacht visits were from an international source location (19 yachts, 57.6%), the remaining (11 yachts, 42.4%) were from interstate locations on the Australian mainland (Figure 11, Table 2).

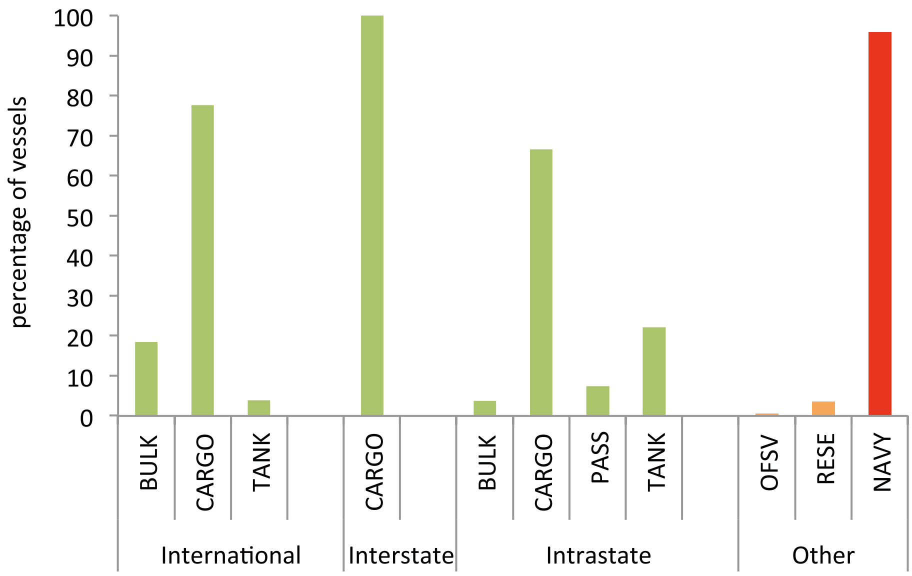

Figure 10 Percentage of commercial vessels arriving into Christmas Island from International, Interstate and Intrastate sources by vessel type and risk (green low risk, orange moderate risk and red high risk).

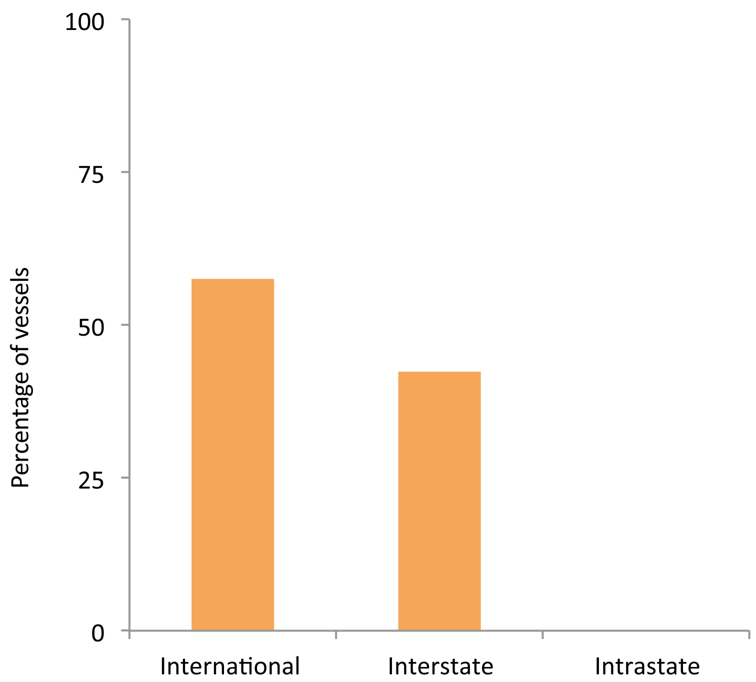

Figure 11 Percentage of recreational vessels arriving into Christmas Island from International, Interstate and Intrastate sources (orange moderate risk).

Of the 431 vessel visits to Christmas Island 398 visits were from commercial vessels. The majority of these commercial vessel visits were international, from nine different countries. All international commercial vessel visits to Christmas Island were from nearby Asian countries (Table 3) which have similar climatic profiles. Forty six percent of international commercial vessel visits were from Indonesia. Malaysia represents the second largest number of visits (31%) and Singapore at 12% (Table 3).

Domestic visits were from five locations only, a single interstate visit (from Darwin) and 27 intrastate visits from four separate locations (Table 3). The Cocos Keeling Islands was the greatest source (66.6%) of intrastate vessel visits; the remaining four locations were ranked Fremantle 18%; Bunbury 11.1% and Port Hedland 3.7% (Table 3).

Forty two percent of visits were classed as ‘other’ these were naval vessels (162 visits), research vessels (6 visits) and a single offshore supply vessel none of which provided details on their last port of call.

Table 2 Summary of recreational vessel visits to Christmas Island port from source locations.

Source	Number of visits	% of visits
International	**19**	**57.6**
Indonesia	17	89.4
Malaysia	1	5.3
Sri Lanka	1	5.3
Interstate	**14**	**42.4**
Brisbane	1	7.1
Cairns	2	14.3
Darwin	11	78.6

Table 3 Summary of commercial vessel visits to Christmas Island port from source locations and country.

Source	number of visits	% of visits
International	**201**	
East Timor	1	0.5
India	1	0.5
Indonesia	93	46.3
Malaysia	63	31.3
Pakistan	1	0.5
Singapore	25	12.4
Thailand	5	2.5
Vietnam	8	4
Philippines	4	2
Interstate	**15**	
Brisbane	1	7.1
Cairns	2	14.3
Darwin	12	78.6
Intrastate	**27**	
Bunbury	3	11.1
Cocos Island	18	66.7
Fremantle	5	18.5
Port Headland	1	3.7
Other	**169**	

5.1.1 Socio-political risk

Of the 16 flag states visiting Christmas Island 6 states were from countries regarded as Flags of Convenience (Figure 12A). Vessels from these FOC states represented 38% of all visits to Christmas Island (Figure 12B). The greatest proportion of FOC vessels were registered to Antigua and Barbuda (34% of FOC state visits), Panama (29% of FOC state visits) and Mongolia (29% of FOC state visits). The other three FOC states were Gibraltar (2% of FOC state visits); Malta and the Marshall Islands (both 3% of FOC state visits) (Figure 12C). Given the association between these states and often lower environmental standards vessels from these states may be regarded as posing a higher biosecurity risk than others.

Of the 16 flag states visiting Christmas Island only 5 (10.6% of total visits) have ratified the IMO BWM convention. However further analysis revealed that 3 of these 5 were from FOC states. FOC states often ratify convention but fail to have either the financial capacity or political will to enforce or implement the ratification. The lower environmental standards often associated with FOC states makes vessels from these countries a particularly high biosecurity risk. This potentially reduces the proportion of recognised flag state vessels that have ratified the IMO BWC entering Christmas Island to only 0.3% of total visits.

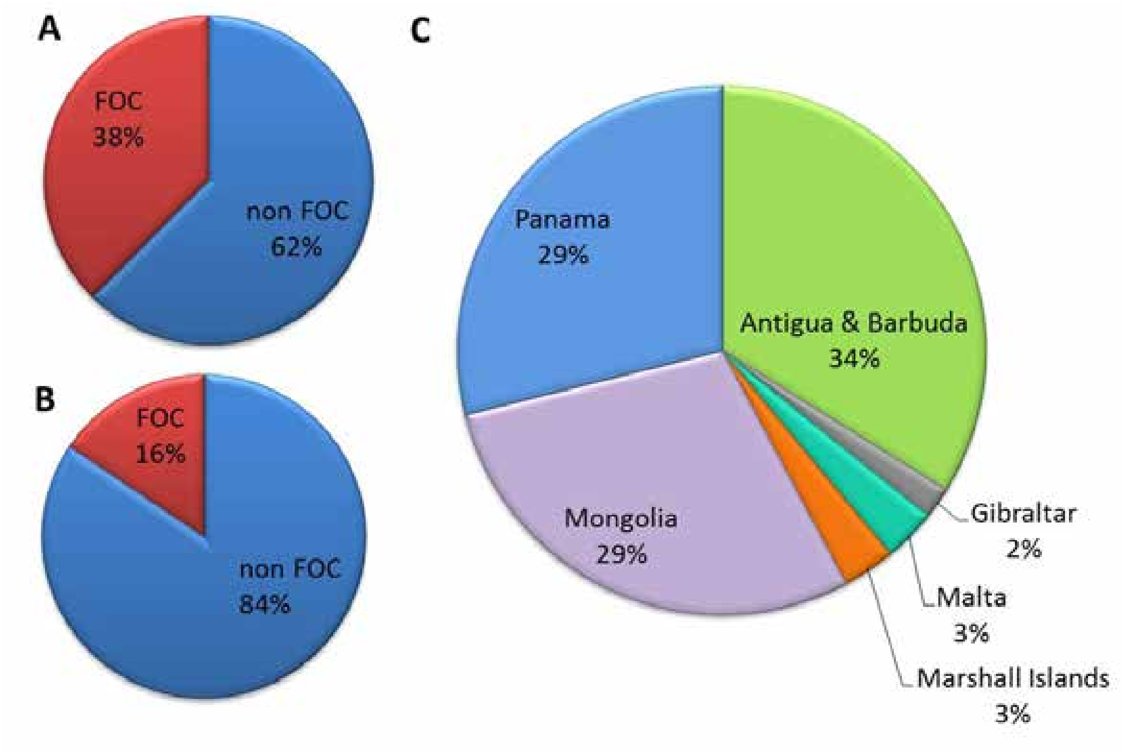

Figure 12 A) Proportion (%) of FOC and non FOC states visiting Christmas Island, B) Proportion (%) of vessel visits from FOC and non FOC states entering Christmas Island. C) Proportion (%) of FOC states visiting Christmas Island shown by country of vessel registry.

It is difficult to determine accurately the overall inoculation risk posed to Christmas Island by the vessels using the port. Although the majority of commercial vessels visiting Christmas Island were classed as low risk, single visit and short stay vessels, the results are confounded by the large number of naval and recreational vessels using the port, for which there are limited data. The high-risk naval vessels do not provided data on their last port of call and they are often in proximity to and dealing with SIEVs. The information for recreational vessels visiting Christmas Island does not include the duration of stay, although typically these vessels have relatively long residence time in ports. Including these unquantified, but potentially considerable risks, it is therefore more likely that the overall inoculation risk is substantially greater than that portrayed by the commercial vessel profile.

5.2 Port Infection and establishment likelihood

There were 23 IMP species identified as present at LPOC locations (*i.e.* source locations) of which, 21 had temperature and salinity tolerances that would potentially allow it to survive at Christmas Island. While all 21 compatible species were located in at least one of the international

LPOCs, several occurred at multiple locations, increasing the infection likelihood (Figure 13). For domestic sources there were two species located interstate and two intrastate (Figure 13). *Caulerpa taxifolia* and *Perna viridis* were present in the most sources (10 and 7 respectively) (Figure 13). The next most common species were *Carcinoscorpius rotundicauda* and *Balanus improvisus* both occurring at six locations each (Figure 13).

The macroalgae *C. taxifolia* has been reported as a problem elsewhere around the globe, however is a native to Western Australia and believed to be native to the IOT region (Huisman pers. comm). The mussel *Perna viridis* is known to have a very high fecundity, and can settle and recruit in very large numbers (NIMPIS, 2013). Both are notorious foulers of both artificial and natural substrates. The horseshoe crab *Carcinoscorpius rotundicauda* while listed as a species of concern has no clear evidence pest risk anywhere in the scientific literature. The barnacle *Balanus improvisus* competes with native organisms and it is an unwanted fouler on the shells of cultivated oysters and mussels and aquaculture cages (Leppäkoski, 1999). All species are discussed in greater detail later in this report.

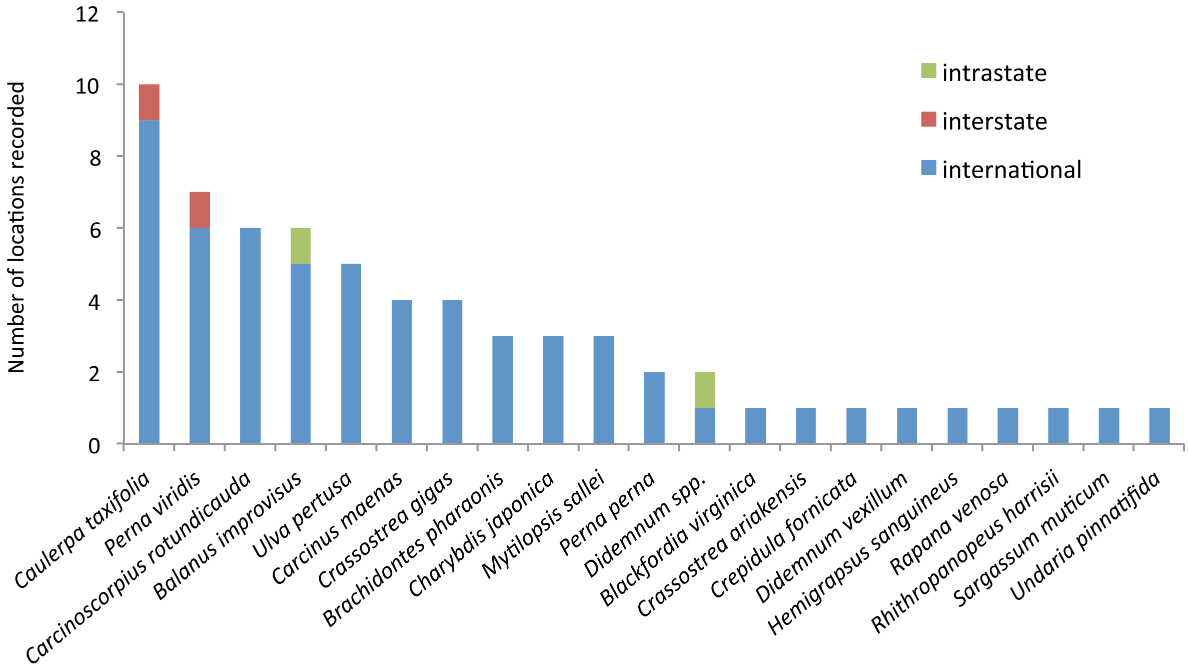

Figure 13 Number of LPOCs at which each of the 21 compatible pest species are found (Based on vessels LPoC).

Based on last port of call data there were nine countries which had vessels visiting Christmas Island that contained either a high or moderate IMP species (Figure 14). These LPOC countries varied considerably in the number and category (high or moderate risk) of IMP species present (Figure 14). Thailand had the greatest number of compatible high risk (11) and moderate risk (4) species (Figure 14). Followed by India (5 high, 4 moderate), Indonesia (4 high, 4 moderate) and then Malaysia (4 high, 3 moderate) (Figure 14). Most of the other LPOC countries had five or fewer high risk IMP. East Timor has no recognised IMP of concern although this is likely to be an artefact of no known IMP surveys being undertaken in this country.

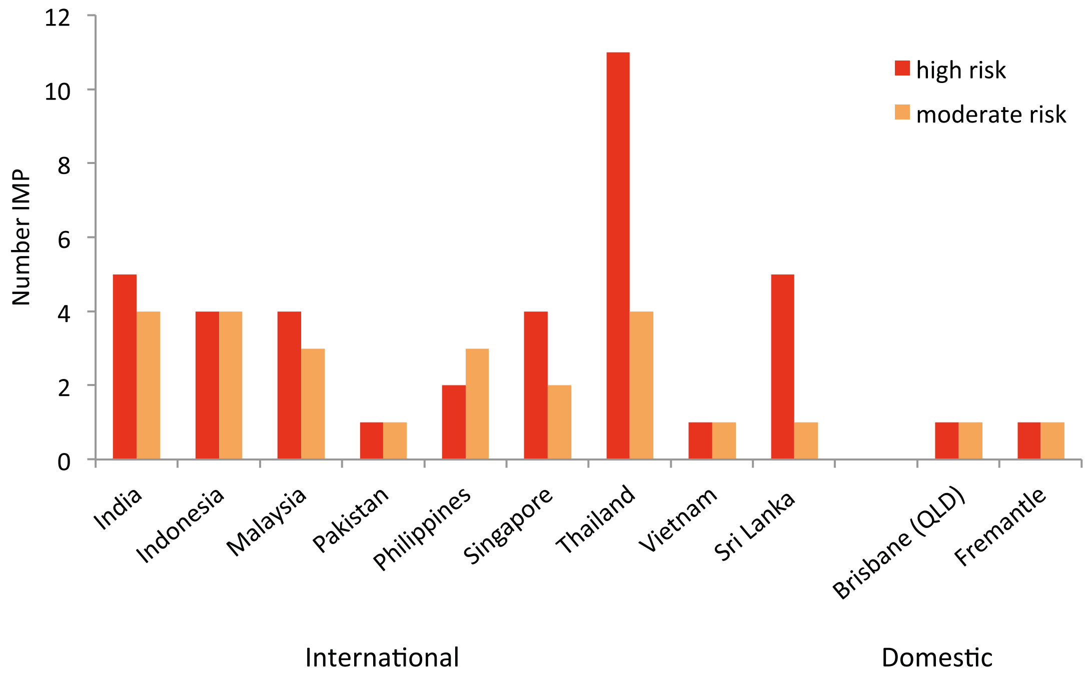

Figure 14 Number of high and moderate risk IMP present at international and domestic sources (based on vessels from LPOC – source locations with no compatible IMP are not included).

In terms of the total infection and establishment risk, when the number of vessels visits from a particular source and the number of species located at that same source are considered together, Indonesia represents an order of magnitude greater risk than all other international sources to Christmas Island Port (Figure 15). Selected IMPs from Indonesia that pose a risk to Christmas Island are shown in Figure 16 and discussed below. Countries or ports, for which the risk is negligible, are not shown.

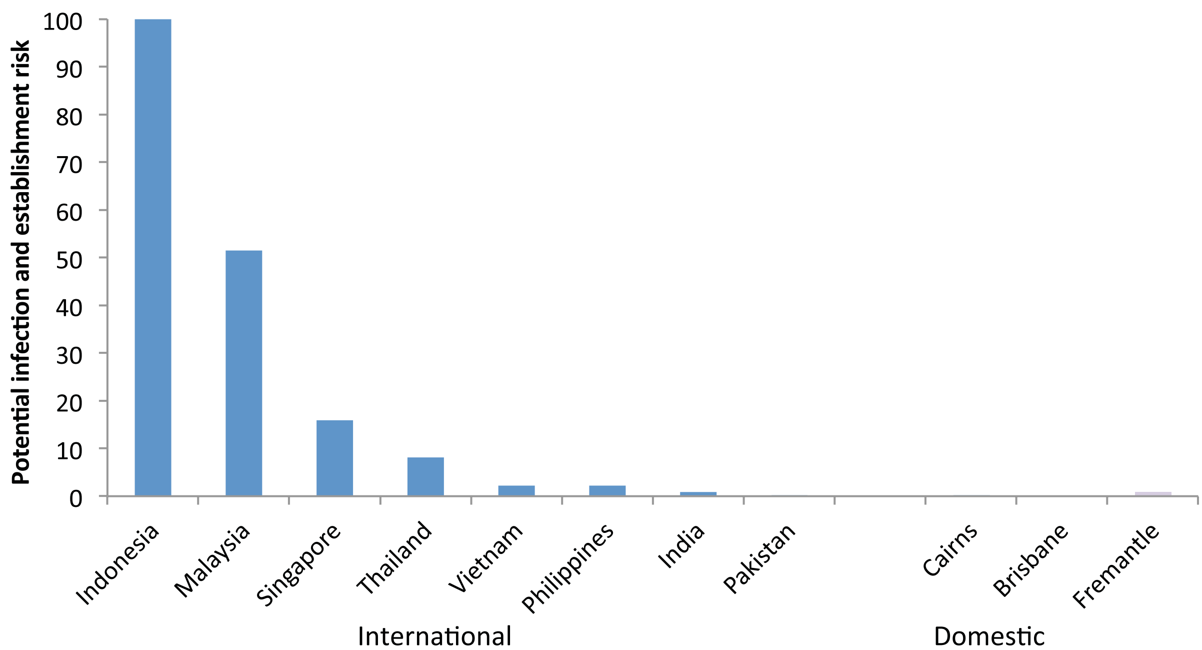

Figure 15 Ranking of the infection and establishment risk posed to Christmas Island Port by international and domestic LPOCs. Each LPOC value is expressed as a relative percentage of the largest LPOC value (*i.e.* Indonesia 100%)

Figure 16 Map showing the proximity of Indonesia (red circle) to Christmas Island (yellow star) and the selected IMPs that pose the greatest risk to Christmas Island Port.

5.2.1 *Caulerpa taxifolia*

Caulerpa taxifolia (Caulerpa) is a fast growing marine alga native to tropical and subtropical parts of Australia and the South Pacific that has colonised various areas outside its natural range. Caulerpa was first identified outside its natural range near Monaco in the Mediterranean Sea in 1984. By the end of 2000, the alga covered approximately 131 km^2 of seafloor in the Mediterranean (Meinesz *et al.* 2001). It was dubbed the aquarium strain as it was believed to have been accidentally released from aquaria. It has since colonised thousands of hectares in the Mediterranean from France to Croatia (although some populations have experienced dieback in recent years) and has also colonised two locations in California. The invasive nature of Caulerpa has raised concerns as it has the potential to grow rapidly, alter marine habitats and affect biodiversity.

It has been listed as one of the world's top 100 worst invasive species because it can potentially invade seagrass beds (Ceccherelli and Cinelli 1999), modify organic and inorganic components of the sediment (Chisholm and Moulin 2003) and threaten biodiversity (Meinesz *et al.* 2001). Expert opinion suggests that, while not specifically recorded, it may occur naturally at the Indian Ocean Territories (Huisman, pers com).

5.2.2 *Carcinoscorpius rotundicauda*

This species occurs only in Asia around the Indo-West Pacific region where the climate is tropical or subtropical (Chiu and Morton, 2003). Horseshoe crabs can be found throughout the Southeast 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 a body of their brackish, swampy water habitat, such as mangroves (Lim *et al.* 2001). While listed as a species of concern and likely to do harm by DOA 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 and Wilkens, 2011).

While acknowledging the data needs updating, this species is also currently listed on the IUCN Red List of Threatened Species (IUCN, 2013). This species, although technically capable of surviving at Christmas Island, is considered unlikely to become a marine pest as its preferred brackish / mangrove habitat does not exist on the island.

5.2.3 *Perna viridis*

Perna viridis is classed as a high-risk species to Australia and regularly tops the top ten lists of unwanted species. This species is native to much of South-East Asia where it is often farmed as a major food crop. It is known to be a prolific breeder, and can recruit in numbers of up to 60,000 individuals/m^2 (NIMPIS, 2013). The sheer numbers of recruiting individuals can smother and exclude native species. It has also been linked to numerous economic impacts relating to its fouling of vessels (Piola and McDonald, 2012; McDonald, 2012) and is notorious for clogging water pipes used by industrial complexes and fouling marine equipment. It has fouled the intake condenser tunnels of power plants in India (Rajagopal, *et al.* (1995) and Florida and navigational buoys where their biomass has grown to up to 72 kg/m^2 (USGS, 2013).

Perna viridis is a filter-feeding organism and as such can accumulate water contaminants including human pathogens and heavy metals if they are present in the water column. This intake and bioaccumulation of toxins has been linked to significant public health and disease risks if they are eaten (NIMPIS, 2013).

5.2.4 *Balanus improvisus*

The barnacle *Balanus improvisus* is another high-risk species likely to come from an international source. *Balanus improvisus* 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 (WoRMS, 2010). It is a fouling species and has been recorded as biofouling on vessels in Australian waters (McDonald pers. obs.)

It is tolerant of both high and low salinity levels and is often found in estuaries and low salinity bays as well as marine areas. As an invasive species it competes with native organisms and it is an unwanted coloniser of the shells of cultivated oysters and mussels and aquaculture cages (Leppäkoski, 1999). Once introduced into a new range this species has the potential to out compete native species for available habitat (Qvarfordt *et al.* 2006). Other impacts of B. improvisus include blocking water intake pipes, fouling mussels and oysters and the sharp shells can pose a health risk to humans (Leppäkoski, 1999).

5.2.5 SIEVs as a further risk consideration

Given the high profile nature of SIEVs it may seem surprising that there is no published data on the marine biosecurity risk that they represent. Yet given the slow moving, often poorly maintained nature of these vessels and the locations through which they travel they may pose a significantly higher quarantine risk than all the other vessel types.

Data concerning the number of SIEV vessels were difficult to source with the only direct information being for number of arrivals at the National level. No data could be sourced specifically for Christmas Island; as such interpretation of data presented below should bear this in mind. Figure 17 shows a clear increase in the incidence of SIEV vessels over the last 24 years. Based on anecdotal reports we estimate that approximately 30% of the totals shown below relate to Christmas Island.

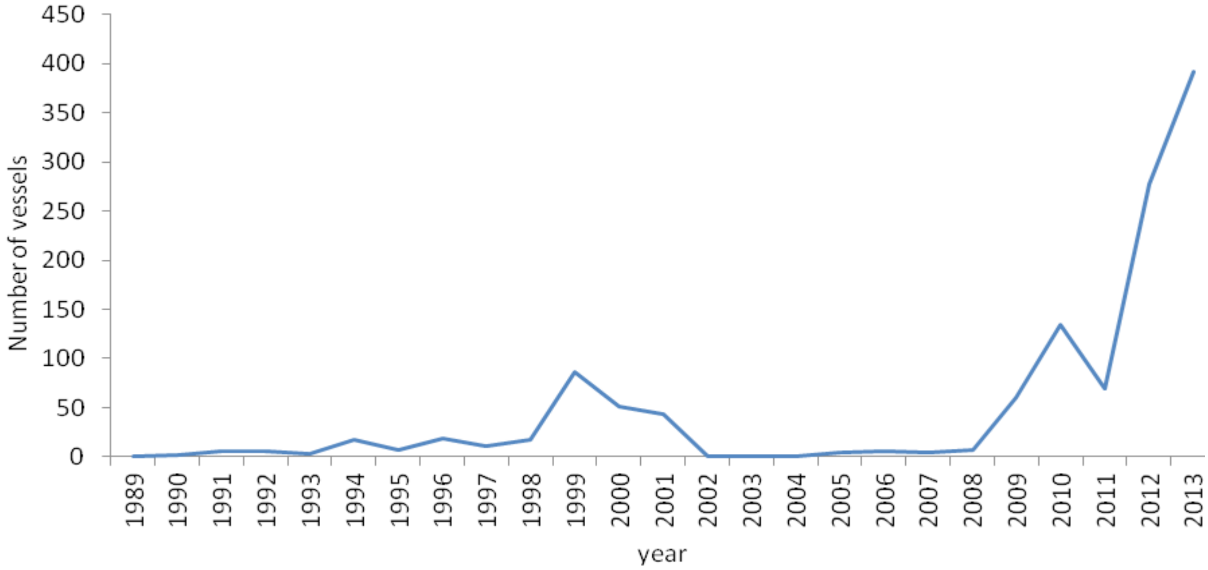

Figure 17 Numbers of SIEVs entering Australian waters annually, between 1989 and 2013.

SIEVs present a stereotypical profile for a vessel presenting a high-risk of introducing an IMP species. Vessels coming into Australia often come from locations where IMPs occur, they are slow-moving, often poorly maintained and undergo no inspection or cleaning prior to entering the country.

Settlement and development of biofouling is most likely in port regions when vessel speeds are low or are anchored / berthed, both from port to vessel (at the donor port), and from vessel to port (at the recipient port). Furthermore, those vessels with the greatest levels of biofouling tend to present the greatest establishment risk. Anecdotal information on a small number of SIEV's that have been inspected indicates that some have been infested with the highly invasive marine pest species Mytilopsis sallei, the black striped mussel, and the Asian green mussel, *Perna viridis*.

Coutts and Taylor (2004) assert that the most serious biofouling vectors are vessels that are poorly maintained or have been inactive for long periods, or vessels which have areas of anti-fouling that have been compromised. Given that many of the vessels entering Australian waters are regarded as un-seaworthy, the probability of effective cleaning and application of anti-foul occurring seem somewhat unlikely.

As this is currently not only an unmanaged, but also unknown risk, we suggest a comprehensive study into the amount and nature of biofouling on seized SIEVs entering Australian waters prior to their imminent destruction. Data on the source, numbers and residence time before disposal of these vessels would be invaluable in accurately assessing the precise risk that these vessels pose. Such data could help inform any future management approaches to SIEVs. Given the proclivity of irregular vessel entries into Australian waters and the high likelihood of IMPs as biofouling, it seems only a matter to time before an incursion occurs.

5.3 Cocos (Keeling) Islands

As mentioned previously, the numbers of vessels that entered the waters around the Cocos (Keeling) Islands during 2013 was considerably less than at Christmas Island. As such the data set was not large enough to analyse in the same way. Nevertheless, some inferences can be made regarding the risk of IMP incursion and establishment.

A total of 104 vessels arrived at the Cocos Islands in 2013, with 78 of those being yachts (75%). The next most common vessel types were SIEVS and cargo ships (10 vessels each) and smaller contributions of fuel tankers, customs vessels and tugs. It is evident from this profile of vessels, that the majority of traffic comprises moderate and high risk vessels, for which there is little or no information about the IMP transfer risk they pose.

6.0 Conclusions and recommendations

Determining the overall likelihood of the introduction of a marine pest can help inform current and future biosecurity risks and management. This document analysed the likelihood of a marine pest inoculating, infecting and establishing in Christmas Island's aquatic resources. The absence of robust data limited any analyses for Cocos Island however given the location and likely visitation by many of the same vessels the biosecurity risks to the Cocos Islands could be assumed to be comparable to those of Christmas Island. This analysis has increased the understanding of the risks posed to Christmas Island port for vessel and donor ports, including:

1. Identifying where the greatest risk of inoculation is coming from (LPOC), internationally, interstate or intrastate.
2. Identifying the IMP most likely to infect the 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.
3. Highlighting 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.

The Indian Ocean Territories receive a significant number of Suspected Irregular Entry Vessels (SIEVs). However to the best knowledge of the authors there are no accessible records that could be used for this analysis. In the absence of robust data to the contrary and based on the general characteristics of these vessels, these vessels and the areas they visit would be classed as high risk. During the compilation of the data for this report, it was confirmed that while information is collected about the terrestrial and human biosecurity risks of SIEVs, no agency collects data on their marine biosecurity risk.

7.0 Recommendations and gaps

There is the very obvious gap in intelligence on the biosecurity risk posed by SIEVs to the IOTs. This gap represents an unacceptable biosecurity risk and needs to be addressed not only for the IOTs but for any other vessels (secondary vectors) that come into contact with the SIEVs and the subsequent locations these secondary vectors may visit (e.g. naval vessels returning to Darwin).

It was evident from the data provided to the Department for this and a related study (Bridgwood and McDonald, in press) that there are considerable gaps in the quality and consistency of data collected by ports. For this analysis a minimum of seven pieces of information were required. These included:

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

8.0 Acknowledgements

The authors would like to thank the Port Authority staff at both Christmas and Cocos (Keeling) ports for their help, advice and the provision of vessel data. Thanks also to Pia Dobson from the Department of Fisheries for her help in tracking down some of the more difficult to obtain data sets used in this publication.

9.0 References

Ahyong, S. T., Wilkens, S. L. (2011) Aliens in the Antipodes: Non-indigenous marine crustaceans of New Zealand and Australia (pp 451-485). In: Galil, B.S., Clark, P.F., Carlton, J.T. (eds) In the Wrong Place – Alien Marine Crustaceans: Distribution, Biology and Impacts, Invading Nature – Springer series in invasion ecology (Vol 6). Springer.

Barry, S. C., Hayes, K. R., Hewitt, C. L., Behrens, H. L., Dragsund, E & Bakke, S. M. (2008) Ballast water risk assessment: principles, processes, and methods. *ICES Journal of Marine Science.* **65:** 121-131.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E. and Geeves, W. (2003) Marine invasive alien species: a threat to global biodiversity. *Marine Policy* **27:** 313-323.

Berry P. F. (1989) *Survey of the Marine Fauna of Christmas Island, Indian Ocean.* Western Australian Museum, Perth, Western Australia.

Berry, P. F. and Wells, F. E. (2000) Survey of the marine fauna of the Montebello Islands, Western Australia and Christmas Island, Indian Ocean, *Records of the Western Australian Museum.* Supplement 59.

Brewer, D. T., Potter, A., Skewes, T. D., Lyne, V., Anderson, J., Davies, C. Taranto, T., Heap, A. D., Murphy, N. E., Rochester, W. A., Fuller, M. and Donovan, A. (2009) *Conservation Values in the Commonwealth Waters of the Christmas and Cocos Islands Remote Australian Territories.* CSIRO, Cleveland.

Bridgwood, S. B. and McDonald, J. M. (in press) A likelihood analysis of the introduction of marine pests to Western Australian Ports via commercial vessels. Fisheries Research report. Department of Fisheries, Western Australia.

Ceccherelli, G. and Cinelli, F. (1999b) *Effects of Posidonia oceanica* canopy on *Caulerpa taxifolia* size in a north-western Mediterranean bay. J*ournal of Experimental Marine Biology and Ecology* **240:** 19-36.

Chiu, H. M. C. and Morton, B. (2003) The morphological differentiation of two horseshoe crab species, *Tachypleus tridentatus* and *Carcinoscorpius rotundicauda* (Xiphosura), in Hong Kong with a regional Asian comparison. *Journal of Natural History* **37:** 2369–2382.

Clarke, C., Hilliard, R., Junqueira, A.de O. R, Neto, A. de C. L., Polglaze, J. and Raaymakers, S. (2004). *Ballast Water Risk Assessment Port Sepetiba Federal Republic of Brazil, December 2003: Final Report.* GloBallast Monograph Series No. 14. IMO London.

Coutts, A. D. M., and Taylor, M. D. (2004) A preliminary investigation of biosecurity risks associated with biofouling on merchant vessels in New Zealand. *New Zealand Journal of Marine and Freshwater Research.* **38:** 215-229.

(DOT) Department of Transport (2013). *Ports Handbook. Western Australia 2013.* Department of Transport. pp. 40.

GHD (2004) *Christmas Island Introduced Marine Pest survey - 2004.* Report to the Department of Transport and Regional Services. Australia pp. 56.

Hayes, K. R. and Sliwa, C. (2003). Identifying potential marine pests – a deductive approach applied to Australia. *Marine Pollution Bulletin.* **46:** 91-98.

Hewitt, C. L. and Martin, R. B. (2001). Revised protocols for baseline port surveys for introduced marine species; Survey design sampling protocols and specimen handling. *Technical Report 22.* CSIRO Marine Research, Hobart. pp. 46.

Hewitt, C., Campbell, M., Coutts, A., Dahlstrom, A., Shields, D. and Valentine, J. (2010) *Assessment of Marine Pest Risks Associated with Biofouling.* Report for the Department of Agriculture, Fisheries and Forestry. Commonwealth of Australia. pp vii + 69.

Hourston, M. (2012) Christmas Island Marine Pest monitoring survey. Post Implementation report 2011. Port of Christmas Island (CXXCH). Department of Fisheries, Western Australia.

Hourston, M. (2013) Christmas Island Marine Pest monitoring survey. Post Implementation report 2013. Port of Christmas Island (CXXCH). Department of Fisheries, Western Australia.

Huisman, J. M., Jones, D. S., Wells, F. E., and Burton, T. (2008) Introduced marine biota in Western Australian Waters. *Records of the Western Australian Museum* **24:** 323-366.

Hulme, P.E. (2009). Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology.* **46:** 10-18.

(IMO) International Maritime Organisation. Frequently Asked Questions. Accessed 13/08/13. URL http://www.imo.org/About/Pages/FAQs.aspx.

(ITWF) International Trade Workers Federation (2014) What are flags of convenience? Accessed 7/04/14 http://www.itfglobal.org/flags-convenience/sub-page.cfm.

(IUCN) International Union for the Conservation of Nature (2013) World Conservation Monitoring Centre 1996. *Carcinoscorpius rotundicauda*. In: IUCN Red List of Threatened Species. Version 2013.1. <www.iucnredlist.org>. Downloaded on 20 August 2013.

Knudsen, O. F. and Hassler, B. (2011). IMO legislation and its implementation: accident risk, vessel deficiencies and national administrative practices. *Marine Policy.* **35:** 201-207.

Lewis, P. N., Riddle, M. J. and Hewitt, C. L. (2004). Management of exogenous threats to Antarctica and the sub-Antarctic Islands: balancing risks from TBT and non-indigenous marine organisms. *Marine Pollution Bulletin.* **49:** 999-1005.

Leppäkoski, E. (1999) "*Balanus improvisus* (Darwin 1854), Balanidae, Cirripedia". In: Gollasch, S., Minchin, D., Rosenthal H. & Voigt, M. (eds.) (1999): Exotics Across the Ocean. Case Histories on Introduced Species: Their General Biology, Distribution, Range Expansion and Impact. Logos Verlag, Berlin. 78 pp. ISBN 3-89722-248-5. Copyright with Logos Verlag, Berlin.

Lim, K. K. P., Murphy, D. H., Morgany, T., Sivasothi, N., Ng, P. K. L., Soong B. C., Tan, H. T. W., Tan K. S., and Tan T. K. (2001) Mangrove horseshoe crab, *Carcinoscorpius rotundicauda*, family Limulidae. In P. K. L. Ng & N. Sivasothi (Eds). *A Guide to Mangroves of Singapore Volume 1.* Singapore Science Centre. <accessed 20/08/2013> http://mangrove.nus.edu.sg/guidebooks/text/2076.htm.

McDonald, J. I. (2008) *A Likelihood Analysis of Non-indigenous Marine Species Introduction to Fifteen Ports in Western Australia.* Fisheries Research Report No. 182. Department of Fisheries, Western Australia. pp. 36.

McDonald, J. I. (2012) Detection of the tropical mussel species *Perna viridis* in temperate Western Australia: a possible association between spawning and a marine heat pulse. *Aquatic Invasions.* **7:**483-490.

McGee, S., Piorkowski, R. and Ruiz, G. (2006). Analysis of recent vessel arrivals and ballast water discharge in Alaska: toward assessing ship-mediated invasion risk. *Marine Pollution Bulletin.* **52:** 1634-1645.

Meinesz, A., Belsher, T., Thibaut, T., Antolic, B., Mustapha, K., Boudouresque, C. F., Chiaverini, D., Cinelli, F., Cottalorda, J. M., Djellouli, A., El Adeb, A., Orestano, C., Grau, AM., Ivesa, L., Jaklin, A., Langar, H., Massuti-Pascual, E., Peirano, A., Tunesi, L., de Vaugelas J,, Zavodnik, N. and Zuljevic, A. (2001) The introduced green alga *Caulerpa taxifolia* continues to spread in the Mediterranean. *Biological Invasions* **3:** 201-210.

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Biodiversity synthesis.* World Resources Institute, Washington, DC.

(NIMPCG) National Introduced Marine Pest Coordination Group (2010) *Australian Marine Pest Monitoring Manual: Version 2.0.* Unpublished report. pp. 45.

(NIMPIS) The National Introduced Marine Pest Information System (2013) "Asian Green Mussel". National Introduced Pest Marine Information System. Accessed August 2013.

Piola R. F., and McDonald, J. I. (2012) Marine Biosecurity: The importance of awareness, support and cooperation in managing a successful incursion response. *Marine Pollution Bulletin.* **64:** 1766-1773.

Pughiuc, D. (2010). Invasive Species: ballast water battles. *Seaways.* March 2010, p 5-7. Available: http://www.imo.org/KnowledgeCentre/PapersAndArticlesByIMOStaff/Documents/Invasive%20species%20by%20DP.pdf.

Qvarfordt, S., Kautsky, H and Torleif, M. (2006). Development of fouling communities on vertical structures in the Baltic Sea. *Estuarine, Coastal Shelf Science.* **67:** 618 – 628.

(USGS) United States Geological Survey (2013). *Non-indigenous Species Information Bulletin: Green mussel, Perna viridis* (Linnaeus,". U.S. Geological Survey. Accessed August 2013.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Rajagopal, S., Venugopalan, V. P., Azariah, J. and Nair, K. V. K. (1995) Response of the green mussel *Perna viridis (L.) to heat treatment in relation to power plant biofouling control. Biofouling* **8:** 313–330.

Ruiz, G. M., Fofonoff, P., W. Carlton, J. T., Wonham, M. J. and Hines, A. H. (2000) Invasion of coastal marine communities in North America apparent patterns, processes, and biases. *Annual Review of Ecology and Systematics.* **13:** 481-531.

(WoRMS) World Register of Marine Species (2010). "*Balanus improvisus* Darwin, 1854". http://www.marinespecies.org/aphia.php?p=taxdetails&id=106218. Retrieved April 18, 2010.

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
	Environment	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
	Environment	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
	Environment	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**