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

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Abstract

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

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

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

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

- Dampier;
- Fremantle; and
- Port Hedland.

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

1.0 Introduction

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

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

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

1.1 Non-indigenous marine species in Western Australia

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

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

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

1.2 Invasion potential

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

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

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

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

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

1.3 The aims of this document

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

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

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

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

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

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

2.0 Methods

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

2.1 Ranking criteria

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

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

2.2 Dead weight tonnage

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

2.3 Vessel risk categorisation

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

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

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

1= low frequency/risk

2= medium or moderate frequency/risk

3= high frequency/risk.

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

< 2 = a low fouling propensity;

2.0 – 2.5 = a moderate fouling propensity; or

> 2.5 = a high fouling propensity

2.4 Ranking the high-risk locations using all likelihood criteria

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

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

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

3.0 Results

3.1 Vessels entering Western Australian ports

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

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

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

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

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

3.2 Ballast water discharge

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

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

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

3.3 Vessel categories

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

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

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

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

International source of ballast water:

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

Domestic source of ballast water:

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

3.4 Vessel Dead Weight Tonnage (DWT)

3.4.1 DWT per vessel category

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

3.4.2 DWT for each high-risk location

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

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

3.5 Vessel risk categorisation

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

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

3.6 Relative likelihood of NIMS introduction for each Port

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

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

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

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

4.0 Discussion

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

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

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

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

4.1 Recommendations

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

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

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

5.0 Acknowledgements

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7.0 Tables and Figures

7.1 Tables

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

7.2 Figures

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

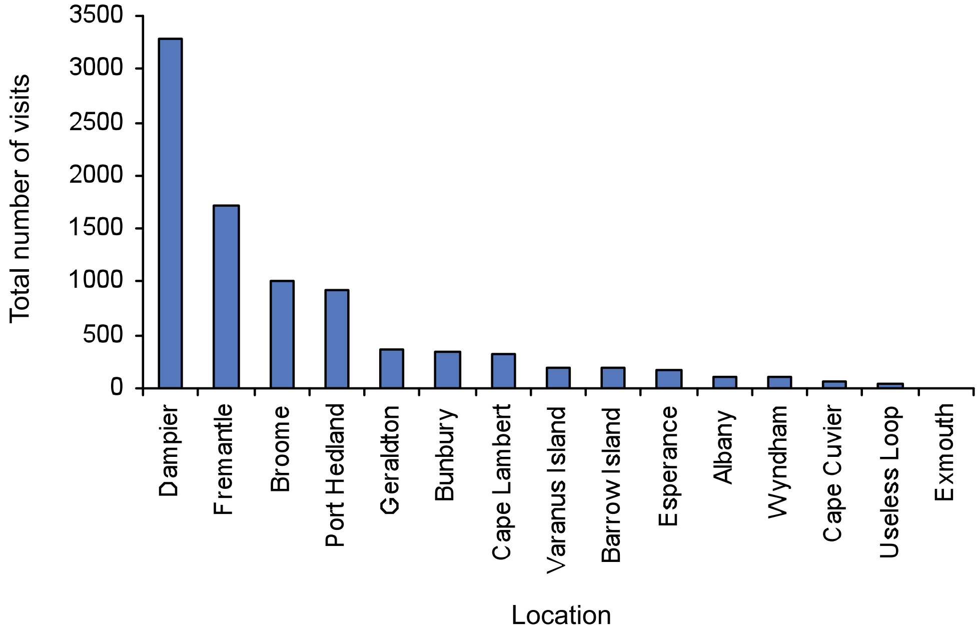

Figure 2. Total number of visits recorded for each port in 2006.

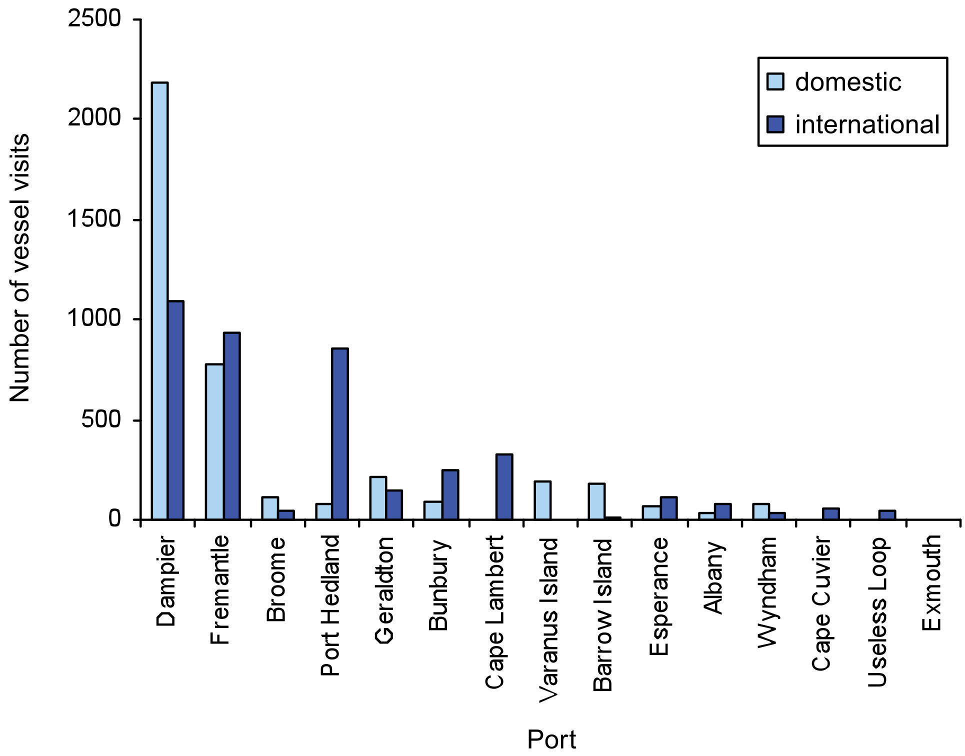

Figure 3. Number of international and domestic visits recorded for each port in 2006.

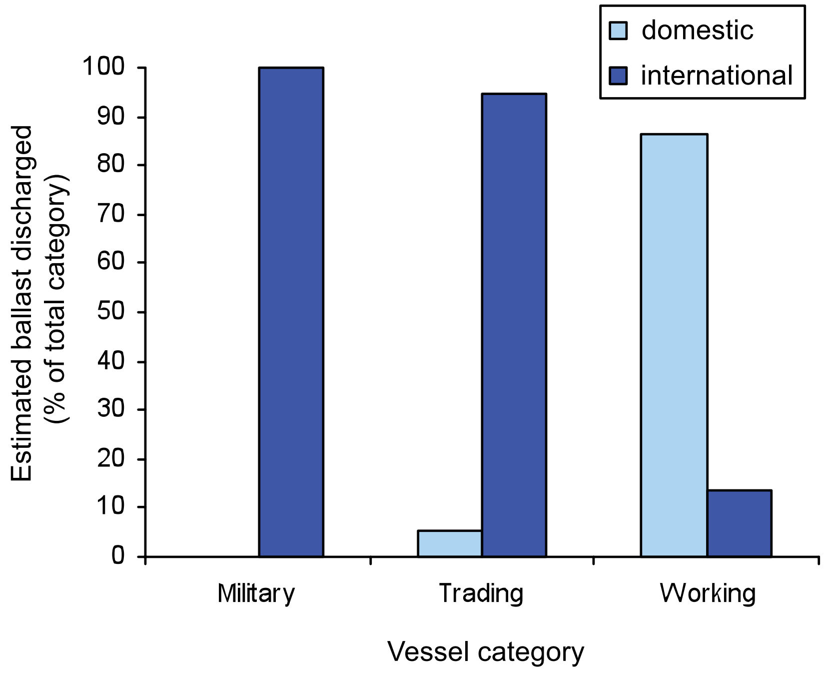

Figure 4. Amount of domestic or international sourced ballast water discharged from three vessel categories (as a percentage of total number) in 2006. Number of vessels per category and amount of ballast water discharged: Military vessels - 2 international vessels (450 tonnes); Trading vessels - 744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

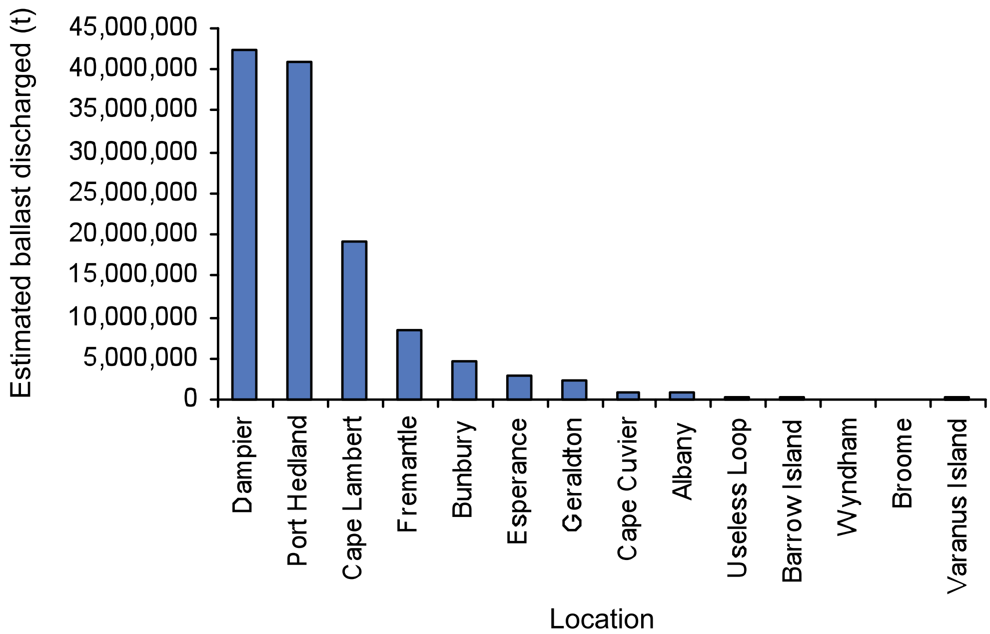

Figure 5. Total estimated ballast water discharged at each port in 2006.

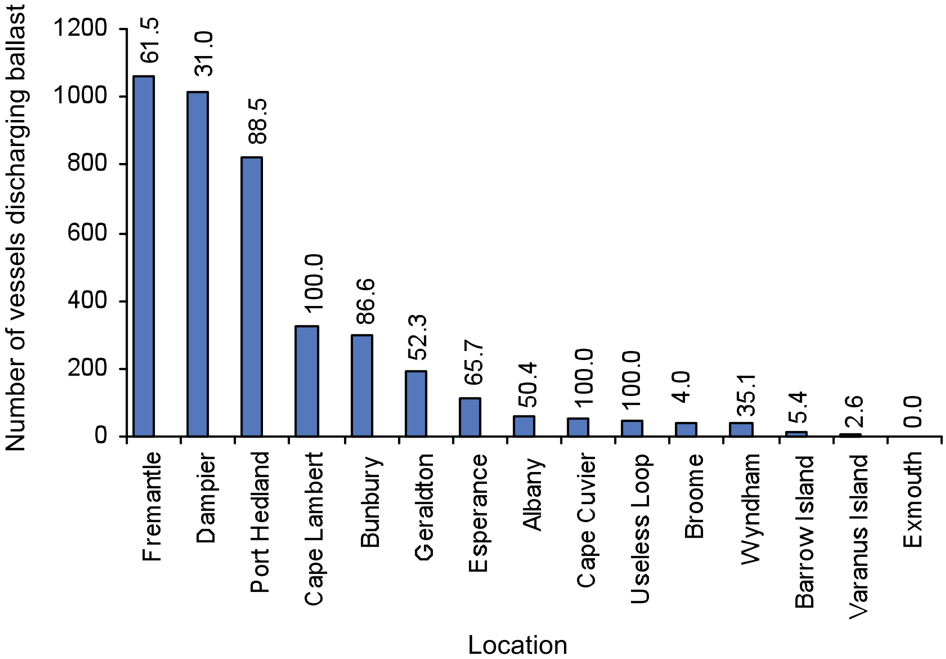

Figure 6. Number of vessels estimated to discharge ballast water at each port in 2006 (Values above bars represent the percentage of vessels estimated to discharge ballast water per port).

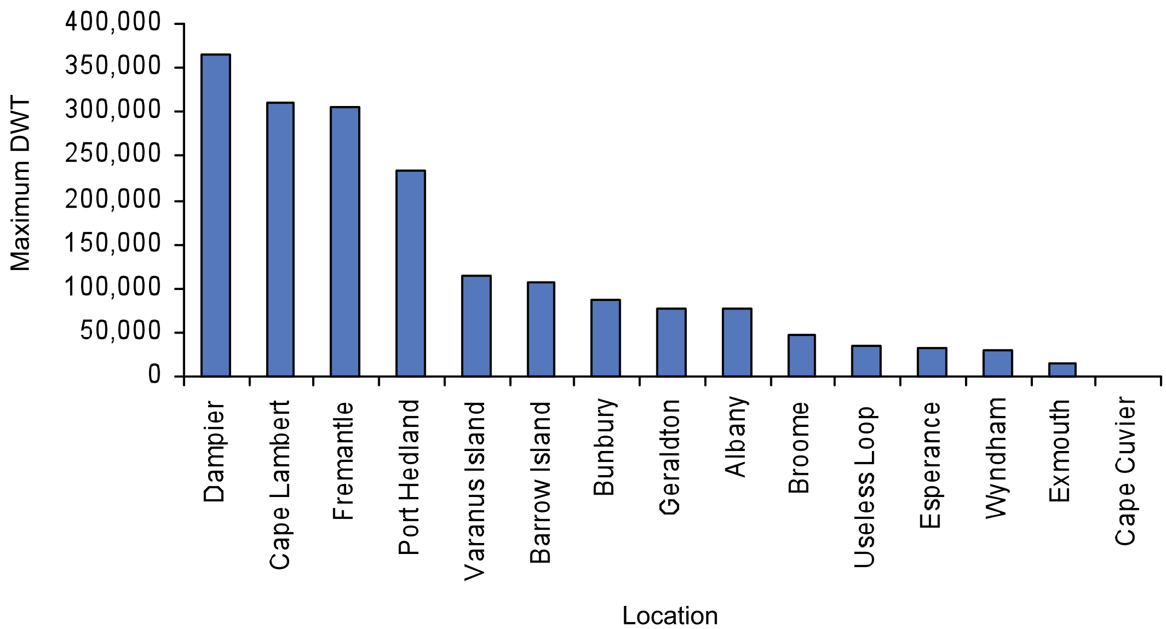

Figure 7. Maximum DWT for vessels visiting each port in 2006.

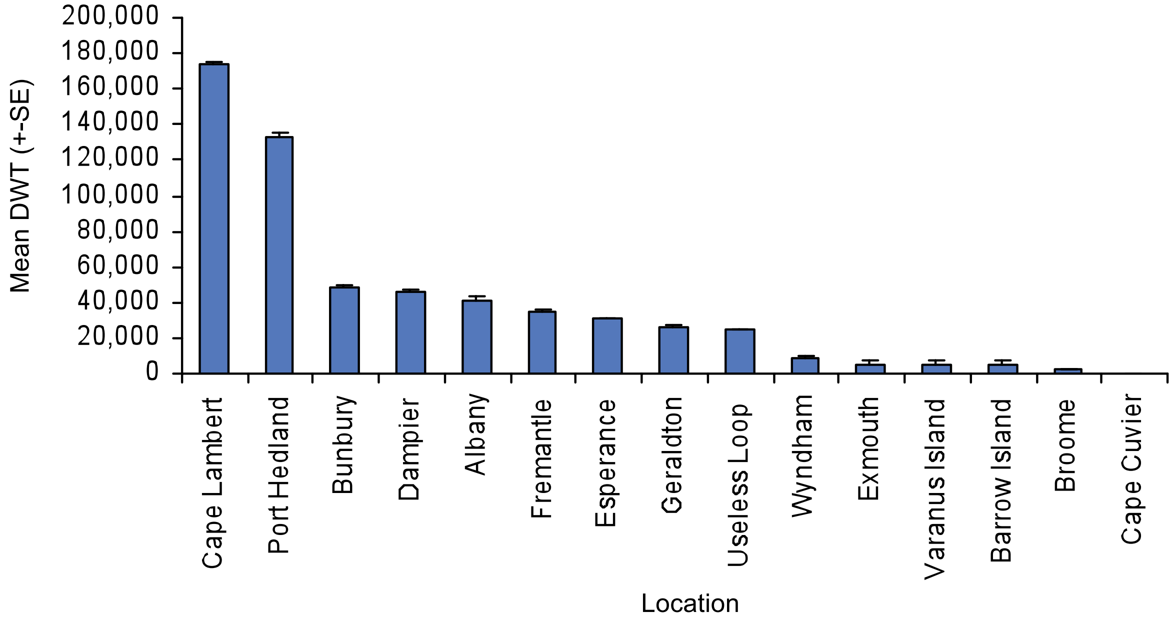

Figure 8. Mean (± SE) DWT for vessels visiting each port in 2006.

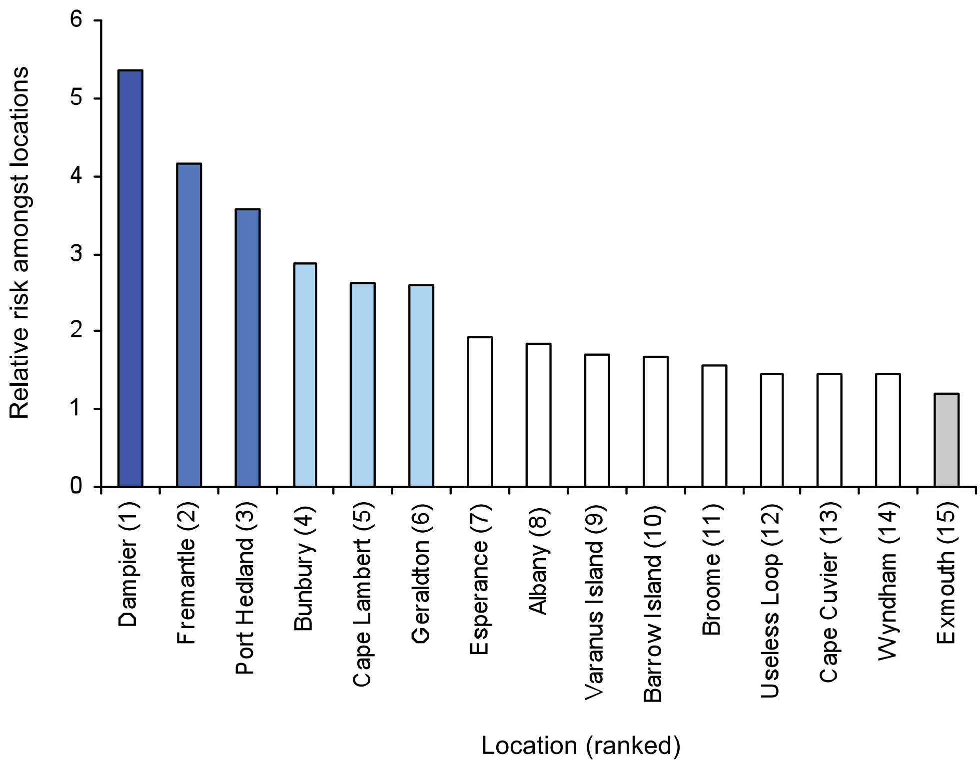

Figure 9. Relative likelihood of NIMS introduction amongst all ports evaluated. Values in brackets alongside location names indicate likelihood ranking from this study.

8.0 Appendices

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

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

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

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

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

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