2000

CENTRE FOR RESEARCH ON INTRODUCED MARINE PESTS

INTRODUCED SPECIES SURVEY, PORT OF FREMANTLE AND COCKBURN SOUND, WESTERN AUSTRALIA

CHAD L. HEWITT, MARNIE L. CAMPBELL, KIRRILY M. MOORE, NICHOLAS B. MURFET

AND FELICITY MCENNULTY

PREFACE

A prerequisite for any attempt to control the spread by shipping of introduced marine pest species in Australian waters is a knowledge of the current distribution and abundance of exotic species in Australian ports. This information base is lacking for nearly all Australian ports. The current port survey program is a joint initiative of the Australian Association of Port and Marine Authorities (AAPMA) and the CSIRO Centre for Research on Introduced Marine Pests (CRIMP) and is supported by the Australian Ballast Water Management Advisory Council (ABWMAC). The program seeks to redress the lack of knowledge about the occurrence of exotic species in Australian ports and provide a consistent basis on which the introduced species status of individual ports can be assessed.

Port surveys designed to identify all exotic species will inevitably be subject to scientific, logistic and cost constraints that will limit both their taxonomic and spatial scope. Recognition of these constraints has lead AAPMA and CRIMP to adopt a targeted approach which concentrates on a known group of species and provides a cost effective approach to the collection of baseline data for all ports. The targeted surveys are designed to determine the distribution and abundance of a limited number of species in each port. These species are listed in Appendix 1 and are made up of:

- those species listed on the Australia Ballast Water Management Advisory Council's (ABWMAC) schedule of introduced pest species;
- a group of species which are major pests in overseas ports and which, on the basis of their invasive history and projected shipping movements, might be expected to colonise Australian ports; and
- those known exotic species in Australian waters that currently are not assigned pest status.

The targeted surveys will also identify species of uncertain status (endemic or introduced) that are abundant in a port and/or are likely to become major pest species. A major component of each port survey is a local public awareness program designed to collect information that might indicate the presence of introduced species in the port and adjacent areas, the approximate date of introduction, and potential impacts on native marine communities.

This report details the targeted ABWMAC pest species results of an introduced species survey of the Port of Fremantle, Western Australia, carried out between 18th April to 14th May, 1999. The survey was funded by a consortium of interests led by the Fremantle Port Authority and was conducted by CRIMP in conjunction with the Marine and Freshwater Research Laboratory , Murdoch University.

CONTENTS

EXECUTIVE SUMMARY

The original Port of Fremantle is located in the mouth of the Swan River on the coast of Western Australia approximately 15 km southwest of Perth (32º 02'S, 115º 44'E). In more recent times further port facilities, specifically large bulk-loading facilities, have been developed in Cockburn Sound (Kwinana region), south of the mouth of the Swan River (32° 12'S, 115° 45'E) (Figure 1). The berths within the Swan River are chiefly container terminals and break bulk berths while in the Kwinana region the principal commodities are alumina, grain, oil and other bulk cargo. Additionally there are numerous artificial small boat harbours in the region, including those around the mouth of the Swan River, (Rous Harbour, Success Boat Harbour, Fishing Boat Harbour and Challenger Harbour), and Jervoise Bay within Cockburn Sound. The Royal Australian Navy base on Garden Island has a number of berths and structures associated with an historically significant location relative to vessel careening.

A survey for introduced species was carried out in the port and on the adjacent coast between 18th April and 14th May, 1999. The survey focused on habitats that were likely to be colonised by introduced species and used the sampling protocols developed for the National Australian Ports Surveys. Of the targeted ABWMAC pest species (*Asterias amurensis*, *Carcinus maenas*, *Corbula gibba, Crassostrea gigas, Musculista senhousia, Sabella spallanzanii*, *Undaria pinnatifida),* two species were detected. The European fan worm, *Sabella spallanzanii,* was widespread throughout the sampling area; and the Asian date mussel, *Musculista senhousia*, was found in the Inner Harbour, Bathers Beach and the Southern Flats in Cockburn Sound. Preliminary results of the dinoflagellate analyses have identified one of the ABWMAC target species, *Alexandrium tamarense,* in low concentrations (<1 cyst/g) in the Inner Harbour, harbour entrance, Challenger Harbour, and Owen Anchorage. Germination efforts to confirm toxicity of these strains have not been successful and molecular genetic sequencing will be required to assess whether they represent native or introduced populations. The cyst assemblages encountered in the port of Fremantle are essentially similar to those found further upstream in the Swan River and the Port of Bunbury.

No other ABWMAC pest species were recorded from the port or immediate adjacent regions.

Several other introduced and cryptogenic (of unknown origin) species were recorded from the region. These species are recognised as having been transferred to Australia in both historic and modern times, but do not pose significant economic or environmental threat. These species include the bryozoans, *Bugula neritina, B. flabellata*, *Tricellaria occidentalis*, *Cryptosula pallasiana,* and *Watersipora subtorquata(?),* the hydroid *Tubularia ralphi*, the ascidians *Ascidiella aspersa* and *Ciona intestinalis,* and the fish *Tridentiger trigoncephalus.* These species are all known from Australia but do not have pest status. The presence of these species in specific portions of the port allows an evaluation of the transport vectors into Australia and highlights invasion "hot spots" within the port to aid in the establishment of monitoring sites.

1. DESCRIPTION OF THE PORT

1.1 GENERAL FEATURES

The port of Fremantle is located on the coast of Western Australia approximately 15 km southwest of Perth (32º 02'S, 115º 44'E). For the purpose of this study, the port of Fremantle was split into eight regions;

1) North Bank Area (Fremantle to Jervoise Bay)
2) Kwinana (Jervois Bay to CBH Jetty)
3) Rockingham and Southern Flats
4) Garden Isle (HMAS Stirling Naval Base and West Coast)
5) Middle Basin of Cockburn Sound
6) Gage Roads and Adjacent Coastline
7) Swan River
8) North of Fremantle Harbour

The North Bank Area includes the original port of Fremantle, which is located in the mouth of the Swan River (Figure 1). The port areas extend along the banks of the Swan River including up to 12 large berths, tug berths, pilot vessels, a slipway and two bridges. The port has a maintenance dredge operation which maintains an average depth of 13.0m in the approach channel and maintains a variety of depths at specific berths (Appendix 2).

Also in the North Bank Area are four small boat harbours (Rous Head Harbour, Challenger Harbour, Fishing Boat Harbour, Success Boat Harbour), located either side of the mouth of the Swan River (Figure 1). These harbours house fishing boats, ferries to Rottnest Island, yachts and other recreational boats. The depths of these harbours range from 3m to 6m. Bathers Beach, immediately south of the mouth of the Swan River, has the remains of a large jetty used as the original port of Fremantle (1837-1897) before the Swan River mouth was dredged out to a depth sufficient to admit large vessels (FPA 1999).

The second region (Kwinana) encompasses the large bulk-loading facilities in Cockburn Sound (Figure 2). This includes an alumina loading berth (Alcoa Wharf), a steel mill berth (BHP), a bulk cargo jetty, an oil loading jetty (BP), and a grain terminal (CBH). All of these large berths are dredged out to an average depth of 14m leading from a large dredged channel (14.7m) leading down Cockburn Sound.

The third region (Rockingham and Southern Flats) extends across the southern coast of Cockburn Sound between the mainland coast and Garden Island. Local yacht club moorings extend immediately off the beach and a causeway connects Garden Island with the mainland (Figure 2).

Fig. 1. Region 1- North Bank Area sampling sites, as in Appendix 4.

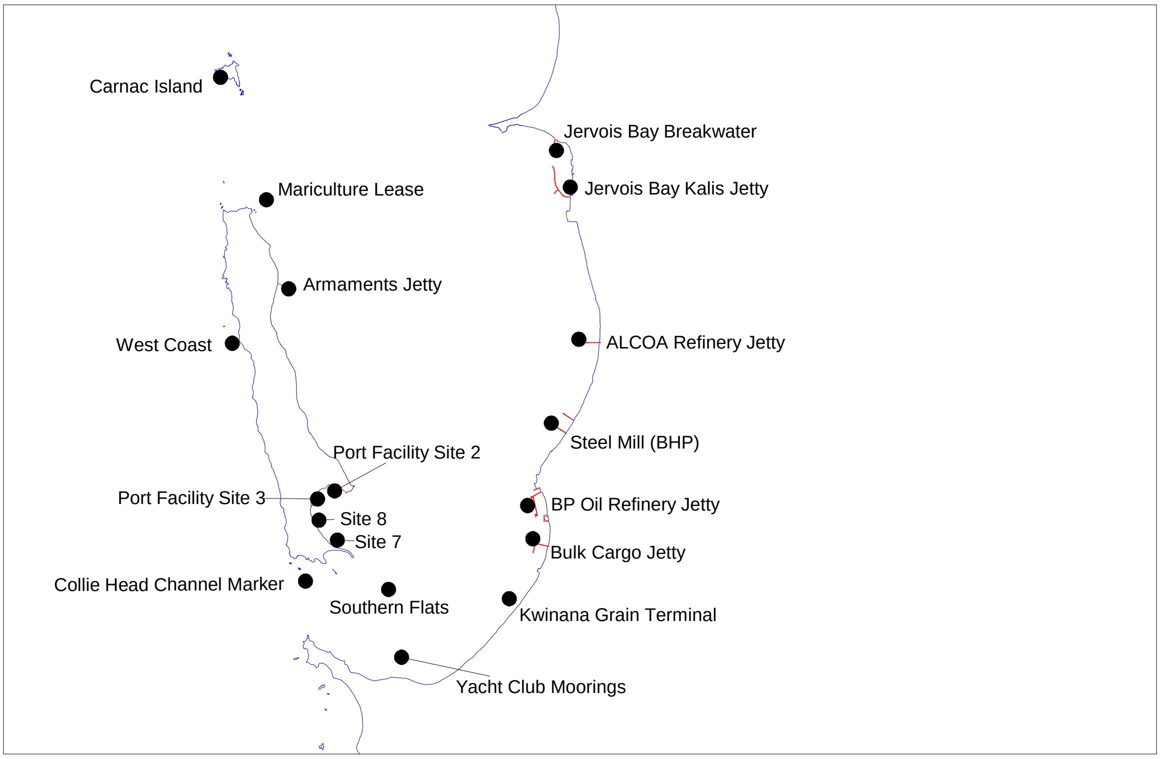


Fig. 2. Kwinana, Garden Island and Southern Flats Sampling Sites; as in Appendix 4

Garden Isle (region 4) houses the HMAS Stirling Naval Base on the eastern shore. The base has an internal port region with three main berths and numerous other artificial structures as well as an armaments jetty further north along the coast (Figure 2). Additionally there is a mariculture facility around the north tip of the island. The rest of the Garden Island coast is relatively undisturbed.

Region 5 (middle basin of Cockburn Sound) is a large expanse between the mainland and Garden Island and the only artificial structures are the channel markers delineating a large dredged channel which serves the bulk-loading facilities of Kwinana (Figure 3).

Gage Roads and adjacent coastline (region 6) encompasses Rottnest Island, Mudurup Rocks, Mewstone Reef and Stragglers Reef (Figure 3). Rottnest Island has a number of boating facilities including the ferry terminal (ferries chiefly come from the North Bank region), a fueling jetty, channel markers and moorings.

Region 7 (Swan River) contains smaller facilities further up the Swan River from the main port facilities, including Butler Hump and the Military Police Wharf. Region 8 (north of Fremantle Harbour) is a single site based at the Sorrento Quay wharf approximately 30kms north of the Swan River (Figure 3).

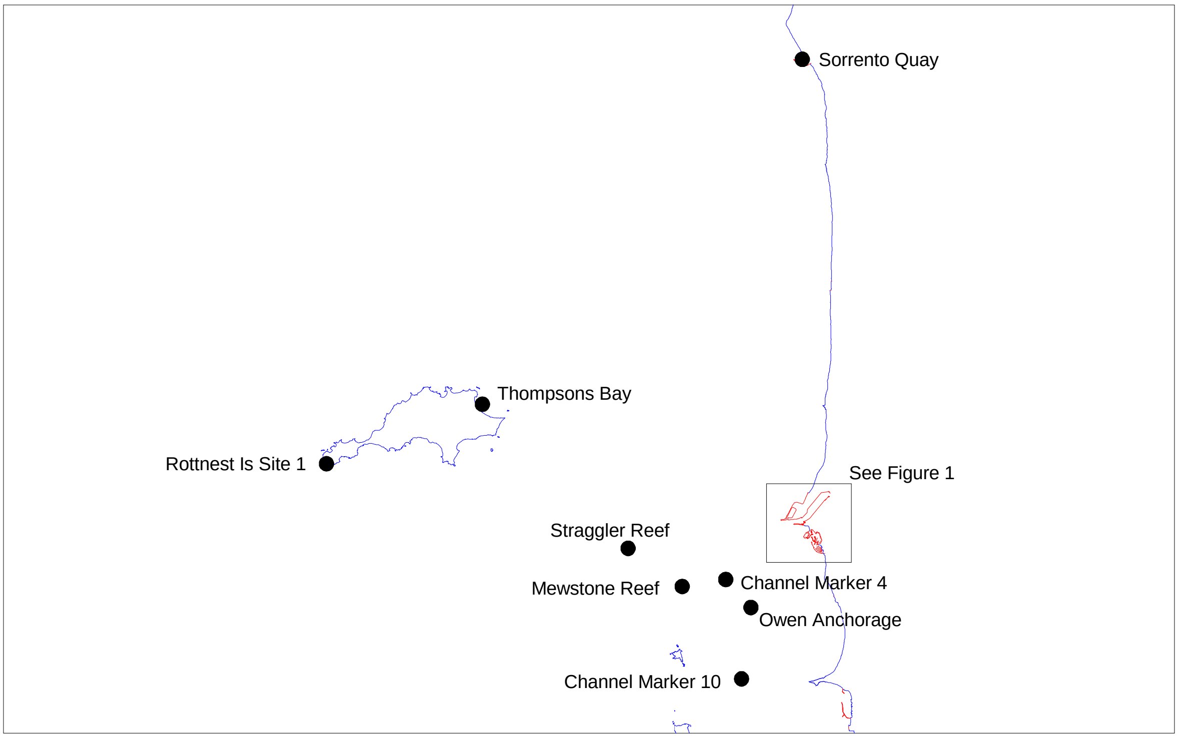


Fig. 3: Gage Roads, Rottnest Island and Sorrento Quay sites, as in Appendix 4

Fremantle has a long and important maritime history, operating as the port for Perth as early as 1840. Originally settled in 1830 as a fishing village, the township of Fremantle became the point of call for all maritime trade to Perth, with commodities unloaded on a large jetty on Bathers Beach then railed to Perth. In 1897 the limestone reef blocking the mouth of the Swan River was removed and the inner harbour of Fremantle was built further extending the shipping trade (FPA 1999). Major export trading partners are the Middle East, South Korea, Japan and other Asian countries and other Australian ports (FPA 1999).

1.2 SHIPPING MOVEMENTS

Details of shipping movements within Fremantle Harbour will be included in the final report.

1.3 PORT DEVELOPMENT AND PORT MAINTENANCE ACTIVITIES

Details of port development and maintenance within Fremantle Harbour will be included in the final report.

2. REVIEW OF EXISTING BIOLOGICAL INFORMATION

A synoptic review of existing biological information on Fremantle Habour and surrounding regions will be included in the final report.

3. SURVEY METHODS

3.1 SAMPLING STRATEGY

The survey was designed to maximise the likelihood that exotic species in the port would be detected. To achieve this, sampling concentrated on habitats and sites in the port and adjacent areas that were most likely to have been colonised by the target species (see Appendix 1). The areas sampled (in priority order) were:

- active wharves;
- disused or inactive wharves;
- slipways;
- known deballasting areas;
- mariculture facilities;
- breakwaters and jetties;
- estuarine areas;
- dredge disposal area.

Sampling methods were selected to ensure comprehensive coverage of habitats and were intended to provide presence/absence information and/or semi-quantitative indices of abundance only. As many of the target species were likely to be rare, sampling concentrated on maximising coverage within a site with minimal sample replication. Replicate sampling was only undertaken in situations were small scale heterogeneity was likely to influence detection of target species (e.g. coring for dinoflagellate cysts). The sampling methods used, habitats sampled and target taxa are summarised in Table 2. Detailed descriptions of sampling procedures are given in Appendix 3.

3.2 SAMPLING METHODS

1. Sampling was distributed over the eight areas previously identified, including the commercially active areas (Regions 1, 2, 3, 4) and regions through which shipping passes or has historically been active (5, 6, 7, 8).

Table 2. Summary of sampling methods, habitats sampled and target taxa, Port of Fremantle survey, April-May, 1999.

Sampling Methods	Habitat(s) Sampled	Target Taxa
Non-targeted surveys		
Qualitative surveys:		
diver searches	Piles, reefs, soft bottoms	invertebrates; fish; algae
video/still photography	Piles, reefs, soft bottoms	invertebrates; fish; algae
shore surveys	Beach wrack, intertidal reefs	invertebrates; fish; algae
Quantitative surveys:		
quadrat sampling	Piles, channel markers	invertebrates, algae
transects	Reefs	invertebrates; algae
video/still photography	Reefs, soft bottoms	invertebrates; algae
large cores	soft bottoms	invertebrate infauna; mobile epifauna; fish
beach seine	soft bottoms	mobile epifauna; fish
Targeted surveys		
diver searches	Piles, reefs, soft bottoms	*Sabella, Asterias, Carcinus*
traps	Piles, soft bottoms	*Carcinus*
small cores	Mud/silt bottoms	dinoflagellate cysts
poison stations	Piles, reefs	fish
plankton net - 100υm	Water column	zooplankton, phytoplankton
plankton net - 20υm	Water column	phytoplankton, dinoflagellates

Sampling methods employed in each of these areas are summarised in Table 3 and details of sampling sites are given in Appendix 4. Sampling was most intense in the port area and focused on habitats on and around wharf piles, and the adjacent soft bottoms. Visual surveys, video transects, still photography and coring were undertaken by divers; trapping and plankton sampling were carried out from research vessels or wharves.

Sampling was completed between 18th April and 14th May 1999. The survey was a joint operation between CRIMP and Marine and Freshwater Research Laboratory (MRFL), Murdoch University. Initial rough sorting and preservation was carried out immediately after sampling. Further sorting to the level of species (or Least Taxonomic Unit) was carried out at the MFRL laboratory, Perth, with the assistance of a reference collection of known introduced species from CRIMP

Table 3. Summary of the distribution of sampling methods by area, Port of Fremantle survey, April-May, 1999.

Method	North Bank	Kwinana	Rocking-ham	Garden Isle	Middle Basin	Gage Roads	Swan River	North Coast
Diver searches	X	X	X	X	X	X	X	X
Quadrat sampling	X	X		X	X	X	X	
Video/still photography	X	X	X	X	X	X	X	X
Small cores	X	X		X	X	X	X	X
Large cores	X	X	X	X	X	X	X	X
Traps							X	
Shore surveys	X	X	X					
Poison stations	X							
100 µm Plankton net								
20 µm Plankton net								

3.3 PUBLIC AWARENESS PROGRAM

A local public awareness program was initiated in the week prior to the commencement of the survey and continued during the survey period. The program involved a press release in conjunction with the Fremantle Port Authority, distributed to state and locally based media and subsequent radio, television and newspaper interviews. Groups or individuals were encouraged to contact CSIRO or the port authority with any observations or information that they felt would assist CSIRO identify exotic species in the port area, assess their impacts and indicate the possible time of introduction. Wherever possible CSIRO staff were available to follow up and assess any responses during the survey period so that observations could be investigated while the survey team was in the area.

4. SURVEY RESULTS

4.1 PORT ENVIRONMENT

The Inner Harbour of the Port of Fremantle is a natural estuarine system with some freshwater flow from the Swan River and tributaries. Some quantities of sediment are carried into the port through soil erosion. Tidal flow and currents are relatively minimal except at the Traffic Bridge where a substantial current can develop due to the narrow confines of the river at that point. The sediment loading in the water column was relatively low. Water temperatures range from 14°C- 26°C although freshwater runoff from the Swan River can lower the Inner Harbour temperature.

The other areas of the port environment were entirely marine and often exposed to wind chop and swell. Underwater visibility in these areas varied according to depths and degree of disturbance from weather conditions.

Examination of the wharf pile communities within the Inner Harbour indicated only a minor influence of freshwater runoff. The majority of piles carried well developed communities, dominated intertidally by barnacles, mussels and bryozoans. Below the tidal range, sponges, ascidians, algae, and bryozoans dominated the communities. This pattern was manifest in all pile communities examined during the survey. The maximum tidal range in the port is negligible (<1m).

Surface sediment adjacent to piles under and around most berths was a combination of fine mud and silt. In regions where there is significant flow (e.g., around the channel markers, Rottnest Island and parts of the southern flats) the fine material was replaced by fine to coarse sand (Appendix 6).

4.2 INTRODUCED SPECIES IN THE PORT

4.2.1 ABWMAC TARGET SPECIES

Two ABWMAC pest species were recorded from the Port of Fremantle during the survey. Specimens of the European fan worm (*Sabella spallanzanii*) were collected or noted at a number of sites including Rous Head Harbour, North Quay, Channel Marker 10, Bulk Cargo Jetty, Oil Refinery Jetty, Kwinana Grain Terminal and the Steel Mill (BHP). Most of these sightings were of occasional healthy adult worms except for Rous Head which appeared to have large numbers of juvenile worms coating the pylons. The worms were noted chiefly on pylons, at all depths.

The bivalve *Musculista senhousia* is native to eastern Asia, from the Siberian Coast down to Singapore but had been introduced to many places around the world including the Mediterranean, parts of the USA, India and New Zealand (Wilan 1987). In Australia it has been recorded from Port Phillip Bay (Vic), Devonport and the Tamar River in Tasmania and St. Kilda in South Australia. The species was previously recorded in the Swan Estuary in 1982. This survey detected *Musculista senhousia* from many sites in the North Bank Area, the Swan River sites and the southern flats.

Preliminary results of the dinoflagellate analyses have identified one of the ABWMAC target species, *Alexandrium tamarense,* in low concentrations (<1 cyst/g) at 9 sites in the Inner Harbour, harbour entrance, Challenger Harbour, and Owen Anchorage. Germination efforts have been made to confirm toxicity of these strains, however they have been unsuccessful (Hallegraeff pers. comm). Molecular genetic sequencing will be needed to assess whether they represent indigenous or introduced populations (Scholin *et al.*, 1994).

Both *Gymnodinium catenatum* and *G. microreticulatum* cysts were absent from samples in the port despite their detection in the Port of Bunbury (CRIMP 1997a) and Albany (CRIMP 1997b). Well over 700 cysts have been examined from a wide range of locations in

Fremantle and Cockburn Sound during this survey and therefore the absence of these species can be taken to accurately reflect their distribution in Western Australia.

The cyst assemblages encountered in the present work are essentially similar to those found further upstream in the Swan River (Patron 1999) and the Port of Bunbury (Hallegraeff & Hosja 1993; CRIMP 1997).

No other ABWMAC pest species were recorded from the port or adjacent regions.

4.2.2 OTHER INTRODUCED SPECIES

Other introduced and cryptogenic (native status unknown) species collected during this survey and identified to this point include the bryozoans, *Bugula neritina, B. flabellata*, *Tricellaria occidentalis*, *Cryptosula pallasiana,* and *Watersipora subtorquata,* the hydroid *Tubularia ralphi*, and the ascidians *Ascidiella aspersa* and *Ciona intestinalis*, and the fish *Tridentiger trigonocephalus*.

Bugula flabellata is an erect anascan bryozoan with a cosmopolitan distribution in ports around the world. A second erect anascan bryozoan, *Bugula neritina*, native to European waters, was also found in the port (Gordon and Mawatari 1992, Ryland and Haywood 1977). *Tricellaria occidentalis*, has been recorded from New Zealand, the United States, Japan and China and many places within Australia. Similarly *Cryptosula pallasiana* is widespread around the world and Australia (Gordon and Mawatari 1992, Ryland and Hayward 1977). The bryozoan *Watersipora subtorquata* is suspected to be introducedor cryptogenic but is yet to be verified. All these species are found throughout the port in pile communities in the North Bank Area, Cockburn Sound. and Garden Island

The hydroid, *Tubularia ralphi* (=*Ectopleura crocea),* is thought to be native to the Atlantic north temperate seas and has been introduced to the west coast of the USA, the Mediterranean and Japan. The species is widely distributed in the port of Fremantle and was found in all primary regions.

Ascidiella aspersa is known from the Mediterranean, the waters around the UK, New Zealand and the east coast of the USA (Kott 1985). It has been previously recorded from temperate waters in Australia including the Swan River. In this survey, this species was found in all the small boat harbours (Jervois Bay, Fishing Boat Harbour, Rous Head Harbour, Success Boat Harbour and Challenger Harbour) as well as the sites further up the Swan River. Additionally, *Ciona intestinalis*, which has a world-wide distribution, was collected from all major regions within the port except Rottnest Island and Sorrento Quay. The tunicates and hydroid are fouling organisms typically associated with ship hull fouling.

The Japanese fish, *Tridentiger trigonocephalus,* is thought to be present in Fremantle Harbour and Cockburn Sound and has previously been recorded from the Swan River. In this survey it was collected from the Swan River only. It is native to the waters around Japan, eastern China, the Korean peninsular and southeastern USSR and has been introduced to the Californian coast and parts of Australia (Pollard and Hutchings 1990).

4.3 PUBLIC AWARENESS PROGRAM

No reports due to the public awareness program resulted in the findings of additional introduced species.

5. POTENTIAL IMPACTS OF INTRODUCED SPECIES FOUND IN THE PORT

The preliminary analysis of specimens collected during the survey detected the presence of two ABWMAC pest species, the European fan worm, *Sabella spallanzanii* and the Asian date mussel, *Musculista senhousia*, one ABWMAC target species, *Alexandrium tamarense*, and an additional 9 introduced and cryptogenic species from the bryozoa, hydroids, sea-squirts and fish.

The fan worm, *Sabella spallanzani* is a native of the Mediterranean and Atlantic east coast as far north as the English Channel. Recent surveys have established that the fanworm is abundant in Port Phillip Bay, Victoria (Hewitt *et al.* 1999); West Lakes, North Haven, and the Port River in South Australia (K.Gowlett-Holmes, pers. comm.); Devonport, Tasmania; and Twofold Bay, New South Wales (CRIMP Port Surveys). In Western Australia the species is known from Esperance (Clapin pers.comm.), Albany, Bunbury, Cockburn Sound and Fremantle (Clapin and Evans 1995). In all these areas it causes major fouling on man-made structures (wharf piles, buoys, pontoons etc) and may prevent settlement by other organisms. In Port Phillip Bay and parts of Cockburn Sound, *S. spallanzanii* forms dense beds on open soft bottoms. When present in high densities, *S. spallanzanii* is likely to have a severe impact on wild scallop fisheries in areas such as Port Phillip Bay. It may adversely affect shellfish (oyster, mussel and scallop) culture operations that rely on the settlement of wild spat either by reducing recruitment success or by reducing the availability of planktonic food.

The small infaunal mussel *Musculista senhousia* is native to Asia from the Siberian coast to the Red Sea and has been introduced into Australia, New Zealand, eastern Mediterranean via the Suez Canal, the south of France and is widespread on the Pacific coast of North America (Crooks 1996). The opportunistic bivalve can colonise vertical hard substrate as well as anchor vertically into soft-sediment habitats by forming byssal thread nests. A fast growth rate and high fecundity means *M. senhousia* can out compete native species and colonise most available substrate (Morton 1974). When occurring in large numbers *M. senhousia* is known to alter the nature of a soft-sediment habitat by binding the nests into thick byssal mats and forming mud flats (Crooks 1998, Morton 1974). These mats in turn affect the resident biotic communities, altering densities and species richness (Crooks 1998).

Germination efforts for the *Alexandrium tamarense* cysts to determine the toxicity of the cyst assemblages encountered in the port have not been successful despite several attempts. G. Hallegraeff has stated that both he and Was Hosja have verified *A. tamarense* from old Fremantle plankton samples. The native or introduced status of the strain detected in Fremantle cannot be determined until molecular genetic evaluations occur.

Several species of toxic dinoflagellates (including strains of *Alexandrium tamarense*) can form extensive blooms which concentrate potent neurotoxins. These neurotoxins are concentrated by shellfish and, when eaten by humans, cause Paralytic Shellfish Poisoning (PSP). Toxicity may develop in both wild and cultured shellfish. Marine animals may also by affected during blooms as a result of physical damage, oxygen depletion, and the effects of toxins, either directly or through the food chain (White 1990, 1982; Grosselin *et al.* 1989; Jones 1991). This impact is likely to be greatest on shellfish mariculture activities, however no *A. tamarense* blooms have been recorded in the Port of Fremantle.

The vast majority of introduced and cryptogenic species detected in the Port of Fremantle are not known to have a significant impact on the native communities. The arborescent bryozoans, *Bugula flabellata* and *B. neritina*, are found in port regions throughout the world. *B. flabellata* is known from the Gulf of St. Vincent and Port Adelaide, SA and from Port Stephans to Eden in NSW (Furlani 1996). It was also collected from Bunbury, Port Lincoln and Newcastle during CRIMP Port Surveys. *B. neritina* is recognised from Spencer Gulf and the Gulf of St. Vincent, SA (Furlani 1996), and Port Kembla, Shell Pt, Cronulla, Port Hacking NSW (Moran and Grant 1993). The species has also been recorded in Newcastle, Port Lincoln, Albany, Bunbury, Mackay, Eden and Flinders Island during CRIMP Port Surveys. Several of the other species of bryozoans are widespread both worldwide and in Australian port environments and none of them are likely to have high impact on native fauna and flora.

The hydroid *Tubularia ralphii* (=*Ectopleura crocea*) has an almost cosmopolitan distribution but often is restricted to ports and harbours. In Australia it has been recorded from Sydney Habour and Port Kembla in NSW, Yarra River in Victoria and Fremantle in Western Australia (Watson 1999). It is a common fouling species, capable of growing on most hard substrates including piles, boat hulls and moorings and has been recorded in seawater intakes on submarines (Watson 1999). The species grows rapidly and can form large clumps.

Ascidiella aspersa is known from the Saint Vincent Gulf, South Australia; Port Phillip Bay, Victoria; and Spring Bay, Bruny Island and the d'Entrecasteaux Channel, Tasmania as well as Albany, Bunbury and the Swan River in Western Australia (Kott 1985). Kott 1985 also notes that all Australian records are from protected or semi-enclosed waterways. This species occupies marine and brackish portions of estuaries and semi-protected bays. *A. aspersa* forms dense monocultures in encrusting or fouling communities.

Ciona intestinalis is found in ports throughout Australia: Port Adelaide and Adelaide outer harbour, South Australia; Portland and Port Phillip Bay, Victoria; the Derwent Estuary, Tasmania; Port Jackson, Newcastle, New South Wales; and Rockhampton, Queensland as well as Albany, Fremantle and the Swan River in Western Australia (Kott 1985). *C. intestinalis* is a known introduction in many parts of the world including North America, Hong Kong, and the China Sea. *C intestinalis* dominates encrusting communities of pilings and wharves and is commonly found in both marine and estuarine protected bays and estuaries. Kott 1990 notes that Australian populations are in decline since the 1950's.

The introduced Japanese goby, *Tridentiger trigonocephalus*, is native to Japan, China and Korea and has also been introduced to California, USA (Furlani 1995). The Australian distribution is constrained to harbours and includes Port Phillip Bay, Victoria (Paxton and Hoese 1985); Rozelle Bay, Sydney Harbour,, Port Kembla, New South Wales (Pollard and Hutchings 1990) as well as Bunbury, Cockburn Sound and Swan River, Western Australia. *T. tigonocephalus* is found in salinities higher than 22‰ and prefers warmer, subtropical ocean temperatures. This species is a generalist predator and its impacts are likely to be through direct and indirect competition with native fishes. *T. trigonocephalus* can attain dominance in disturbed habitats and may lead to the exclusion of native species. This species is associated with pile and wharf communities, often found in the growths on well fouled hulls of ships.

6. ORIGIN AND POSSIBLE VECTORS FOR THE INTRODUCTION OF EXOTIC SPECIES FOUND IN THE PORT

Exotic species in the Port of Fremantle are likely to have been introduced to the port by one of three mechanisms:

(i) natural range expansion of species introduced to other parts of the southwest coast of the Australian mainland;

(ii) directly to the port by shipping using the port, either in ballast water or by hull fouling;

(iii) by domestic translocation from fishing and recreational vessels.

Those species likely to have become established in Fremantle as a result of natural range expansion may include the bryozoans and other species with a planktonic phase in their life history. For all species however, additional domestic translocations may have occurred by human activities (e.g., fishing, marine farming, coastal shipping, etc…). The bryozoans, hydroid and the tunicates have broad distributions throughout southwest Australia and are well known to establish on hulls of vessels as well as have a planktonic life history phase. These species are likely to have been introduced through multiple invasion events.

Several species are also likely to have been introduced either directly from international shipping or indirectly from other first-entry ports via commercial, recreational and fishing vessels or slower moving vessels. Extensive hull fouling can develop on these slow-moving vessels due to longer port residence times and the relative infrequency of dry-docking and brush-cart service (in water hull cleaning). Slower moving vessels are likely to increase the survival of species encrusting the hulls, leading to the entry and potential colonisation of the port of a diverse and adult community.

Because of the high frequency of ship visits in the port, several species are likely to have been introduced directly to Fremantle from either international or domestic shipping. The relatively short voyage times from Asian ports to Fremantle gives a high chance of survival for species entrained in ballast water. Additionally, there are a significant number of non-trading vessels, including recreational vessels and fishing boats, which have relatively short voyage times to Fremantle from other Australian ports.

7. EFFECT OF THE PORT ENVIRONMENT AND PORT PRACTICES ON COLONISATION AND SURVIVAL OF INTRODUCED SPECIES

The resident fauna of the Port of Fremantle is indicative of a marine environment enclosed and sheltered from the open coast, with only some exposure to variations in salinity. Of the introduced species detected in the port, the majority of species are not restricted to estuarine environments and would therefore be capable of extending their range beyond the Fremantle locale.

Port enhancement activities such as maintenance dredging, berth development and revetment construction create disturbed and novel habitats which may lead to increased invasion success. Many introduced species appear to require some form of disturbance in order to enter an existing native community. These activities in the port may have influenced the establishment of some encrusting or fouling species.

Hull cleaning activities, either in water (brush cart cleaning) or in dry dock, can have significant influence on the inoculation and establishment of species. The slipways at Arthur Head and the wet dock facilities in the Fishing Boat Harbour are both likely areas for introductions.

8. ASSESSMENT OF THE RISK OF NEW INTRODUCTIONS TO THE PORT

The successful introductions of an exotic species to a port through hull fouling or ballast water discharge requires some level of environmental matching between the donor and receiving ports; the degree of matching required and important characteristics will depend on the environmental tolerances of individual species. In the absence of this species-level information some general observations can be made on the risks of new introductions to the Port of Fremantle.

Given the current level of international ship visits to the Port of Fremantle, the risk of new introductions from overseas appears to be greatest in the North and South Quay and in Kwinana at the bulk-loading berths. Vessels visiting these areas discharge large volumes of ballast water and are likely to carry many hull fouling organisms compatible with the environment in Fremantle. Japanese bulk carriers (eg, woodchip vessels) have previously been documented as carrying toxic dinoflagellate cysts in the sediments into Eden (Hallegraeff and Bolch 1992) and will carry, and discharge, significant numbers of larvae entrained in the ballast water. Carlton and Geller (1993) examined the ballast water of a number of woodchip vessels, including the *Eden Maru*, entering Coos Bay, Oregon, USA from Japanese ports and found over 212 different taxa from 36 phyla. It is likely that these numbers can apply equally to ballast arriving in Fremantle. It should be noted that none of these identified species are considered to be pests.

Fremantle is often the first and last port of call for international vessels coming from Singapore, South and East Asia, India, the Middle East, Europe and South Africa (FPA 1999). Given the average voyage time from Singapore of four and a half days, introduction of international species from these vessels is very possible. Fremantle also accommodates cruise ships and naval vessels originating at a multitude of other international ports.

The periodic presence of slow-moving long residence vessels such as dredging vessels in the port may present an opportunity for significant fouling communities to establish themselves while in the port. Previous work in the north Pacific has demonstrated the ability for these vessels to transport complete assemblages over long distances (Carlton 1985). The long resident times allow for reproductive populations to establish themselves.

9. ASSESSMENT OF THE RISK OF TRANSLOCATION OF INTRODUCED SPECIES FOUND IN THE PORT

An assessment of risks of translocation of introduced species from the Port of Fremantle to other ports by shipping involves similar considerations to those discussed in assessing the risks of new introductions. Many vessels load ballast water in Fremantle and are therefore likely to discharge water from Fremantle in other Australian ports. The likelihood of transport and successful establishment of species in those new environments will be determined by the presence in the water column during uptake in Fremantle, as well as the survival during the voyage and the environmental regime in the recipient port. This information is outlined in Hayes and Hewitt (1998) as the foundation of the risk assessment based Decision Support System being developed by the Australian Quarantine and Inspection Service.

A number of vessels are likely to move organisms via hull fouling, as recorded and evidenced by dry dock facilities worldwide (see also Hewitt *et al.* 1999). These organisms are likely to include the various encrusting polychaetes (e.g., *Sabella spallanzanii*), bryozoans, hydroids, bivalves (e.g., *Musculista senhousia*) and sea squirts such as those detected in this report. There are significant numbers of ships importing and exporting into Fremantle from other Australian ports and are possibly carrying organisms from Fremantle to similar environments (FPA 1999). Despite this, the likelihood of species establishment on the hulls of vessels will be related to their duration of stay in port, which is less than twelve hours in most instances (G. Valenti pers. comm.) and vessels which have been recently cleaned. Consequently the risk of translocation and subsequent establishment of species in ports that trade with Fremantle is deemed to be moderate. Until a full scale evaluation of hull fouling on vessels trading in Australia occurs, the strength of this vector will remain unknown.

10. RECOMMENDATIONS

10.1 MANAGEMENT OF EXISTING INTRODUCED SPECIES IN THE PORT

All the introduced species detected in this survey appear to be well established in the port. For these species eradication from the port by physical removal ceases to be a realistic option.

- It is recommended that an initial plankton monitoring program be conducted to determine the timing (seasonality) and density of toxic dinoflagellate species which may be released as ballast water discharge or periodically bloom from cysts established in the port.

- It is recommended that a monitoring program be initiated with qualitative evaluations of the berth regions on an annual basis and, based on frequency of ship visits and ballast discharges, the port should be resurveyed in three to five years, targeting those regions with high invasions and/or high active ballast water discharge. Currently, efforts are underway to identify methods of effective monitoring. Unlike floral and faunal surveys of native species, the survey and evaluation presented in this report is temporally limited and will become outdated once a new introduction occurs.

10.2 PREVENTION OF NEW INTRODUCTIONS

There is currently no information available to base the evaluation of risks posed to the port by hull fouling. A hull fouling survey of vessels entering the port will provide sufficient information to begin such an evaluation.

Managing the risks posed by ballast water discharges are currently the focus of activities by the Australian Ballast Water Management Advisory Council and AQIS. The development of an efficient Ballast Water Decision Support System is predicated on the maintenance and procurement of specific information needs, baseline port surveys is one of them. Additional data needs will be databases of temperature and salinity readings (preferably from several regions of the port) in addition to a detailed database of vessel movements and ballast water origins (both international and domestic). In order to facilitate consistency between databases, it would be useful to incorporate an agreed upon set of port names of the world. CRIMP has compiled a list and will make that available on request.

10. REFERENCES

Bolch C.J.S. 1997. The use of sodium polytungstate for the separation and concentration of living dinoflagellate cysts from marine sediments. *Phycologia* **36:** 472-478.

Carlton, J.T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Ocean. Mar. Biol. Ann. Rev.* **23**: 313-371.

Carlton, J.T., and Geller, J.B. 1993. Ecological roulette: the global transport of non-indigenous marine organisms. *Science* **261**: 78-82.

Clapin, G. and Evans, D.R. 1995 The status of the introduced marine fanworm *Sabella spallanzanii* in Western Australia: A preliminary investigation. Centre for Research on Introduced Marine Pests. Technical Report #2, CSIRO Marine Reserch, Hobart, Tasmania.

CRIMP 1997. Introduced Species Survey, Port of Bunbury, Western Australia. CSIRO Marine Research.

Crooks, J.A. 1996 The population ecology of an exotic mussel, *Musculista senhousia,* in a southern California Bay. *Estuaries* **19(1)**:42-50

Crooks, J.A. 1998 Habitat alteration and community-level effects of an exotic mussel, *Musculista senhousia*, *Mar.Ecol.Prog.Ser.* **162:** 137-152

Fremantle Port Authority, 1999. Fremantle Port Authority home page. *http://www.freport.wa.gov.au/www/homepage.nsf*

Furlani, D. M. 1996. A guide to the introduced marine species in Australian waters. *Centre for Research on Introduced Marine Pests, Technical Report* #5, CSIRO Marine Reserch, Hobart, Tasmania.

Geraci, J.R., Anderson, D.M., Timperi, R.J., St Aubin, D.J., Early, G.A., Prescott, J.H., and Mayo, C.A. 1989. Humpback whales (*Megaptera novaeangliae*) fatally poisoned by dinoflagellate toxin. *Can. J. Fish. Aquat. Sci.* 46: 1895-1898.

Gordon, D.P. and Mawatari, S.F. 1992 Atlas of marine-fouling bryozoa of New Zealand ports and harbours. Miscellaneous Publications of New Zealand Oceanographic Institute **Vol 107.**

Gosselin, S., Fortier, L., and Gagné, J.A. 1989. Vulnerability of marine fish larvae to the toxic dinoflagellate *Protogonyoulax tamerensis*. *Mar. Ecol. Prog. Ser.* 57: 1-10.

Grosberg, R.K. 1988 Competitive ability influences habitat choice in marine invertebrates. *Nature* **290:** 700-702

Hallegraeff, G.M. and Bolch, C.J. 1992. Transport of dinoflagellate cysts in ship's ballast water: Implications for plankton biogeography and aquaculture. *J. Plankt. Research* **14**: 1067-1084.

Hallegraeff G.M. & Hosja W. 1993. Bunbury Port survey for Dinoflagellate cysts: aquaculture site evaluation and potential ballast water risks. South West Development Authority. Draft Report.

Hayes, K.R. and Hewitt, C.L. 1998. Risk assessment framework for ballast water introductions. *Centre for Research on Introduced Marine Pests Technical Report #14*, CSIRO Marine Research, Hobart, Tasmania.

Hewitt, C.L., Campbell, M.L., Thresher, R.E. and Martin, R.B. 1999 Marine Biological Invasions of Port Phillip Bay, Victoria. *Centre for Research on Introduced Marine Pests. Technical Report #20*. CSIRO Marine Research, Hobart, Tasmania. 344pp.

Jones, M.M. 1991. Marine organisms transported in ballast water: A review of the Australian scientific position. *Bureau of Rural Resources Bulletin* 11.

Kay, A.M. and Keough, M.J. 1981 Occupation of patches in the epifaunal communities on pier pilings and the bivalve *Pinna bicolor* at Edithburg, South Australia. *Oecologia* **48:** 123-130

Kott, P. 1985. The Australian Ascidiacea Part I. Phlebobranchia and Stolidobranchia. *Mem. Qld Mus.* **23**: 1-440.

Kott, P. 1990. The Australian Ascidiacea Part II. Aplousobranchia (1). *Mem. Qld Mus.* **29**: 1-266.

Kott, P. 1997 Chapter 23: Tunicates (sub-phylum Tunicata). *In:* Shepard, S.A. and Davies, M. (eds), Marine Invertebrates of Southern Australia. Part III. Government Printer, Adelaide. pp 1092-1255

Moran, P.J., and Grant, T.R. 1993. Larval settlement of marine fouling organisms in polluted water from Port Kembla Harbour, Australia. *Marine Pollution Bulletin* **26**: 512-514.

Morton, B. 1974. Some aspects of the biology, population dynamics and functional morphology of *Musculista senhousia* Benson (Bivalvia, Mytilidae). *Pacific Science* **28:** 19-33.

Patron J.J. 1999. Distribution of dinoflagellate resting cysts and factors affecting their germination in the surface sediments of the Swan River estuary. M.Sc. thesis, University of Western Australia.

Paxton, J.R. and Hoese, D.F. 1985 The Japanese sea bass, *Lateolabrax japonicus* (Pisces, Percichthyidae), an apparent marine introduction into eastern Australia. *Japanese Journal of Ichthyology* **31:** 369-372

Pollard, D.A. and Hutchings, P.A. 1990 A review of exotic marine organisms introduced to the Australian region. I Fishes. Asian Fisheries Science **3**:205-221.

Scholin C.A., Herzog M., Sogin M. & Anderson D.M. 1994. Identification of group- and strain-specific genetic markers for globally distributed *Alexandrium* (Dinophyceae) II: sequence analysis of a fragment of the LSU rRNA gene. *Journal of Phycology* **30:** 999-1011.

Ryland, J.S. and Hayward, P.J. 1977 British anascan bryozoans. Cheilostomata: Anasca. Keys and notes for the identification of the species. Synopses of the British Fauna, n.s., 10:[iii] +188p.

Watson, J. 1999 Review of hydroids introduced to Victorian waters. pp. 88-107. *In:* Hewitt, C.L., Campbell, M.L., Thresher, R.E. and Martin, R.B. (eds.) Marine Biological Invasions of Port Phillip Bay, Victoria. *Centre for Research on Introduced Marine Pests. Technical Report # 20*. CSIRO Marine Research, Hobart. 344pp.

White, A.W. 1980. Recurrence of fish kills of the Atlantic herring (*Clupea harengus harengus*) caused by dinoflagellate toxins transferred through herbiverous zooplankton. *Can. J. Fish. Aquat. Sci.* 37: 2262-2265.

White, A.W. 1982. The scope of impact of toxic dinoflagellate blooms on finfish of Canada. *Can. Tech. Rep. Fish. Aquat. Sci.* 1063: 103-109.

Zaniolo, G., Burighel, P. and Brunetti, R. 1977 Hibernation in the colonial ascidian *Botrylloides leachi* (tunicata). *In:* 8th National Congress of Italian Society of Marine Biology, Taormina. *Mem.Biol.Mar.Oceanogr.* **6:** 85-87

Schedule 1**. Australia Ballast Water Management Advisory Council (ABWMAC) schedule of target introduced pest species (taxa).**

Gymnodinium spp. & *Alexandrium* spp. (toxic dinoflagellates)
Undaria pinnatifida (Japanese seaweed)
Asterias amurensis (northern Pacific seastar)
Crassostrea gigas – feral (Pacific Oyster)
Corbula gibba (Asian bivalve)
Musculista senhousia (Asian date mussel)
Sabella spallanzanii (giant fan worm)
Carcinus maenas (European shore crab)

Schedule 2. Marine pest species that pose a significant threat to Australia.

Mnemiopsis leidyi (comb jelly)
Potamocorbula amurensis (Chinese clam)
Philine auriformis (sea slug)
Mytilus galloprovincialis (mussel)

Schedule 3. Known exotic species in Australian waters.

Species	Possible origin	Australian distribution
ANIMALIA		
Bougainvillia ramosa (hydroid)	N. Hemisphere	NSW
Hydroides elegans(serpulid)	Europe	WA, Vic, NSW, Tas
Boccardia proboscidea (spionid)	Japan/NE. Pacific	Vic
Polydora ciliata (spionid)	Europe	WA, NSW
Pseudopolydora paucibranchiata (spionid)	Japan/NE. Pacific/NZ	Vic
Sabella spallanzanii (fan worm)	Mediterranean	WA, NSW, SA, Tas, Vic,
*Euchon*e (?) sp (fan worm)	?	Vic?
Maoricolpus roseus (screw shell)	NZ	Tas, NSW
Zeacumantis subcarinatus (screw shell)	NZ	NSW
Aeolidiella indica (sea slug)	widespread	NSW
Janolus hyalinus (sea slug)	Europe	Vic
Okenia plana (sea slug)	Japan	Vic, NSW
Polycera capensis (sea slug)	S. Africa	NSW
Polycera hedgpethi (sea slug)	California	WA, Vic, NSW
Godiva quadricolor (sea slug)	S. Africa	WA
Thecacera pennigera (sea slug)	?	NSW
Crassostrea gigas (Pacific oyster)	Japan	WA, NSW, SA, Tas, Vic
Neilo australis (clam)	NZ	Tas
Corbula gibba (clam)	Europe/Mediterranean	Vic
Ostrea lutaria (NZ mud oyster)	NZ	Vic
Paphirus largellierti (clam)	NZ	Tas
Perna canaliculus (NZ green mussel)	NZ	Tas

Musculista senhousia (Asian mussel)	Pacific/Asia	WA, Vic, Tas
Soletellina donacoides (tellinid)	NZ?	Tas?
Theora lubrica (semelid)	Pacific/Asia	WA, Vic
Amaurochiton glaucus (chiton)	NZ	Tas
Neomysis japonica (mysid shrimp)	Japan	NSW
Tanais dulongi (tanaid)	Europe	SA
Cirolana hardfordi (isopod)	USA	WA, Vic, NSW
Eurylana arcuata (isopod)	NZ/Chile	SA, NSW
Paracerceis sculpta (isopod)	USA/S. America	Qld, WA, NSW
Paradella dianae (isopod)	USA/S. America	Qld
Sphaeroma serratum (isopod)	widespread	WA

Schedule 3 continued

Synidotea laevidorsalis (isopod)	?	?
Balanus improvisus (barnacle)	Atlantic	SA?
Megabalanus rosea (barnacle)	Japan	WA
Megabalanus tintinnabulum (barnacle)	cosmopolitan	WA
Notomegabalanus algicola (barnacle)	S. Africa	NSW
Cancer novaezelandiae (crab)	NZ	Vic, Tas
Carcinus maenas (European shore crab)	Europe	WA, SA, Vic, NSW, Tas
Halicarcinus innominatus (crab)	NZ	Tas
Pyromaia tuberculata (crab)	E. Pacific	WA
Petrolisthes elongatus (half crab)	NZ	Tas
Palaemon macrodactylus (shrimp)	N. Pacific	NSW
Sergiella angra (shrimp)	?	?
Anguinella palmata (bryozoan)	Atlantic	NSW
Bugula flabellata (bryozoan)	Atlantic/Mediterranean	SA, NSW
Conopeum tubigerum (bryozoan)	Atlantic	Qld
Cryptosula pallasiana (bryozoan)	?	WA, SA, NSW, TAS
Membranipora membranacea (bryozoan)	cosmopolitan	SA, Vic?, Tas?
Schizoporella unicornis (bryozoan)	Japan	WA, SA, NSW, Qld
Watersipora arcuata (bryozoan)	Mexico	WA, SA, NSW, Qld
Asterias amurensis (seastar)	Japan	Vic, Tas
Astrostole scabra (seastar)	NZ	Tas
Patiriella regularis (seastar)	NZ	Tas
Ascidiella aspersa (ascidian)	Europe	WA, SA, Vic, Tas.
Ciona intestinalis (ascidian)	Europe	WA,SA,Vic,Tas,NSW, Qld
Molgula manhattensis (ascidian)	N. Atlantic	Vic, Qld
Styela clava (ascidian)	NW. Pacific/Europe	Vic
Styela plicata (ascidian)	widespread	WA, SA, NSW, Qld
Latelabrax japonicus (Japanese sea bass)	Japan	NSW
Triso dermopterus (grouper)	W.-Equat. Pacific	Qld
Sparidenrax hasta (Sobaity sea bream)	Arabian Gulf	WA
Tridentiger trigonocephalus (striped goby)	W.-Equat. Pacific	WA, Vic, NSW
Acanthogobius flavimanus (yellowfin goby)	W.-Equat. Pacific	Vic, NSW
Fosterygion varium (blenny)	NZ	Tas
Oreochromis mossambicus (tilapia)	SE Asia	WA, Qld
Salmo salar (Atlantic salmon)	N. America	Tas
Salmo trutta (brown trout)	UK	Tas
Oncorhynchus mykiss (rainbow	NZ (California)	Tas

trout)		
PLANTAE		
Caulerpa filiformis (green alga)	S. Africa	NSW
Caulerpa taxifolia (green alga)	Atlantic/Indo Pacific	WA
Codium fragile tomentosoides (green alga)	Atlantic Europe	Vic
Gymnodinium catenatum (dinoflagellate)	Japan?	Vic, Tas, WA
Alexandrium minutum (dinoflagellate)	Mediterranean?	WA, SA, Vic, NSW, WA
Alexandrium catanella (dinoflagellate)	Japan?	WA, SA, Vic, NSW
Alexandrium tamarense (dinoflagellate)	Europe?Japan?	SA, Vic, Tas, WA
Arthrocladia villosa (red alga)	N. hemisphere	?
Sperococcus compressus	N. hemisphere	?
Antithamnionella spirographidis	N. hemisphere	?
Polysiphonia brodiaei (red alga)	N. hemisphere	?
Polysiphonia pungens (red alga)	N. hemisphere	?
Undaria pinnatifida ("wakame")	Japan	Tas, Vic
Discosporangium mesarthrocarpum	Mediterranean	SA
Spacella subtilissima (brown alga)	Mediterranean	SA
Zosterocarpus spp. (brown alga)	Mediterranean	SA

DETAILS OF PORT FACILITIES[1]

NORTH BANK AREA

NORTH QUAY, BERTH 2

Berth 2 is a common user wharf run by FPA. It has a berth length of 175m and a design depth of 11m.

NORTH QUAY, BERTH 4

Berth 4, 5 and 6 are P & O Ports container berths with a combined length of 526m length and a depth of 13m. They are used for loading containers as well as bulk and general cargo.

NORTH QUAY, BERTH 7

Berth 7, 8 and 9 are Patrick the Australian Stevedore container berths with a combined length of 765.5m (including Berth 10) and a depth of 13 m. They are used for loading containers as well as bulk and general cargo with large, specific container cranes

NORTH QUAY, BERTH 10

Berth 10 is part of the Patrick the Australian Stevedore container berths mentioned above. It has a designed depth of 11m

NORTH QUAY, BERTH 12

Berth 12 is a common user, heavy duty wharf run by FPA. It has a berth length of 233m and a design depth of 11m.

VICTORIA QUAY, BERTH B

No information could be found on Berth B

VICTORIA QUAY, BERTH D

Berth D is a common user berth run by FPA and used mainly for limited lay-up. It has a length of 176m and a design depth of 11m.

VICTORIA QUAY, BERTH F

Berth F is a common user berth run by FPA and used mainly for general cargo purposes, including livestock carriers, scrap metal export and car carriers. It also supports a refurbished Passenger Terminal and a function and Exhibition Facility. It has a length of 204m and a design depth of 11m.

VICTORIA QUAY, BERTH H

Berth H is a common user berth run by FPA and used mainly for general cargo purposes, including livestock carriers, scrap metal export and car carriers. It has a length of 275m and a design depth of 11m.

KWINANA

ALCOA WHARF

Alcoa of Australia Ltd built and operates Alcoa Wharf for unloading bulk caustic soda and loading refined alumina. The berth is 244m long and 11.6m deep. A specifically designed belt conveyor system is used for loading the bulk alumina.

STEEL MILL (BHP)

Steelworks Jetty No 2 (owned and operated by BHP transport) is used in association with local industries for loading and unloading bulk products (gypsum slag, fertilisers, coal, petroleum coke, soda ash, sugar, cement clinker, mineral sands, silica sands, LPG, copper concentrates, iron ore, limestone, dolomite and manganese). The berth is 498.3m long and

[1] Information obtained from Fremantle Ports Corporation web page

12.2m deep and has a conveying system (2300 tonnes per hour) and an unloader (4000 tonnes per hour)

BULK CARGO JETTY

Bulk cargo jetty berths 1 and 2 are operated by FPA and provide facilities to unload bulk products (rock phosphate, sulphur, phosphoric acid, ammonium sulphate, potash, ammonia and urea) and liquid bulk commodities, including petroleum. The two berths have a combined length of 480m and an alongside depth of 13.4m

OIL REFINERY JETTY

This jetty is operated by the BP Refinery and is used purely for unloading and loading bulk petroleum products. The combined length of the three berths is 214.2m with a depth of 14.7m.

KWINANA GRAIN TERMINAL

The Kwinana Grain Terminal is operated by the Co-operative Bulk Handling Limited for loading bulk grain cargoes. The berth is 291m long and 16.8m deep alongside.

SAMPLING PROCEDURES

1. ABWMAC TARGET SPECIES

1.1 DINOFLAGELLATES

1.1.1 SEDIMENT SAMPLING FOR CYST-FORMING SPECIES (SMALL CORES)

Sediment cores were taken from locations within the estuary where the deposition and undisturbed accumulation of dinoflagellate cysts was likely to occur. Selection of sites was based on depth, local hydrography and sediment characteristics of the area. At each site triplicate sediment cores were taken by divers using 20 cm long tubes with a 2.5 cm internal diameter. Tubes were forced into the sediment then capped each end with a bung to provide an air-tight seal. Cores were stored upright in the dark at 4°C prior to size fractionation and examination for dinoflagellate cysts.

1.1.2 SEDIMENT PREPARATION AND CYST IDENTIFICATION

The top 6 cm of sediment core was carefully extruded from the coring tube and stored at 4°C in a sealed container until further examination. Subsamples (approx. 1–2 cm^3) of each core sample were mixed with filtered seawater to obtain a watery slurry. Subsamples (5–10 ml) were sonicated for 2 min (Braun Labsonic homogenizer, intermediate probe, 100 watts) to dislodge detritus particles. The sample was screened through a 90 µm sieve and collected onto a 20 µm sieve and the remaining fraction was panned to remove denser sand grains and larger detritus particles. Subsamples (1 ml) were examined and counted on wet-mount slides, using a compound light microscope. Where possible, a total of at least 100 cysts were counted in each sample. Identification of species followed those of Bolch and Hallegraeff (1990). Cysts of suspected toxic species were photographed with a Zeiss Axioplan light microscope using bright field or differential interference contrast illumination.

1.1.3 CYST GERMINATION

Following sonication and size-fractionation of sediments, cysts of suspected toxic species were located and isolated by micro pipette under a Zeiss Axioplan microscope and then washed twice in filtered seawater. Individual cysts were placed into tissue culture wells containing 2 ml of 75% filtered seawater with nutrients added according to medium GPM of Loeblich (1975). Additional incubations were carried out using size-fractionated sediments. Subsamples of the 20–90 µm size fraction were added to 20 ml of growth medium in sterile polystyrene petri-dishes, and sealed with parafilm. All incubations were carried out at 20.0°C at a light intensity of 80 $\mu E\ m^{-2}\ s^{-1}$ (12 h light: 12 h dark) and examined regularly for germination. Actively swimming dinoflagellate cells from incubations were isolated by micro pipette, washed in sterile growth medium and their identity determined where possible.

1.1.4 PLANKTON SAMPLING AND CULTURE

Plankton samples were collected by vertical and horizontal tows of a hand-deployed plankton net (25 cm diam. opening, 20 µm Nytal mesh, Swiss Screens, Melbourne Vic.). The samples were sealed in plankton jars, placed in a cooled container and returned to the laboratory for analysis. In the laboratory, net samples were diluted 1:1 with growth medium. Germanium dioxide (10 mg $\cdot\ l^{-1}$) was added to inhibit overgrowth by diatom species and these enrichment cultures incubated as described above. Incubations were examined regularly by light microscopy, and single cells of suspected toxic species isolated by micro pipette for further culture and toxicity determination.

1.1.5 TOXICITY TESTING

Suspected toxic species were grown in laboratory culture, under the conditions described previously, and tested for toxin (saxitoxin) production by High Performance Liquid Chromatography (HPLC)(Oshima *et al.*. 1989).

1.2 *CARCINUS MAENAS*

1.2.1 TRAPPING

The European shore crab, *Carcinus maenas*, and other crab species were sampled using light-weight plastic-coated wire-framed traps (60 cm long, 45 cm wide and 20 cm high) covered with 1.27 cm square mesh netting. Entry to the trap was through slits at the apex of inwardly-directed V-shaped panels at each end of the trap. The internal bait bag was baited with salmon, pilchards and pink ling heads. Traps were weighted with chain or divers weights and deployed with surface buoys. Whenever possible, traps were deployed in the late afternoon and recovered early the next morning.

1.2.2 VISUAL SEARCHES

Visual searches for crabs and other target species were also made at selected wharves in the port area. Divers swam the length of the wharf, searching between the surface and the bottom, to provide a complete visual survey of the outer wharf. Surveys of beach wrack were made on beaches to collect crab exuviae.

1.3 *ASTERIAS AMURENSIS, SABELLA SPALLANZANII* AND *UNDARIA PINNATIFIDA*

1.3.1 VISUAL SEARCHES

Visual searches for the northern Pacific seastar, *Asterias amurensis,* the macroalga *Undaria pinnatifida* and the fan worm *Sabella spallanzanii* were carried out by divers in rocky reef and wharf areas, and over soft bottoms. Divers were free swimming. Diver searches in wharf areas and surveys for *Undaria* in beach wrack followed procedures described for *Carcinus* above.

2. NON TARGET SPECIES

2.1 ZOOPLANKTON

Zooplankton were sampled with a standard 100 µm mesh, 50 cm diameter tow net. The net. One vertical tow (approximately 10m) was conducted at each site. On recovery the net was washed down on the outside only to avoid contamination of the sample. Retained plankton were preserved in 5% formalin and returned to the laboratory for sorting and identification.

2.2 HARD SUBSTRATE INVERTEBRATES

2.2.1 WHARF PILE COMMUNITIES

Piles or projecting steel facings were selected from wharves having different types of shipping activity. Two or three piles or facings were selected in series from near one end of each wharf, starting about 5 m from the end to reduce "edge" effects, with about 10 m distance separating each piles or facing. Three piles or facings were sampled from all wharves.

The selected piles or facings were marked and their positions recorded and photographed. For each pile divers then took:

(i) video film of the outer surface of each pile/facing from approximately high-water level down to the deepest exposed part of the pile/facing using Hi-8 video camera recorder (Sony CCD-TR3000E) in an underwater housing (Sony MPK-TRB Handycam Marine Pack). The housing was fitted with twin 20 W (Sony HVL-M20) underwater lights and a distance-measuring rod with a scale and a digital depth meter. The rod ensured that the camera was a constant distance (approx. 50 cm) from the pile or sea floor. The scale and depth meter were positioned so they fell within the field of view of the camera and provided real-time depth information on the video recording.

(ii) 35 mm still photographs using a Nikonos V underwater camera with a 35 mm lens and a 1:6 overlens and single SB-102 flash to provide higher-resolution records of the fouling communities and selected species.

(iii) representative samples of the fouling communities present at various depths by scraping attached animals and algae as carefully as possible into plastic bags. These samples were preserved in 5% buffered formalin for subsequent sorting and identification in the laboratory.

2.2.2 BREAKWATERS

Using equipment detailed in section 2.21 above, divers took video and still photographs, and collected representative samples of the attached plant and invertebrate communities.

2.3. SOFT SUBSTRATE INVERTEBRATES

2.3.1 EPIBENTHOS

Visual searches by divers to locate and collect non-target, soft-bottom, epibenthic species were carried out at selected sites as described for target species in sections 1.2 and 1.3 above.

At each wharf sampled, divers video filmed a 50 m transect between one of the piles and the outer series of infaunal cores (see section 5.2 below), along a weighted transect line marked at 1 m intervals.

2.3.2 BENTHIC INFAUNA

Divers took infaunal samples using a tubular 0.025 m^2 (17.9 cm internal diameter) hand corer. The 40 cm corer had a pair of handles close to the upper end and was marked externally with grooves at 20 cm and 25 cm from the bottom to indicated the depth to which a core was taken. The upper end of the corer was closed except for a mesh-covered 8 mm diameter hole which could be sealed with a rubber bung to aid retention of the infaunal sample when the corer was withdrawn from the sediment.

When sampling around wharves, a core was taken within 1 m of the bottom of each outer pile and facing sampled, and a second core 50 m directly out from the wharf. For each wharf area sampled this provided three samples close to the wharf ("inner" cores) and three 50 m from the wharf ("outer" cores). When sampling around channel markers or single pylons three replicate cores were taken 1 m from the base of the pile. Each sample was transferred to a 1-mm mesh bag with drawstring mouth and then sieved underwater, either in situ or after the diver returned to the surface. The retained material was then washed into a plastic bag and preserved in 5% buffered formalin for subsequent sorting and identification in the laboratory.

2.4 FISH

2.4.1 POISON STATIONS

Rotenone was used to sample fish associated a small wreck and around the bottom of piles. The rotenone was mixed with seawater containing 5% detergent immediately before use and dispensed from squeeze bottles. Poisoned fish were collected by divers using hand-nets.

2.4.2 NETS

Seine nets were used to collect fish in the port and nearby ocean beaches. Seine netting used a 20 m seine with 10 mm mesh. All species taken with the seine nets were recorded.

3. ENVIRONMENTAL DATA

3.1 TEMPERATURE AND SALINITY

A submersible data logger (SDL) equipped with pressure, conductivity, and temperature sensors was used to record data on salinity and water temperature, usually at 1 m intervals from the surface to near the bottom. Turbidity at different depths was measured using a 0.2 m^2 Secchi disk.

3.2 SEDIMENT ANALYSIS

3.2.1 SEDIMENT COLLECTION

Sediment samples (minimum 100 g wet weight) were taken for analysis of grain size and organic content, to characterise the habitats of any introduced epibenthic and infaunal species found. Samples were taken with each set of infaunal cores ("inner" and "outer") and at other selected sites. The sediment was collected by divers in sealable plastic bags, which were then frozen to stabilise the organic content levels and returned to the laboratory for analysis.

3.2.2 PARTICLE SIZE ANALYSIS

After samples were thawed in the laboratory a subsample, approximately 25 g (dry wt), of sediment was taken for organic content analysis. The remaining sediment was wet-sieved through a 2 mm mesh sieve and separated into < 2 mm and > 2 mm fractions. Both fractions and the organic content subsample were then oven-dried at 80° C (2-4 days). The two fractions were analysed as follows:

> 2 mm fraction. The total fraction was dry-sieved through a nest of sieves and the fraction retained on each sieve (2, 2.8, 4, 5.6 and 8 mm meshes: 0.5 Phi intervals) was weighed. Sediment retained on the largest sieve included all particle with size larger than 8 mm. The individual sieved weights were then added to the dry weight of the < 2 mm fraction to give a total dry weight for the entire sediment sample. The proportion of each component in the > 2 mm fraction was then calculated as a percentage of the total dry sample.

< 2 mm fraction. The dry weight of the total < 2 mm fraction was measured to 0.01 g and the sediment or, depending on the amount available, a subsample (taken by "coning and quatering"), was analysed using a Malvern Laser Particle Size Analyser at the Marine Geophysical Laboratory, James Cook University, Queensland. Particle size data from this analysis was combined with data from the analysis of the > 2 mm fraction.

3.2.3 ORGANIC CONTENT

Approximately 25 g of dry, unsieved sediment was weighed in a crucible to 0.00001 g then ashed in a muffle furnace at 480° C for 4 hrs. The crucible was allowed to cool before being reweighed. The difference between the nett dry and nett ash-free weights was then calculated. This difference, or weight loss, was then expressed as a percentage of the initial dry weight and represents the organic content of the sediment sample.

REFERENCES

Loeblich, A. R. 1975. A seawater medium for dinoflagellates and the nutrition of *Cachinina niei*. *J. Phycol.* 11, 80–86.

Oshima, Y., K. Sugino, and T. Yasumoto. 1989. Latest advances in HPLC analysis of paralytic shellfish toxins. *In:* (S. Natori, K. Hashimoto and Y. Ueno, eds) Mycotoxins and Phycotoxins '88, Elsevier Science Publishing Co., New York, pp. 319-326.

APPENDIX 4: SAMPLING SITE DETAILS

APPENDIX 4: SAMPLING SITE DETAILS

APPENDIX 4: SAMPLING SITE DETAILS

APPENDIX 4: SAMPLING SITE DETAILS

APPENDIX 4: SAMPLING SITE DETAILS

APPENDIX 4: SAMPLING SITE DETAILS

APPENDIX 4: SAMPLING SITE DETAILS

APPENDIX 4: SAMPLING SITE DETAILS

SHIPPING INFORMATION PROFORMA

A. VISITING VESSELS

1 Origin of vessel entering the port
- 1.1 international
  - 1.1.1 last international port
  - 1.1.2 last port of call (if any) within Australia
- 1.2 domestic
  - 1.2.1 last port of call
  - 1.2.2 other ports visited

2 Frequency of visits
- 2.1 regular service
  - 2.1.1 frequency
  - 2.1.2 duration of service
- 2.2 occasional visits
  - 2.2.1 frequency
  - 2.2.2 over what period

3 Ballasting
- 3.1 vessel in ballast during voyage to port
- 3.2 port where ballast loaded
- 3.3 ballast water exchanged at sea
- 3.4 reballasting in or near port
  - 3.4.1 ballast water discharged; estimated volume discharged
    - at berth
    - within port (not at berth)
    - outside port
  - 3.4.2 ballast water loaded; estimated volume loaded
    - at berth
    - within port
    - outside port
    - no reballasting in or near port

4 Hull condition
- 4.1 level and type of fouling
- 4.2 date when last slipped and cleaned
- 4.3 port where last slipped and cleaned

5 Location (berth) in port

6 Turn round time
- 6.1 average turn round time
- 6.2 maximum time in port

B. VESSELS IN PORT FOR EXTENDED PERIODS (DREDGES, BARGES ETC.)

1 Type/name of vessel

2 Previous location
- 2.1 name of port
- 2.2 duration of stay in that port

3 Duration of stay in port

4 Location (berth or area of operation) in port

5 Destination (if departed)

6 Hull condition
- 6.1 on arrival
  - 6.1.1 level and type of fouling
  - 6.1.2 date when last slipped and cleaned
  - 6.1.3 not cleaned
- 6.2 at departure
  - 6.2.1 level and type of fouling
  - 6.2.2 date when last slipped and cleaned
  - 6.2.3 not cleaned

APPENDIX 6: SEDIMENT ANALYSIS

APPENDIX 7: SURVEY RESULTS

APPENDIX 7: SURVEY RESULTS

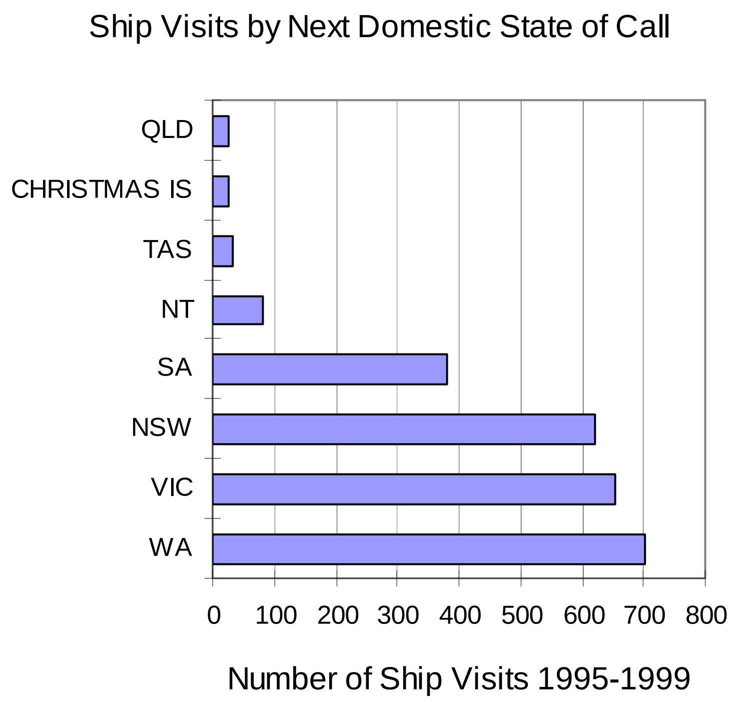
APPENDIX 7: SURVEY RESULTS

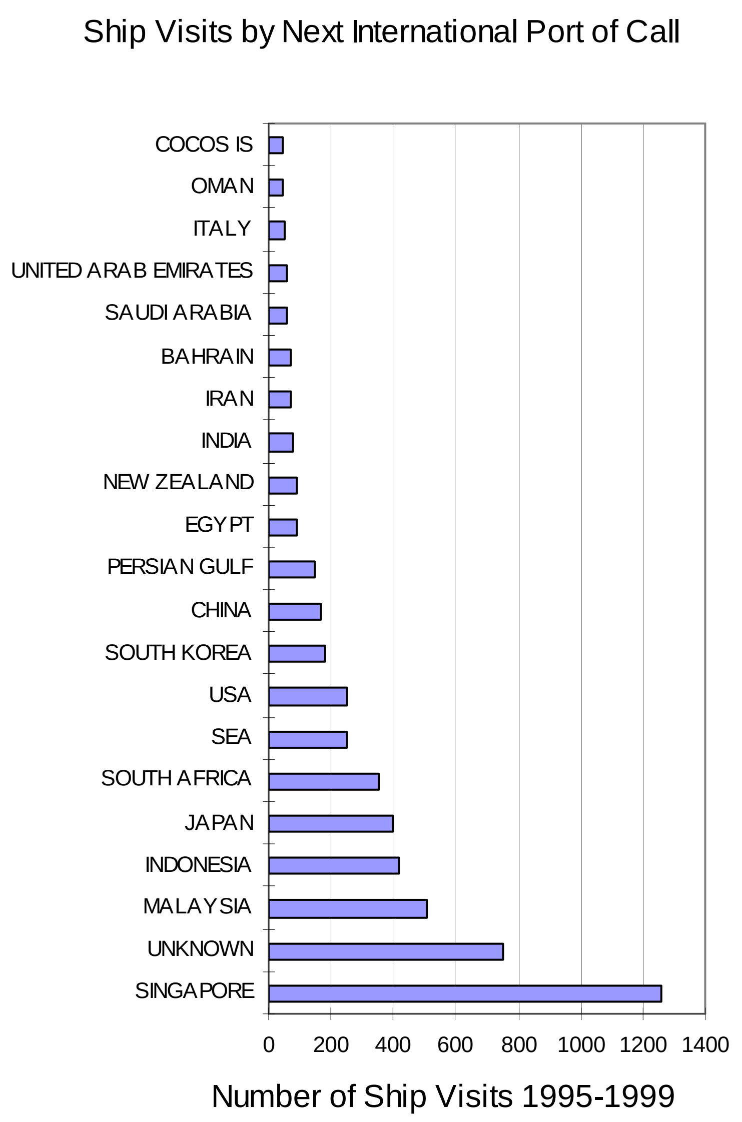
APPENDIX 7: SURVEY RESULTS

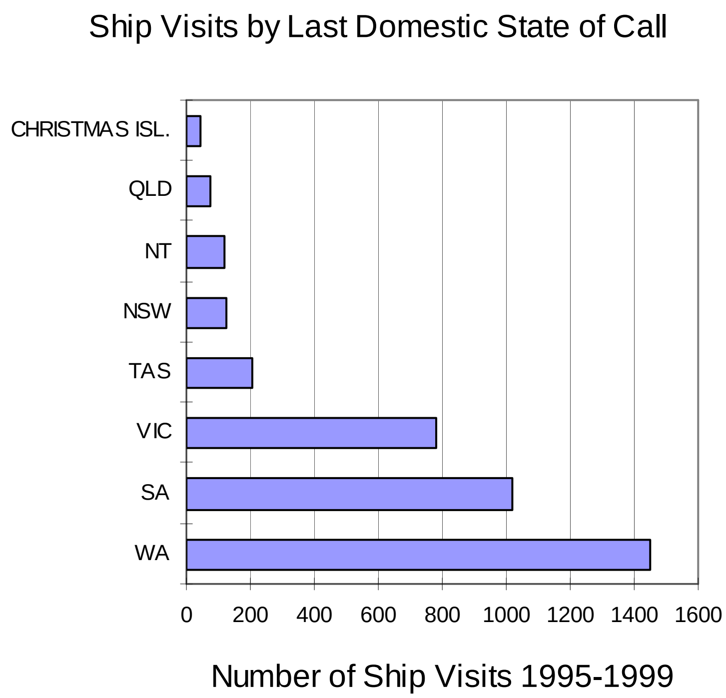
APPENDIX 7: SURVEY RESULTS

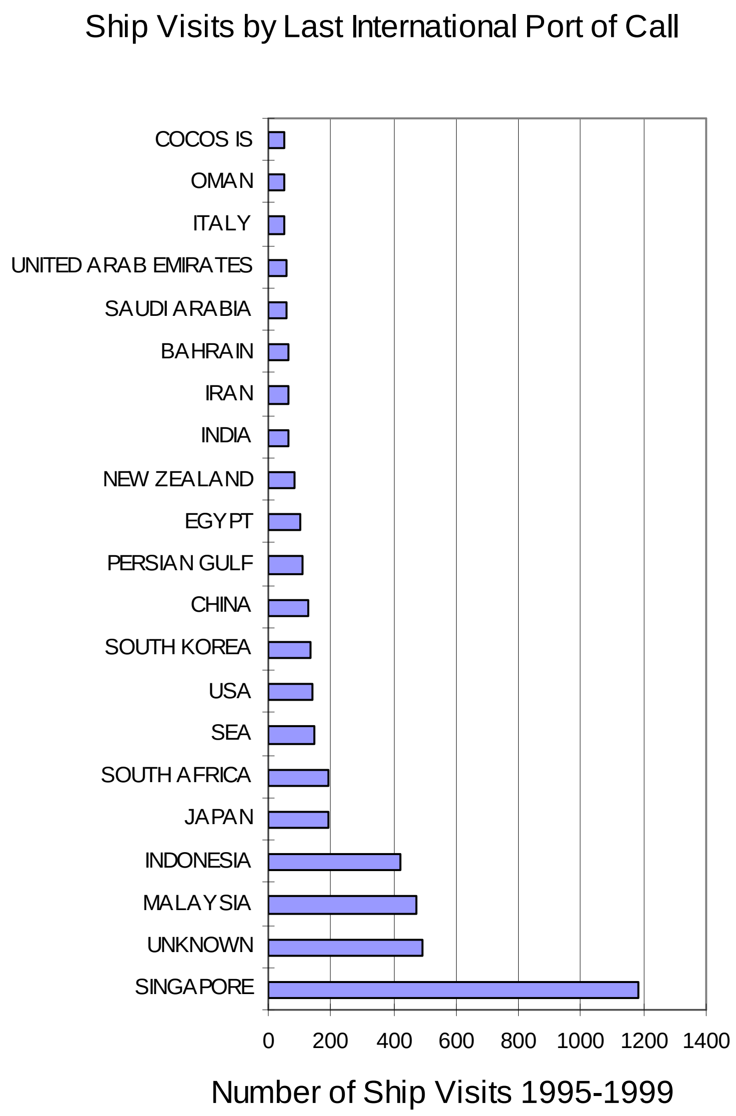
APPENDIX 7: SURVEY RESULTS

APPENDIX 7: SURVEY RESULTS


Ship Visits by Next Domestic State of Call
QLD
CHRISTMAS IS
TAS
NT
SA
NSW
VIC
WA
0
100
200
300
400
500
600
700
800
Number of Ship Visits 1995-1999


Ship Visits by Next International Port of Call
COCOS IS
OMAN
ITALY
UNITED ARAB EMIRATES
SAUDI ARABIA
BAHRAIN
IRAN
INDIA
NEW ZEALAND
EGYPT
PERSIAN GULF
CHINA
SOUTH KOREA
USA
SEA
SOUTH AFRICA
JAPAN
INDONESIA
MALAYSIA
UNKNOWN
SINGAPORE
0
200
400
600
800
1000
1200
1400
Number of Ship Visits 1995-1999


Ship Visits by Last Domestic State of Call
CHRISTMAS ISL.
QLD
NT
NSW
TAS
VIC
SA
WA
0
200
400
600
800
1000
1200
1400
1600
Number of Ship Visits 1995-1999


Ship Visits by Last International Port of Call
COCOS IS
OMAN
ITALY
UNITED ARAB EMIRATES
SAUDI ARABIA
BAHRAIN
IRAN
INDIA
NEW ZEALAND
EGYPT
PERSIAN GULF
CHINA
SOUTH KOREA
USA
SEA
SOUTH AFRICA
JAPAN
INDONESIA
MALAYSIA
UNKNOWN
SINGAPORE
0 200 400 600 800 1000 1200 1400
Number of Ship Visits 1995-1999