Marine invasive species literature review

Theme: Fisheries and Aquatic Resources

WAMSI Westport Marine Science Program

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ABOUT THE MARINE SCIENCE PROGRAM

The WAMSI Westport Marine Science Program (WWMSP) is a $13.5 million body of marine research funded by the WA Government. The aims of the WWMSP are to increase knowledge of Cockburn Sound in areas that will inform the environmental impact assessment of the proposed Westport development and help to manage this important and heavily used marine area into the future. Westport is the State Government's program to move container trade from Fremantle to Kwinana, and includes a new container port and associated freight, road and rail, and logistics. The WWMSP comprises more than 30 research projects in the biological, physical and social sciences that are focused on the Cockburn Sound area. They are being delivered by more than 100 scientists from the WAMSI partnership and other organisations.

FUNDING SOURCES

The $13.5 million WAMSI Westport Marine Science Program was funded by the Western Australian Government, Department of Transport. WAMSI partners provided significant in-kind funding to the program to increase the value to >$22 million.

DATA

Finalised datasets will be released as open data, and data and/or metadata will be discoverable through Data WA and the Shared Land Information Platform (SLIP).

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Front cover image: A school of pink snapper in Cockburn Sound (DPIRD).

Contents

The WAMSI Westport Marine Science Program is a $13.5 million body of research that is designed to fill knowledge gaps relating to the Cockburn Sound region. It was developed with the objectives of improving the capacity to avoid, mitigate and offset environmental impacts of the proposed Westport container port development and increase the WA Government's ability to manage other pressures acting on Cockburn Sound into the future. Funding for the program has been provided by Westport (through the Department of Transport) and the science projects are being delivered by the Western Australian Marine Science Institution.

1 Marine Invasive Species Literature Review

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Project
4.7 Marine Invasive Species Literature Review

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Executive Summary

Invasive marine species introduced anthropogenically into new marine areas are a worldwide issue. This literature review of invasive marine species in Cockburn Sound and Owen Anchorage provides a baseline for understanding the potential risks posed by the Westport Project. To ensure no species were missed, the analysis included the Fremantle marine area from Cottesloe to Cockburn Sound and the Swan River. Seventy introduced species were recorded that may have established populations, 29 of which have been found in Cockburn Sound and/or Owen Anchorage. Four of these species are considered noxious in Cockburn Sound/Owen Anchorage by DPIRD. Two are planktonic: the toxic dinoflagellates *Alexandrium catenella* and *A. minutum* have been recorded in barely detectable numbers. Two benthic species, the alga *Codium fragile fragile* and the ascidian *Didemnum vexillum* are actively monitored by DPIRD, along with *D. perlucidum*. The potential effects of the three species are discussed. Invasive marine species are concentrated on artificial surfaces. Eco-engineering is a new field that attempts to ameliorate invasive marine species, but there have been mixed results to date. As Cockburn Sound is relatively small, it would be difficult to prevent these species from colonising new Westport structures. The goal should be to prevent new invasive marine species from being introduced to Westport through ballast water or biofouling. Rigorous quarantine procedures are in place for both risk factors, and vessels mobilising to Westport should proactively adhere to all quarantine requirements. The risk of introducing marine pest species will be greatest during construction, but experience during the construction boom in the Pilbara demonstrated the issue is manageable. During operations most vessels arriving at Westport would previously have gone to Fremantle Inner Harbour, so the increased risk results only from increased numbers of vessels or changes in where vessels are arriving from.

2 Introduction

Invasive marine species (also known as introduced marine pests) are one of the most important anthropogenic threats to marine ecosystems (Katsanevakis et al. 2014; Crowe & Frid 2015; McDonald et al. 2020; Salimi et al. 2021). They have a wide variety of potential effects, including: introducing human and other diseases (Hallegraeff et al. 1988); displacing native species though predation or competition (Arcella et al. 2014; Branch & Steffani, 2004); damaging local habitats (Robinson et al. 2007); and changing the ecology of native communities (Colautti & Lau 2015; Rius et al. 2015) either directly or through cascading community-level impacts (Griffiths et al. 1992; Shine 2010); and clogging pipes and damaging critical marine infrastructure (Wells et al. 2009).

While there are several mechanisms for species introductions such as deliberate introduction for aquaculture or accidental introduction, shipping, either as biofouling or in ballast water, is the dominant vector in most areas (Seebens et al. 2013; Salimi et al. 2021). As an island continent, 98% of trade into or out of Australia is on vessels (Ports Australia 2022). In recognition of the IMS threat, a strategy of quarantine measures to prevent the introduction of marine pests into Australia (e.g., Vessel-Check 2022) and monitoring for any that penetrated the barriers, was developed by the Commonwealth and Western Australian governments. A list of 55 monitoring target species was included in the strategy (NIMPCG 2009a, 2009b), later replaced by an enlarged WA prevention list of about 80 species by DPIRD (2016).

Fortunately, most introduced marine species are apparently innocuous, causing no known adverse effects; only a small portion become pests. For example, in a comprehensive survey of Western Australia (WA), Huisman et al. (2008) and Wells et al. (2009) recorded 60 introduced marine species living in WA waters. Only three (mussel *Musculista senhousia*, fanworm *Sabella spallanzanii* and dinoflagellate *Alexandrium minutum*) were on the national marine pest list (NIMPCG 2009a; 2009b). Four additional marine pests have subsequently been recorded in WA, including the ascidians *Didemnum perlucidum* (Muñoz et al. 2015) and *D. vexillum* (DPIRD 2023), Asian paddle crab *Charybdis japonica* (DoF 2015) and alga *Codium fragile* (McDonald et al. 2008).

Introduced marine species and marine pests are more common in temperate than tropical waters (Coles & Eldredge 2002; Hewitt 2002; Huisman et al. 2008; Freestone et al. 2011). Several possible reasons have been proposed for this, including "the higher diversity of native tropical communities conferring an increased resistance to invasions through an increase in biotic interactions". Alternatively, it has been suggested that tropical waters have been less surveyed, resulting in fewer detections, or our lack of taxonomic knowledge of the biodiverse tropics may result in introduced species remaining undetected (Hewitt 2002). However, three recent studies in have demonstrated a low number of introduced marine species and marine pests in biodiverse, well surveyed warm waters. Wells (2018) developed a database of 5532 shallow water marine species known in the Pilbara region of northwestern WA, but the only marine pest was the ascidian *D. perlucidum*, which is known to occur throughout WA. Singapore is the most connected port in the world, with direct services to over 600 ports, but only 22 of 3650 species examined were introduced (Wells et al. 2018). Similarly, only 33 of 4615 species recorded in the Florida Keys were known to have been introduced and have established populations or their status is unclear. However, the number of introduced marine species is not the full story; severe problems are being caused by the lionfish *Pteroid volitans* and *P. miles* in southern Florida and the Caribbean Sea (Côté et al. 2013; Green et al. 2013).

Marine Pests (2023) presents a map of the known distribution of eight species in 17 Australian ports. All eight are recorded in six southern Australia between Newcastle NSW and Fremantle WA; none are recorded in the 11 ports further north. Thirty-seven of the 60 introduced marine species recorded by

Huisman et al. (2008) were temperate, occurring from Geraldton south, 6 were tropical species that occurred from Shark Bay to the north and 17 were detected in both the southern and northern halves of WA. With 46 species, the Fremantle marine region (Cottesloe to Cockburn Sound, including the Swan River) had the greatest number of introduced marine species in WA. This was due to the Port of Fremantle being in a temperate marine environment and having a large and diverse range of vessels accessing the port.

Westport is the WA State Government's long-term program to investigate, plan and build a future port in Kwinana with integrated road and rail transport networks. The Western Australian Marine Science Institution (WAMSI) has partnered with Westport to deliver a major collaborative science program on the marine environment at Cockburn Sound. The WAMSI Westport Marine Science Program (WWMSP) will ensure the environmental impact assessment for Western Australia's future container port is based on independent and outstanding science. The goal of this Marine Invasive Species Literature Review is to deliver a comprehensive and systematic literature and database review of invasive marine species to contribute to understanding the current state and distribution of nonindigenous marine species in Cockburn Sound, specifically those associated with artificial habitats and of importance to the Westport development. Specific requirements of the project are to develop information on:

a. Existing data and knowledge in relation to the recognised introduced marine species detected and reported from soft-sediment, seagrass, and hard natural and artificial substrates in Cockburn Sound and Owen Anchorage.
b. Key introduced marine species' traits and biogeographic information will be collated from the literature and reference collections including: reproductive and settlement timing; reproduction type; pelagic larval duration; light requirements; habitat requirements; depth restrictions; functional trophic level; native and introduced biogeographic regions; known Australian distribution.
c. Impacts based information on environmental, economic, social and cultural, and human health values following the methodologies presented in Ojaveer et al. (2015).
d. Factors affecting the success of introduced marine species establishment and spread in artificial habitats (including the port infrastructure) that can be used as a mitigation strategy including engineering design and pre-seeding of native species and/or accelerated community development.

3 Materials and Methods

3.1 Introduced marine species recorded in the Fremantle marine area

A contract requirement for this study was that it follow the protocols of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) developed by Page et al. (2021). In this context, the present study updates and revises the statewide survey conducted by Huisman et al. (2008).

Huisman et al. (2008) compiled all available data on introduced marine species in Western Australia, including published information, Western Australian Museum (WAM) and Western Australian Herbarium (WAH) records, unpublished reports, consultant information, etc. All grey literature reports were checked against WAM and WAH records. The State was divided into 14 marine areas, including all the major ports. A total of 102 species were investigated, 60 of which were considered to have been introduced into WA and to have established populations. Data presented for each species were, WA records and vouchers, distributions elsewhere and remarks.

3.1.1 Eligibility criteria

Forty-six species of the 60 introduced marine species were reported from the Fremantle marine area, which included Cockburn Sound, Fremantle, Swan River and Cottesloe. Data on these species was extracted from Huisman et al. (2008) and included in the present report. The Huisman et al. (2008) data were updated with new records on the Atlas of Living Australia (ALA 2023), the Australian National Introduced Marine Pest Information System (NIMPIS 2023) and the Smithsonian Institution Environmental Research Center's National Estuarine and Marine Exotic Species Information System (NEMESIS 2023). The World Register of Marine Species (WoRMS 2023) was checked to ensure the taxonomy used in the present report is the latest available. Where names have been changed since Huisman et al. (2008) was published, the new and old taxonomic names are shown. A similar process was followed for the 42 species not considered to have been introduced by Huisman et al. (2008) to ensure there had been no changes to scientific understanding since 2008. Scopus, Web of Science and PhD theses from WA universities from 2000 onwards were checked to supplement Huisman et al. (2008).

A key requirement of the PRISMA methodology (Page et al. 2021) is that potential records are assessed carefully for their accuracy. ALA (2023) presents records from a variety of sources of varying quality. Many of the ALA records are taken from iNaturalist and are visual records by citizen scientists with no specimens provided. Once the reports are "verified" they are included on iNaturalist and uploaded onto ALA. There is no indication of how or by whom the verification was done but many of the species involved require examination by experts on specific taxonomic groups. As previous experience has demonstrated that many of the iNaturalist identifications are incorrect, only ALA records from State museums were used. The major Australian museums have provided data for ALA. Note that this is not a complete record of the museums' holdings. Only a small proportion of the collections of each museum have been databased, particularly WAM; only digital records are shown on ALA. Also, some records may be incomplete. For example, if a species is recorded from "WA" with no further information the default position on the map is Perth, which for marine species would suggest the species was recorded from Fremantle. This is not a problem for species recorded by Huisman et al. (2008).

For the last 15 years the WA Department of Fisheries, and now DPIRD, has had an extensive program of vessel inspections to detect potential marine pest species on vessels arriving in WA. Inspections have been conducted overseas or interstate before the vessels mobilised to WA or after arrival in a WA port. Many of the inspections were undertaken at Henderson or HMAS Stirling at Garden Island in Cockburn Sound or in Fremantle Harbour. When IMS species have been detected the vessels have been cleaned, usually in drydock. Inspection records discussed by Huisman et al. (2008) have been included in the present study. Other records since 2008, primarily barnacles (Jones 2012), have not been included, as the organisms were removed from the vessels and did not establish in the local marine environment. DPIRD does not record species records from vessel inspections (Dr J McDonald, DPIRD, pers comm.).

All information sources were searched during the period of 1 June to 31 December 2023.

3.1.2 Search Strategy criteria

Online searches were used to search for all 102 species listed by Huisman et al. (2008) to search for new records of the species in WA. If the taxonomy of a species has changed since Huisman (2008) was compiled, both the old and new terms were searched. New records for the Fremantle marine region were searched using combinations of the terms: introduced marine pests, introduced marine species and invasive marine species combined with geographical terms including Western Australia, Fremantle, Cockburn Sound, Cottesloe and Owen Anchorage.

3.1.3 Data Collection Process

All literature research and data reviews were undertaken by the report author, Dr Fred Wells. Information on aspects of the project was obtained from: Dr Al Kendrick, WAMSI; Dr Glenn Hyndes, Edith Cowan University; and Drs Justin McDonald and Gary Jackson, DPIRD.

3.1.4 Abbreviations

The following abbreviations are used for Australian museums and herbaria:

- AMS, Australian Museum Sydney.
- MAGNT, Museums and Art Galleries of the Northern Territory.
- MV, Museums Victoria.
- QM, Queensland Museum.
- WAH, Western Australian Herbarium.
- WAM, Western Australian Museum.

4 Results

4.1 Existing data and knowledge in relation to the recognised introduced marine species

Appendix 1 provides information on all species recorded during the literature search: scientific name, records in the Fremantle marine area, vouchers (if any), range outside WA, range in WA, habitat, WA literature records and any notes about the species. Seventy species are discussed. Of these:

- 1 species is cryptogenic (a species whose native range cannot be determined at present).
- The taxonomy of seven species in the shipworm family Teredinidae cannot be adequately assessed. These molluscs have a minute bivalve shell at their anterior end and secrete a calcified tube in which the animal lives. They readily burrow into wood and have been widely distributed by wooden vessels over thousands of years. Teredinids are poorly known and have been little studied in Western Australia. The only significant publication on the group in WA is from Dampier (Brearley et al. 2003).
- 5 species are native to WA.
- 9 species are not considered to have been established in the Fremantle marine area. Most of these species were identified during vessel inspections. The vessels were cleaned, and the species are not in the environment.
- 48 species are thought to have been introduced and established populations in the Fremantle marine area. Some of these species have been found incidentally on only a few occasions, sometimes many years ago. They may/may not actually be present in the area, but there have been no surveys for the species.

The 48 species established in the Fremantle marine area vary in where they were located:

- 3 were found at Cottesloe.
- 20 in the Swan River.
- 28 at Fremantle.
- 11 at Owen Anchorage.
- 27 in Cockburn Sound.

The distribution of individual species in the Fremantle marine area varies; some species were detected at only one of the five sites, while others were found at all sites. Given the sporadic nature of the records it should be assumed that most of the 48 species could be present in Cockburn Sound, but this does not mean the species are equally distributed in the Fremantle marine area. For example, there are an estimated 3.6 billion *Batillaria australis* (a species of snail) living in the Swan River (Thomsen et al. 2010), but there are only isolated records from Cockburn Sound.

Only 11 introduced marine species have been reported from Owen Anchorage, but 28 in Fremantle immediately to the north and 27 in Cockburn Sound to the south. There are two probable reasons for this. Firstly, there has been less survey activity in Owen Anchorage. Secondly, the anchorage is more exposed to the open sea and has very few hard substrates on which most of the introduced species occur. Most of the Owen Anchorage records were not in the open anchorage but were found along hard intertidal habitats on the eastern shoreline.

Forty-four of the species have been introduced from overseas; only four are from eastern Australia: the barnacle *Tesseropora rosea* (Jones 1990c), the bivalve molluscs *Eumarcia fumigata* (Brearley & Wells 2019) and *Scaeochlamys livida* (Morrison & Wells 2009) and the gastropod *Batillaria australis* (Ewers 1965). *Eumarcia fumigata* is unique in being present in the fossil record in the Swan River, but the species became restricted to eastern Australia in the late Pleistocene. It was first recollected in the Swan River in 2012 (Brearley & Wells 2019).

Given the relatively short history of European settlement in WA, it is not surprising that there is a dearth of information on the timeline of the introduction of marine species. The University of Western Australia appointed its first marine biologist, Dr EP Hodgkin, after World War II. While it was founded in 1891 as the Geological Museum, the WA Museum did not appoint its first curator until 1958. While the Museum is the primary agency responsible for documenting the fauna of Western Australia, even now it has only 3.5 full time equivalent curators in the Department of Aquatic Zoology responsible for documenting the thousands of species of marine biota living in >20,000km of coastline, and freshwater and terrestrial groups such as the diverse land snails and other groups. Marine mammals and other vertebrates are handled by the Department of Terrestrial Zoology.

4.2 Key invasive marine species' traits and biogeographic information

In the early 2000s the National Introduced Marine Pests Coordination Group (NIMPCG) developed a strategy of quarantine barriers to reduce the chance of a marine pest being introduced into Australian waters and a companion monitoring plan to detect any species that penetrated the quarantine barriers. NIMPCG consisted of representatives of the Australian governments, State and Territory jurisdictions, industry and environmental groups. A list of 55 potential marine pests was developed (NIMPCG 2009a; 2009b). While it was potentially effective, the original monitoring strategy was labour intensive and expensive, involving extensive sampling in diverse habitats using a variety of techniques including shoreline visual surveys, subtidal ROV surveys, benthic grabs, trawls and settlement arrays. Implementation of the program was patchy; some states monitored but others did not; WA was by far the most active jurisdiction in implementing this program.

In 2012, the WA Department of Fisheries (now part of DPIRD) developed a draft 'WA Prevention list for Introduced Marine Pests' which expanded the NIMPCG (2009a; 2009b) list to about 80 species. Species on the list were declared to be noxious and it became illegal to own, transport, introduce, etc. the listed species in Western Australia. DPIRD (2016) is the current WA prevention list. To streamline monitoring, a new strategy, the State-Wide Array Surveillance Program (SWASP) was developed based on passive settlement arrays deployed in the ports around WA. Marine growth on the arrays is collected and processed using Next-Generation Sequencing to detect species on the potential marine pest list (McDonald et al. 2020). As part of the SWASP program an extensive DNA database of potential marine pest species that includes most of the taxa on DPIRD (2016) list has been developed (Dias et al. 2017).

At a national level, NIMPCG was terminated and replaced by the Marine Pests Sectoral Committee (MPSC) which is restricted to representatives of the Australian government, States and Territories. Following external consultation, to concentrate species of primary concern, on the MPSC developed a much smaller Australian Priority Marine Pest List (APMPL) that identifies 10 of Australia's significant marine pests (MarinePests 2023). This list includes 3 species that are established in parts of Australia (none are in WA) and 7 exotic species.

DPIRD's SWASP program is currently focusing on three species that have been introduced into Cockburn Sound: the ascidians *Didemnum perlucidum* and *D. vexillum* and the alga *Codium fragile fragile* (Dr Justin McDonald, DPIRD, pers. comm.). As the three are the primary focus of the regulatory agency and are present in Cockburn Sound, they are discussed in detail below.

4.2.1 Didemnum perlucidum

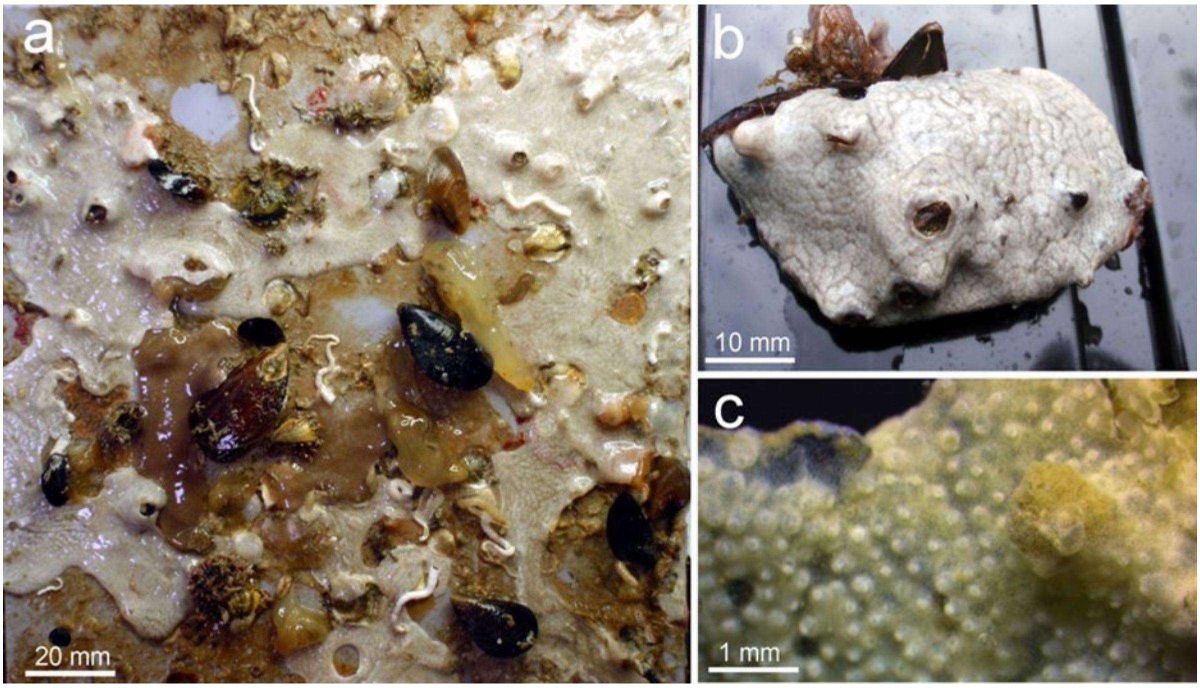

Figure 1. *Didemnum perlucidum* on a settlement plate in the lower Swan River. Source: Smale & Childs (2012).

Reproductive and settlement timing: Muñoz et al. (2015) reported that larvae of *D. perlucidum* were present throughout the year in the Perth region but were more abundant in summer. Recruitment was low during winter; below detectable levels on experimental plates. There was also a tendency for colonies to senesce in winter, when colony sizes were reduced to 1-25cm^2, compared to 100-900cm^2 in summer.

Reproduction type: *Didemnum perlucidum* has three methods of reproduction: sexual, cloning and fragmentation. The species is hermaphroditic, with both male and female gonads in each zooid. Fertilisation is internal and larvae develop in the colony. When they are fully developed, the larvae are expelled through exhalant water canals and become planktonic. Cloning occurs when zooids form buds, allowing spread of the colony. Fragmentation occurs when a portion of the colony is broken off, carried by currents into a new area, then settles and grows (Muñoz et al. 2015). The multiple methods of reproduction and establishment of new colonies provide the species with a distinct competitive advantage.

Pelagic larval duration: Larvae remain in the plankton for about 48 hours before settling, usually a few metres from the parent colony (Muñoz & McDonald 2014).

Light requirements: There is no published information, but colonies are most numerous near the sea surface.

Habitat requirements: *Didemnum perlucidum* occurs on a wide range of hard substrates and is particularly abundant on artificial habitats, especially steel mooring buoys.

Depth restrictions: Although the species can occur deeper, it is most abundant within the upper 5m from the surface.

Functional trophic level: The species is a suspension feeder on plankton and suspended organic matter.

Native and introduced biogeographic regions: Described from Guadeloupe in the Caribbean in 1983, the native range of the species is unknown. Following the original description, *D. perlucidum* was rapidly reported in a wide range of localities, including Brazil, West Africa, and the Indo-Pacific (NEMESIS 2023). The first Australian record was in the Swan River in 2010 (Smale & Childs 2012).

Known Australian distribution: In Australia it is known from the Northern Territory and northern Queensland. It occurs throughout WA, from Esperance to the Kimberley (NIMPIS 2023).

Notes: *Didemnum perlucidum* was first recorded from Gove NT in 2007. It was recorded from the Swan River estuary in 2010 as part of a study of the community structure of organisms growing on experimental plates (Smale & Childs 2012; NIMPIS 2023). In 2011 and 2012 the then Department of Fisheries developed a marine pest monitoring program that demonstrated *D. perlucidum* was already spread over 2800km of the WA coastline (Bridgwood et al. 2014). Later research concluded *D. perlucidum* was introduced into Australia at least twice, and possibly three times, and subsequently spread within WA (Dias et al. 2021). The timing of the introductions is not known, but it is possible the species was present for some time before becoming apparent. Other species are known to have been introduced and present in a new marine environment for extended periods before their populations exploded. For example, the mussel *Brachidontes pharaonis* was recorded in the eastern Mediterranean a century before it developed substantial populations (Rilov et al. 2004). Dr Patricia Kott of the Queensland Museum undertook the seminal work on Australian ascidians and did not report *D. perlucidum* in her publications on the Didemnididae (Kott 2001; 2005). Her work on the WA biota was based on the collections of the WA Museum which was focussed on recording species in natural habitats over 20,000km of coastline, and was not targeted at artificial habitats. The curator of marine invertebrates at the WAM specialised in echinoderms and to a lesser extent corals. Ascidians were one of 15 phyla for which she had taxonomic responsibility. It would not be surprising if *D. perlucidum* was present in WA for some time and simply not collected (F Wells, pers. obs.). Regardless of the timing of *D. perlucidum* being introduced to WA, it is now permanently a part of the local marine fauna.

4.2.2 Didemnum vexillum

Figure 2. *Didemnum vexillum.* Photo from Outbreak (2023). Copyright DPIRD.

Reproductive and settlement timing: *Didemnum vexillum* spawns in summer, though there may be some residual reproduction in winter. Northern hemisphere populations typically reproduce for three to five months, but in the southern hemisphere this may be as long as nine months (Fletcher et al., 2013a).

Reproduction type: Like *D. perlucidum, D. vexillum* can reproduce both sexually with planktonic larvae and asexually by fragmentation (Stefaniak & Whitlatch, 2014). Fragmentation of larvae-packed tendrils from an existing colony helps with the natural dispersal of *D. vexillum*. The fragments can survive in the water column for up to four weeks, creating considerable dispersal ability for the species (Lambert 2009). The colonies develop tendrils up to 1m long (Coutts & Forrest 2007), which are easily broken off, creating the potential for new colonies to be established.

Pelagic larval duration: Usually less than a day, but some larvae settle rapidly after they are released. Settlement is usually within 250m of release but may be up to 1km away (NEMESIS 2023).

Light requirements: Not recorded.

Habitat requirements: *Didemnum vexillum* attaches to hard structures, including aquaculture and port infrastructure, and can become established on gravel surfaces (NIMPIS 2023). It is more common on artificial than natural surfaces (NEMESIS 2023).

Depth restrictions: The ascidian is most abundant near the sea surface but has been recorded at depths of up to 81m (NIMPIS 2023).

Functional trophic level: Filter feeder on phytoplankton, suspended organic matter, diatoms and bacteria (Daniel & Therriault 2007).

Native and introduced biogeographic regions: Native to the northwest Pacific, probably Japan (NEMESIS 2023); introduced to Europe, North America and New Zealand (ALA 2023; NIMPIS 2023).

Known Australian distribution: Only known from Cockburn Sound and in Sydney (NIMPIS 2023; Outbreak 2023).

Notes: The species was first detected at HMAS Stirling at Garden Island in April 2021, and spread to Henderson, where it was found in January 2023 (DPIRD 2023). It is currently subject to a level 2 incident (DPIRD 2023). It has also recently been recorded in Sydney (Outbreak 2023).

4.2.3 *Codium fragile fragile*

Figure 3. *Codium fragile fragile.* Photo: Dr Rob Hilliard, from Fisheries WA (2016).

Reproductive and settlement timing: There is no information on *C. fragile fragile* reproduction in WA, but Campbell (1999) reported that in Port Philip Bay, Victoria the species was seasonal. Maximum densities and biomass occurred from January to May and minima from July to December. Juvenile recruitment occurred between February and May.

Reproduction type: *Codium fragile fragile* is dioecious, but monoecious (both sexes present on one plant) thalli do exist. Reproduction in the introduced strain is parthenogenetic with the alga releasing female gametes that can germinate without fertilisation. Asexual reproduction by fragmentation occurs particularly in colder months.

Pelagic larval duration: Gametes begin to geminate within hours, or at most a few days, after settlement.

Light requirements: None reported, but the species lives near the sea surface.

Habitat requirements: *Codium fragile fragile* attaches to a range of hard surfaces in subtidal marine and estuarine environments, including rocky reefs, boulders, cobbles, shellfish, wharf pylons and aquaculture facilities. It has wide temperature and salinity tolerances (NIMPIS 2023).

Depth restrictions: The species occurs in intertidal and shallow subtidal environments. It is usually found in the upper 3m but has been recorded at 15m (Chapman 1999).

Functional trophic level: Autotrophic.

Native and introduced biogeographic regions: Native to Japan, now widely distributed in Europe, Mediterranean Sea, North American east and west coasts.

Known Australian distribution: In eastern Australia from New South Wales to South Australia and Tasmania (Florabase 2023). In Cockburn Sound and Albany, WA (McDonald et al. 2008; 2015).

Notes: *Codium fragile fragile* was identified by Hayes et al. (2005) as one of the ten most serious potential pest species in Australian waters. Its ability to overgrow and smother oyster beds has caused it to be popularly known as 'oyster thief' and it readily grows on commercially valuable shellfish such as scallops, oysters and clams (Naylor et al. 2001; Trowbridge 1998a; McDonald et al. 2015).

4.3 Impacts of invasive marine species occurring in Cockburn Sound/Owen Anchorage

With respect to *Didemnum vexillum*, NEMESIS (2023) states: *"Didemnum vexillum* is widely considered to be an invasive species with potentially important economic and ecological impacts. As a recent invader in many parts of the world, the extent of its impacts has only just begun to be studied." This statement could be made for the vast majority of introduced marine species.

The impacts of non-indigenous species are a key focus of management agencies, legislators, environmental groups and others in developing management strategies for combatting the effects of invasive marine species. Invasive alien species have been defined in various ways, including as having "a significant negative impact on biodiversity as well as serious economic and social consequences (European Commission 2014, cited by Ojaveer et al. 2015). This definition includes all environments (terrestrial, freshwater and marine) and is used here for invasive marine species. But what are these species? Ojaveer et al. (2015) highlight several issues in determining what species are in fact invasive and their impacts.

On a global scale there is very little detailed information on species present in local marine environments. This is particularly true in Western Australia, including the Fremantle marine area. Marsh (1956) completed an MA thesis on the fauna of intertidal limestone platforms, concentrating on Cottesloe. Between 1956 and 1960 the WA Naturalists Club undertook a survey of the gastropod and bivalve molluscs of Cockburn Sound (Wilson et al. 1978). Chalmer et al. (1976) surveyed benthic molluscs, echinoderms and coelenterates in the Swan River. Wells & Keesing (1986) undertook a multiyear examination of molluscs at three intertidal platform reefs in the metropolitan region, including Cottesloe, and later extended the coverage to echinoderms (Wells et al. 1986). These studies concentrated on molluscs. While they contributed substantial information on species present in the Fremantle marine area, there were considerable gaps in the above projects. Since the 1980s a variety of studies have further developed information on the biodiversity of the region, but major gaps remain. Many phyla, particularly those with smaller species, have never been studied in the Fremantle marine area. There has been only one survey of introduced marine species in the area (Hewitt et al. 2000).

A second issue highlighted by Ojaveer et al. (2015) is that in many regions, the existing baseline understanding of native species present has been developed after many decades or centuries of translocations of marine species by anthropogenic mechanisms. For example, in Singapore there has been a widespread marine trade using wooden boats since at least the 1200s that potentially distributed marine species that have become naturalised in Singapore and their introduced origins have been obscured (Yeo et al. 2011). This is less of a problem in the Fremantle region. While there were sporadic voyages along the WA coast dating back to the 1600s, the Swan River Colony was founded in 1829, and the first steamship arrived in Fremantle in 1845. As the Perth metropolitan area has grown, so has the Port of Fremantle; the largest general cargo port in Western Australia. In 2022-2023 there were 1546 vessel visits to the port (Fremantle Ports 2023).

Ojaveer et al. (2015) highlighted the fact that the effects of many introduced marine species have never been examined, so there is a general, untested, assumption that there is no impact. This situation has changed little in the last eight years. The few successful removals of marine pest species have all been in situations where the invader was recognised early, was present in a restricted environment and prompt action was taken. The only successful removal of a marine species in Australia occurred in Darwin where the false mussel *Mytilopsis sallei* was eliminated from locked marinas adjacent to the harbour (Willan et al. 2000). The removal was made possible by the planktonic veligers washed out of the marinas when the lock gates were opened not surviving the transition from the low salinities of the marinas to the high salinity of the open harbour (Wells 2019). Additionally, there is a risk that impacts may not occur until many years, or even decades after the species invaded an area. For example, the Red Sea mussel *Brachidones pharaonis* was first detected in the Mediterranean Sea in

1869, just after the Suez Canal was opened, but did not become a pest until a century later (Rilov et al. 2004).

Ojaveer et al. (2015) concluded that most of the demonstrated impacts in marine habitats have related to native biodiversity and ecosystem health. There has been very little research on the impacts of introduced species in Cockburn Sound. Apart from the European fanworm, *Sabella spallanzanii* and the ascidian *Didemnum perlucidum*, the information on almost all of the introduced marine species in the Fremantle marine area is simply a record of the species being present at specified locations, often by only one or a few reports.

4.3.1 Sabella spallanzanii

The first published record of *S. spallanzanii* in WA was by Clapin & Evans (1995). The species was found to be widespread in Cockburn Sound, Owen Anchorage and Fremantle Harbour but was not present in the Swan River upstream from the harbour or at Carnac Island or Mewstone Rocks, suggesting the species cannot colonise undisturbed natural habitats. Patches of *S. spallanzanii* in sandy areas of the Southern Flats of Cockburn Sound with a mean density of 256/m^2 were visible on aerial photographs. Artificial habitats such as wharf pylons, channel markers and shipwrecks were also colonised by the fan worms. Aerial photographs suggested *S. spallanzanii* had been present in Cockburn Sound at least since the early 1980s; a specimen in the WA Museum was collected at Albany in 1965. The worm was found at depths of up to 18m in Cockburn sound, but a specimen from a wreck off Mindarie Keys was at 30m. Clapin & Evans (1995) found little evidence that *S. spallanzanii* was threatening commercial fisheries or native species; nor did it occur in healthy seagrass beds, being present primarily on artificial structures or in disturbed habitats. Clapin (1996) subsequently suggested the species might be restricted to eutrophic waters, a statement later verified by Currie et al. (2000). Elsewhere some previously dense populations of *S. spallanzanii* have declined over time (NIMPIS 2023), as they have in Cockburn Sound.

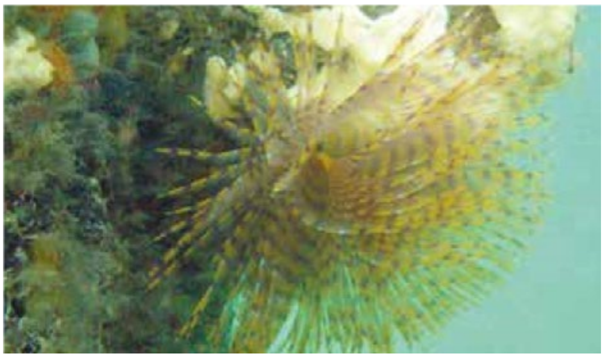

Figure 4. *Sabella spallanzanii*. Photo: Dr Justin McDonald.

NIMPIS (2023) summarises the limited information on the effects of *S. spallanzanii* in eastern Australian ports. On hard substrates recruitment of other sessile taxa to areas where *S. spallanzanii* was present were variable: recruitment of some species decreased, but they were not totally excluded, while settlement of other species increased (Holloway & Keough 2002a; 2022b; O'Brien et al. 2006). In areas with soft substrates Ross et al. (2007) concluded the possible effects of *S. spallanzanii* in Port Phillip Bay, Victoria were likely to be negligible.

4.3.2 Didemnum perlucidum

The report of on *Didemnum perlucidum* in the Swan River (Smale & Childs 2012) prompted a rapid series of papers on the species in Western Australia. Bridgwood et al. (2014) demonstrated two years later that the species was already spread over 2800 km of the WA coastline, suggesting that it had been present but undetected for some time. Dias et al. (2016) investigated its cryptogenic status and concluded it had been introduced at least twice. Muñoz & McDonald (2014) explored possible management options and later (Muñoz et al. 2015) described the reproductive ecology and growth of the species. Despite this intensive research commitment, there is little hard data on the effects of the species.

Muñoz & McDonald (2014) considered *D. perlucidum* to be invasive because of its high reproductive output, rapid growth and ability to colonise disturbed environments, a view widely shared in the published literature (e.g., NEMESIS 2023; NIMPIS 2023). The initial WA report (Smale & Childs 2012) shows the species dominating PVC test plates in the Swan River (Figure 1). Muñoz & McDonald (2014) reported that *D. perlucidum* was a heavy fouler at a mussel farm in the southern part of Cockburn Sound where it was thought to increase the mortality of mussel spat by up to 80%.

Didemnum perlucidum is well known to rapidly colonise artificial surfaces (Lambert 2009), often becoming the dominant species present. In the lower Swan River it has colonised the small seagrass species *Halophila ovalis*, smothering plant tissue, and reducing biomass of the seagrass (Simpson et al. 2016). The areas where this occurred were near infrastructure, particularly mooring buoys, infested with the ascidian, suggesting these were the source of *D. perlucidum* recruits on the seagrasses. Densities of the snail *Batillaria australis* were reduced in these seagrass beds. It should be noted that *B. australis* is itself an introduced species (Wells 1984; Wells & Bryce 1986; Huisman et al. 2008) and has an estimated population of 3.6 billion living individuals in the Swan River (Thomsen et al. 2010).

4.3.3 Didemnum vexillum

Didemnum vexillum, the carpet sea squirt, was first reported in Maine in the northeastern United States in 1982. By 2004 it had extended south to New York state and had also spread to the Canadian east coast. In 1991 it was found in the Netherlands and has since expanded along much of the European Atlantic coast and into the Mediterranean Sea. The first record on the US west coast was in San Francisco Bay in 1993. Within a few years *D. vexillum* had extended its range along the California coast and north to British Columbia. The first record in New Zealand was in October 2001. Initially the widespread, temporally overlapping outbreaks suggested multiple species were involved. Kott (2002) described *D. vexillum* from New Zealand and considered it to be a native species. However, subsequent research concluded there is only a single species, *D. vexillum*, which is thought to be native to northeast Asia, possibly Japan (Lambert 2009; NEMESIS 2023).

The rapid spread of *D. vexillum* raised concerns in the various regions where it was invasive. It has a broad capability of attaching to a range of surfaces, then forming a mat up to 10 cm thick that makes it difficult for other species to penetrate, reducing areas suitable for settlement and larval recruitment. Colonies develop long tendrils that are easily broken off and carried about by currents. The detached portions can continue to produce larvae. The combination provides an exceptional ability for *D. vexillum* to colonise new areas.

There have been several papers suggesting adverse consequences of *D. vexillum* including fouling of vessels and in water infrastructure (Turrell et al. 2018), reduction in aquaculture production of the New Zealand green mussel *Perna canaliculus* (Pannell & Coutts 2007) and *Mytilus edulis* in the United States (Auker 2010). In New Zealand *D. vexillum* increased fouling biomass of mussel aquaculture lines, reducing mussel crops and adding weight on infrastructure. This has led to substantial mitigation and control costs (Pannell & Coutts 2007; Turrell et al. 2018).). Fletcher et al. (2013) examined the impact of *D. vexillum* on three size classes of *P. canaliculus* on a mussel farm in Marlborough Sound. They found mussels may only be vulnerable to direct *D. vexillum* fouling impacts at early stages of production, and that impacts may be restricted to displacement of mussels as opposed to reduced size and condition. Blue mussels (*M. edulis*) in the United States fouled by *D. vexillum* were shown to have smaller shell lengths and lower condition values than those free of fouling within experimental systems (Auker 2010).

Loch Creran in Scotland was designated as a European Special Area of Conservation in 2005 because it has the largest serpulid (*Serpula vermicularis*) reefs in the world. It also has important flame shell (*Limaria hians*) and horse mussel (*Modiolus modiolus*) reefs. *Didemnum vexillum* was first detected in the lock in 2015, the first time that such a highly marine invasive species has been found within a protected area of global significance (Cottier-Cook et al. 2019).

Like most other invasive marine species, *D. vexillum* is frequently found in disturbed or artificial habitats. The species is unusual, however, in also occurring in natural, open water, undisturbed habitats such as Georges Bank, located between Cape Cod, Massachusetts, USA and Cape Sable Island, Nova Scotia, Canada. The tunicate was first reported on the bank in 2002 and by 2009 had colonised at least 230 km^2 of the bank bottom, an exponential increase in seven years. Lengyel et al. (2009) undertook a detailed photographic survey of the bottom and concluded *D. vexillum* had significant effects, outcompeting other macrofaunal and epifaunal species, but conversely the abundance of two polychaete species was increased.

Turrell et al. (2018) summarised the effects of *D. vexillum* as smothering other sessile species, modifying habitats it colonises and fouling man-made structures, infrastructure and vessels. It can restrict water exchange through nets or bags used to contain shellfish aquaculture species, reducing food supply and decreasing internal water quality. Buoys and ropes can become weighed down with fouling. Infestations of marine pests such as *D. vexillum* can lead to increased maintenance and management costs for aquaculture, and reduced income associated with reduced growth or increased mortality of the aquaculture species.

Management actions undertaken in Cockburn Sound highlight the degree of concern over the potential effects of the detection of *D. vexillum* at HMAS Stirling. The detection in 2021 was referred to the national Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE). CCIMPE concluded there was a possibility of eradication (Outbreak 2023). The Department of Defence is coordinating response efforts at Garden Island as the outbreak is at a Commonwealth facility. Response activities include:

- delimiting surveys to show the extent of the pest colonies
- targeted control and removal of the colonies, such as underwater cleaning
- surveillance and monitoring
- extra vessel management procedures to prevent spread.

Didemnum vexillum was later detected at the Australian Marine Complex at Henderson in January 2023, where DPIRD leads the response activities which include:

- a marine surveillance program at Port of Fremantle and Cockburn Sound
- delimiting surveys to show the extent of the pest colonies
- extra vessel management procedures to prevent spread.

A Quarantine Area Notice (QAN) was issued on 17 March 2023 (Outbreak 2023) covering waters adjacent to the Australian Marine Complex Common User Facility (AMC CUF) at Henderson South, encompassed by seawalls to the north and west, and extending 250m down the coastline south of the AMC CUF. The aim of the QAN is to (Outbreak 2023):

- manage the movement of vessels into the QA to minimise the spread of the pest.
- strengthen the requirements for biofouling inspections and treatments for vessels that regularly operate in the Quarantine Area or have been in the Quarantine Area for a period of six days or more.

DPIRD is also working with local stakeholders and Fremantle Port Authority to manage the incursion.

4.3.4 *Codium fragile fragile*

Codium fragile fragile was identified by Hayes et al. (2005) as one of the ten most serious potential pest species in Australian waters. Its ability to overgrow and smother oyster beds has caused it to be popularly known as 'oyster thief' and it readily grows on commercially valuable shellfish such as scallops, oysters and clams (Trowbridge 1998a; Naylor et al. 2001; McDonald et al. 2015). This has caused it to be regarded as a marine pest along the North Atlantic coast of the United States, but in most other areas it is not considered a pest (Trowbridge 1998b).

Trowbridge (1998b) provided a detailed analysis of the species, including impacts. As with other invasive marine species, most of the cited impacts for *C. fragile fragile* are anecdotal and lack quantitative data. In addition to the direct effects of reducing growth and increasing mortality of commercial shellfish farms, there is an additional cost imposed by fouling of shellfish and equipment, requiring enhanced cleaning. However, there are also positive effects of the introduction of the species. While it is not a preferred food of generalist grazers such as chitons, most snails, isopods and urchins, the alga does provide an additional food source. A variety of epiphytic algae growing on *C. fragile fragile* contribute an additional food source for grazing species. Sacoglossan gastropods consume the alga directly (Trowbridge 1998b). Bulleri et al. (2006) demonstrated that the presence of thalli increased mussel settlement.

4.3.5 *Harmful Algal Blooms*

Harmful Algal Blooms (HAB) are a worldwide problem in freshwater, estuarine and coastal marine areas. Blooms of several species of diatoms and dinoflagellates can cause a variety of serious issues, including fish kills, contamination of shellfish products and drinking water and paralytic shellfish poisoning, which in extreme cases can cause human deaths. Over 30 years ago Hallegraeff (1992) reported an increase in the frequency, intensity and geographical distribution of HABs in Australian coastal, estuarine and fresh waters. In recognition of the issue, DPIRD (2016) lists seven species of toxic dinoflagellates as noxious species, three of which have been reported in WA. *Alexandrium minutum* is widespread in southwestern estuaries and coastal waters and is known to have been present in the Swan River since 1982 (Hallegraeff et al. 2021). The 2000 marine pest survey of Fremantle and Cockburn Sound detected low concentrations of *A. tamarense*-like cysts (Hewitt et al. 2000), but the identification could not be confirmed as the cysts failed to germinate (Huisman et al. 2008). Using a combination of morphological and DNA techniques, Dias et al. (2015) confirmed the presence of low concentrations of *A. catenella* in Cockburn Sound, but no problems have been reported.

4.3.6 *Financial costs*

Management of marine pests in Western Australia clearly imposes a financial cost. Vessel operators must comply with regulations on ballast water and biofouling management. Risk assessments of vessels are undertaken, which may result in them needing to be cleaned. Inspections may result in vessels being taken out of the water and cleaned on short notice, imposing expenses for both cleaning and delays to the vessel. Government agencies devote staff time and expenses in maintaining the regulatory environment. There are no data available on the cost benefit of marine pest management in Western Australia.

4.4 Possible mitigation of invasive marine species by the Westport Project

In recent decades the increasing numbers of vessel movements and diversity of high-risk vessels has caused a corresponding increase in the numbers of marine species being introduced into new marine areas worldwide. In a similar way, the increasing construction of artificial structures in coastal marine environments has enhanced the opportunities for newly introduced species to thrive in their new areas. Not only has the numbers of artificial structures increased, but they are more readily colonised by invasive species than natural habitats.

There are numerous factors in artificial environments that favour invasive marine species over native species, summarised by Johnston et al. (2017). The proximity of artificial habitats to each other in highly modified areas such as ports provides steppingstones or corridors for the movement of invasive species from one area to another; larvae produced on one artificial surface only have a short distance to travel to an adjacent artificial surface where invasive marine species may already be common. Recruitment of fouling species can be enhanced near a pier. Piers, jetties, etc. provide hard substrate, often in areas with sand or mud bottoms. Port developments can reduce tidal flushing within the vicinity of the infrastructure, increasing larval settlement rates. Some species preferentially settle on floating artificial structures. Ascidians are one of the major groups that develop invasive characteristics; some are known to prefer downward facing surfaces. Bottom facing habitats are rare in natural environments but are common in modified habitats. The net effect is that many species with low densities in natural environments can become common in artificial habitats (Johnston et al. 2017). The relationship between introduced species and artificial surfaces is so close that it has been suggested as a criterion for classifying species as non-indigenous (Chapman & Carlton 1991).

A substantial literature has been developed in recent years on the use of eco-design to mitigate impacts of infrastructure projects on the ecology, biodiversity, and natural resources of coastal areas. The concept is to include ecological considerations in new coastal infrastructure projects with a goal of designing, creating, or restoring marine "ecosystems that integrate human society with the natural environment that will be of benefit to both" (Mitsch & Jørgensen 2004 cited by Pioch et al. 2018). To be most effective, eco-design must be undertaken at the initial design and planning stages of a project, prioritising avoidance and reduction of ecological impacts. Unfortunately, Pioch et al. (2018) contend that most current work is undertaken to mitigate problems that have already arisen rather than preventing them from occurring.

Current design procedures tend to create uniform habitats, such as seawalls with smooth vertical faces. The lack of habitat diversity reduces the biodiversity of the marine community that develops on the structure. Unfortunately, most of the literature on incorporating ecological principles into the design attempts to increase biodiversity on the newly constructed habitat. There is relatively little research on minimising the colonisation of the new habitat by invasive marine species (Vozzo et al. 2021). Dafforn (2017) suggested four mechanisms for mitigating the risk of invasive marine species on new submerged structures:

- modifying the physical and chemical properties of structures to enhance native recruitment marine invasive species
- pre-seeding structures to enhance their colonisation by native species
- providing access to the structures for native grazers and predators
- timing of construction/maintenance/decommissioning to avoid periods when propagule pressure of invasive marine species is high.

These options are not exhaustive, but instead provide a starting point for consideration (Dafforn 2017). The four are discussed below in relation to the three species of most concern to DPIRD in Cockburn Sound: *Didemnum perlucidum, D. vexillum* and *Codium fragile fragile*.

4.4.1 *Modifying the physical and chemical properties of structures*

As described above, current designs tend to create uniform habitats; the lack of macro structural diversity, topographical complexity and rugosity reduces the biodiversity of the marine community that develops on the structure. The goal of this option is to create diverse habitats to allow a vibrant community of native species to develop on the structure to reduce the opportunity for marine invasive species to occupy vacant spaces. A number of methods have been trialed by increasing the physical complexity of habitats and/or changing the chemistry of the substrate. Studies to date have had conflicting results: some have increased diversity but others have not, and there has been considerable variation between treatments in individual studies (Dafforn et al. 2012; Waltham & Dafforn 2018; Vozzo et al. 2022; Mayer-Pinto et al. 2023). Most have not differentiated the effects on native species versus introduced species; some treatments have in fact increased colonisation by introduced species (Dafforn et al. 2009; Schaefer et al. 2023). Schaefer et al. (2023) concluded there is increasing evidence that the effects of eco-engineering interventions are highly context dependent and that interventions should not be blindly applied in time and space. Results obtained differ depending on the treatment applied and vary between species (Bishop et al. 2022) and vary on scales as low as hundreds of metres (e.g., Clifton et al. 2022). WWMSP is trialing a variety of substrates to determine what species settle and develop on them. Two seasons are being trialed (Prof Glenn Hyndes, Edith Cowan University, pers. comm.). When they become available, the results of that project will help to determine the viability of this approach in Cockburn Sound.

4.4.2 *Pre-seeding native species*

With this approach, local species can be deliberately attached to the new structure to accelerate the development of the marine benthic community. To be most effective, the species to be attached should be readily available, common in the local marine environment, fast growing, and capable of developing high densities. The mussel *Mytilus* spp. is suggested for this purpose. A small wild caught fishery initially developed in Cockburn Sound and was later replaced by aquaculture production. While active production has been moved to Albany, leases are still held in Cockburn Sound.

Dias et al. (2014) found there are two genetic strains of *Mytilus* in Cockburn Sound that cannot be separated based on shell characters. The more common is *M. galloprovincialis,* introduced from Europe, and the less common native species is *M. planulatus.* While *M. galloprovincialis* is an introduced marine species, it occurs throughout southern Australia and has been naturalized into the local marine environment.

Mussel restoration projects are already in progress in the Peel-Harvey Estuary at Mandurah (TNC 2020) and in the Swan River (Murdoch 2023). Techniques developed in these programs could be used for pre-seeding of mussels by the Westport Project. Roberts et al. (2023) analyse the effectiveness of mussel restoration in Australasia.

Project 2.4 is also undertaking a desktop analysis of the potential for a “green wall” approach in Cockburn Sound in early 2024 (Prof Glenn Hyndes, Edith Cowan University, pers. comm.).

4.4.3 *Providing easy access for native grazers and predators*

Many species of *Didemnum* are chemically defended by a variety of compounds and for most species, including *D. vexillum*, this results in a lower surface pH (Bullard et al. (2007). This is likely to also be true of *D. perlucidum*. There is little information on the predators of either species, but the low surface pH and chemical toxicity of the ascidians suggest predation pressure will be low. NIMPIS (2023) reports that *Codium fragile fragile* is consumed by generalist grazers such as snails, sea slugs, chitons, sea urchins and isopods in both native and introduced ranges, but there is no data to suggest predation restricts populations of the alga.

Given that there is little predation on the two species of *Didemnum*, and no hard data on *C. fragile fragile*, it is unlikely that efforts to increase predatory pressure on Westport structures will have any effect on populations of the three invasive marine species.

4.4.4 Timing construction to avoid periods when propagule pressure is high

The only information available on the reproductive periodicity of the three species of most concern to DPIRD in Cockburn Sound is for *Didemnum perlucidum*. Muñoz et al. (2015) reported that larvae are present throughout the year in the Perth region but are more abundant in summer. Recruitment is low during winter. Combined with the tendency for colonies to senesce in winter, this suggests construction during winter would be better for managing *D. perlucidum*. However, as the species is widespread, including the southern part of Cockburn Sound, undertaking construction in winter is not likely to be useful for this species. *Didemnum vexillum* elsewhere in the southern hemisphere spawns primarily in summer but the reproductive period may be up to nine months (Fletcher et al. 2013a). Combined with the ability to establish in new areas by fragmentation and the proximity of colonies at the nearby HMAS Stirling, this option is unlikely to work for *D. perlucidum.* There is no information on *Codium fragile fragile* reproduction in WA, but in Port Philip Bay, Victoria maximum densities and biomass of the species occur from January to May (Campbell 1999). Even if this is also true of *C. fragile fragile* in Cockburn Sound, winter construction is likely to have little effect on the species. Thus, based on limited information there is no clear period when construction would minimise the risk of translocating the three species or of preventing them from establishing on new artificial surfaces.

4.4.5 Summary of mitigation options

Increasing the habitat diversity of new immersed structures and pre-seeding them with native species appear to be the most promising mechanisms for mitigating the invasive marine species risks for the Westport Project.

As discussed above, eco-design is a new and rapidly evolving field that may offer substantial opportunities for enhancing the project by improving the biodiversity of the marine community that develops on immersed surfaces and simultaneously minimising the impact of marine invasive species. To be effective eco-design must be included at the initial planning and design stages of the project. Every marine environment is different, with design issues potentially changing on the scale of hundreds of metres. This is a specialist field that requires specialist knowledge and expertise available at the Marine Research Centre at Macquarie University in Sydney

5 Discussion

In the early 2000s, when invasive marine species began to be recognised as a major threat to the Australian marine environment, CSIRO undertook an extensive worldwide literature search to determine what species had been introduced into new marine areas through anthropogenic means. Over 1500 species were recorded (Hayes et al. 2005). These were extensively risk assessed and a list of 55 species considered to pose the greatest threat to Australia was developed (NIMPCG 2009a; 2009b). DPIRD (2016) updated and enlarged the list to about 80 species. DPIRD subsequently developed a State-Wide Array Surveillance Program (SWASP) that monitors key ports, including Cockburn Sound, for species on the 2016 list. The successor to NIMPCG, MPSC, subsequently developed a much smaller Australian Priority Marine Pest List that identifies 10 of Australia's significant marine pests (MarinePests 2023): 3 species are established in parts of Australia (none are in WA) and 7 are exotic species.

To minimise the chances of missing something in the Cockburn Sound Invasive Marine Species Literature Review, a very broad literature search for introduced marine species in the Fremantle marine area (Cottesloe, Fremantle Harbour, Swan River, Owen Anchorage and Cockburn Sound) was undertaken. Seventy species are discussed in the literature review. Twenty-nine species were recorded from Cockburn Sound and Owen Anchorage which are potentially living there. Many have been recorded on only one or a few occasions and may/may not have established populations.

The great majority of introduced marine species have no known effect; they are only known from isolated records, or if consistently present, cause no apparent changes. Only 4 of the 29 species recorded from Cockburn Sound/Owen Anchorage are on the DPIRD (2016) list of potential invasive marine species for Cockburn Sound/Owen Anchorage: *Codium fragile fragile, Didemnum vexillum, Alexandrium catenella* and *A. minutum. Codium fragile fragile* and *D. vexillum* are actively monitored in Cockburn Sound; both are fully discussed in the report. *Didemnum perlucidum* and *Sabella spallanzanii* are both well established in Cockburn Sound. Neither is listed as of concern in the Fremantle marine area by DPIRD (2016) but DPIRD is monitoring D. *perlucidum*. It is discussed because of its recent invasive history. There was a series of papers on *Sabella spallanzanii* following the first publication in 1995. The species has been recorded across southern Australia and was first found in WA in 1965. It was included because of its long WA history. *Alexandrium catenella* and *A. minutum* are toxic dinoflagellates. As minute planktonic species they are carried about by ocean currents. Both have been recorded in small numbers on occasion in Cockburn Sound, but neither has developed blooms or had any known effects. Both are discussed in a short section on Harmful Algal Blooms as they are on the DPIRD (2016) Prevention List for Introduced Marine Species.

It should always be recognised that lists of invasive marine species are based on species that have been known to cause problems in the past in Australia or elsewhere. Any management of the issue should always remain vigilant for the arrival of new species that have not previously displayed invasive characteristics.

5.1 Existing management practices for vessels arriving in Western Australia

In the last twenty years a robust system of vessel management has been developed to minimise the risks of invasive marine species being introduced into Australian waters from overseas or species already present being translocated into new parts of Australia. There are two primary risks posed by vessel movements: ballast water and biofouling. The two risks are very different and are managed separately.

5.1.1 Ballast water

When a vessel enters the water, it sinks to a desired design level at the water line. This can be readily seen on ships such as container vessels or cargo vessels at anchor or alongside a dock. If they are lightly loaded they will be higher in the water, exposing the usually red anti-fouling coating on the lower hull. If the vessel is fully loaded it will sink so that the red hull is not visible, only the hull above, which is a contrasting colour, often black. To operate safely and efficiently the vessel must be loaded to the waterline. If there is little or no cargo, ballast water is pumped into tanks on the vessel until the desired position in the water column is reached. When the vessel arrives at a new destination the ballast water is pumped back out and the weight replaced by the cargo.

Use of ballast water is an efficient way of maintaining vessels in the water at their design level, but it can create other problems, including the risk of introducing marine species, including invasive species to new areas. Water taken up by the vessel contains a myriad of organisms, including larvae, juveniles and adults of a wide range of taxa. Suspended sediment is also introduced. The sediment settles to the bottom of the ballast water tank and forms a muddy bottom, which can be a metre or more in depth. The muddy bottom, metal sides of the tank and the ballast water itself provide an environment in which species can develop populations. When the water is expelled, the entrained organisms are introduced to a new environment where populations will develop if conditions are suitable.

There are several mechanisms for reducing the risk of introducing species through ballast water, and a considerable international effort is underway to develop new treatments. Regulation of ballast water for vessels in Australian waters is undertaken by the Commonwealth government, following the principles of the International Maritime Organization guidelines. The approved management methods are (DAWE 2020):

- use of a Ballast Water Management System.
- ballast water exchange conducted in an acceptable area.
- use of low-risk ballast water (such as fresh potable water, high seas water or fresh water. from an on-board freshwater production facility).
- retention of high-risk ballast water on board the vessel.
- discharge to an approved ballast water reception facility.

DAWE (2020) requires that vessels arriving from an international location and intending to discharge ballast submit a Ballast Water Report the Maritime Arrivals Reporting System (MARS) for approval prior to arrival. Domestic trading vessels can request a low-risk exemption through a Domestic Risk Assessment. The documentation must be approved prior to arrival and the vessel inspected on arrival.

Trading vessels such as cargo vessels, tankers, bulk ore carriers and container vessels use the most ballast water. Some of the largest vessels export over 100,000 tonnes of iron ore from the Pilbara in one shipment; the ballast water they release has a similar weight. Other vessels, such as tugs, barges and dredges have much smaller changes in weight and correspondingly much smaller volumes of water are used.

5.1.2 Biofouling

When a vessel enters the water biofouling rapidly begins to develop on immersed surfaces. A slimy biofilm layer begins to develop, then filamentous algae. Tertiary fouling has a dense assemblage that can include algae, limpets, barnacles, mussels, crabs and ascidians, resulting in an entire community developing on the vessel surface, even attracting free swimming fish. A fully developed community contains a myriad of habitats for species, including invasive marine species, to live.

There are a variety of methods for combatting the development of biofouling. The most common is application to immersed surfaces such as the vessel hull of an antifouling coating (AFC) with incorporated biocides. From the late 1960s to the early 2000s tributyltin (TBT) was the primary biocide, but with increasing evidence of deleterious environmental effects, TBT was banned internationally in 2008 and has been replaced by copper compounds. AFC is initially effective, but becomes less effective over time, and may be damaged or scaped off if the vessel grounds the sea floor or scrapes along the wharf, etc. Additionally, there are many surfaces such as propellors, anodes, sensitive equipment and internal seawater systems where AFC cannot be applied.

As management of biofouling issues is undertaken by individual jurisdictions, the regulations vary in different parts of Australia. In WA, marine pest management was undertaken by the Department of Fisheries until it was incorporated into DPIRD. Vessels entering state waters undertake a risk assessment (Vessel-Check 2022). In general, low risk vessels are allowed to enter freely, but medium and high-risk vessels must be inspected by a biofouling inspector recognised by DPIRD. The inspector recommends a course of action to DPIRD, but the decision on action(s) to be taken are made by DPIRD. It is common for construction vessels mobilising from overseas locations to be inspected and possibly cleaned in drydock offshore before they are mobilised to WA.

5.2 Invasive marine species risks of the Westport Project

The invasive marine species risks of the Westport Project can be divided into two periods:

- Construction.
- Operations.

5.2.1 Construction

Construction vessels such as barges, dredges, tugs, etc. pose a higher risk of introducing invasive marine species. They typically remain stationary or operate at very low speeds in ports for extended periods, often months or even years; areas where invasive marine species are most concentrated with time to attach to the vessel. Construction vessels may contact the sea floor, other vessels, wharves, etc., scraping off or otherwise damaging the AFC. A diverse and dense biofouling community often develops on immersed surfaces, potentially including invasive species. Invasive marine species risks are highest during project construction.

5.2.2 Operations

Risks are much lower once construction has been completed. Any remaining high-risk vessels such as tugs are locally based, so they will not introduce more species.

Container vessels using the facility during the operational period are likely to be assessed as low risk. These vessels operate at high speeds, minimising opportunities for marine species to become attached. They spend as little time in ports as possible and spend much of their time in the open ocean where larvae of benthic species are at minimal densities. The vessels may transit across temperature zones where attached species cannot survive.

5.3 Minimising the invasive marine species risks of the Westport Project

There are two components to minimising the invasive marine species risks of the Westport Project:

- quarantine barriers
- translocation within Cockburn Sound

5.3.1 *Quarantine barriers*

The key to invasive marine species management is prevention of species arrivals. Once they have entered the new area, invasive marine species are almost impossible to eliminate. Fortunately, there are strong quarantine barriers in place in Western Australia for both ballast water and biofouling. As described above, the primary mitigation of invasive marine species being introduced to Cockburn Sound/Owen anchorage by the Westport Project will be undertaken through the existing quarantine barriers managed by the Australian Government (ballast water) and WA Government through DPIRD (biofouling). The only action the Westport Project needs to take is to ensure all vessels adhere to the government requirements.

5.3.2 *Translocation within Cockburn Sound*

Cockburn Sound is a small, semi-enclosed body of water. It has a central basin with a depth of 17-22 m, with relatively steeply sided walls that rise to subtidal flats that are most extensive on the eastern side of the sound. The width varies between 9 and 12km, for a total area of 124km^2 (CSMS 2022). It is bounded on the east and south by the continental mainland and on the west by Garden Island, and the causeway from Rockingham to the island. The northern side is open to Owen Anchorage, but there is a sill depth of <10m on Parmelia Bank (Sampey et al. 2011). Steedman & Craig (1983) found that the bathymetry of Cockburn Sound means that it is essentially a closed system.

The fact that Cockburn Sound is a small, semi-enclosed body of water with relatively little exchange with the open sea means that planktonic larvae of invasive marine species spawned in the sound or tissue fragments originating in the sound will tend to remain in the sound. The Kwinana Grain Terminal is only about 6 km from HMAS Stirling and 12 km from the Australian Marine Complex at Henderson, very small distances for an invasive marine species introduced over thousands of kilometres from overseas. The difficulty of preventing translocations within Cockburn Sound is demonstrated by the failure to prevent the spread of *Didemnum vexillum* from HMAS Stirling to Henderson (Section 4.2.2).

5.4 Increased invasive marine species risk caused by the Westport Project

Increased risks of invasive marine species introductions will occur during the Westport Project will differ during the construction and operational phases of the project.

5.4.1 *Construction*

As there are no final plans for construction of the project, it is not known how many or what types of high-risk construction vessels will be required. During the construction boom in the Pilbara there were large numbers of construction vessels mobilised from overseas ports, many of which remained on site for months or made multiple entries into Western Australia, without any invasive marine species being introduced to the State (Wells 2018), demonstrating the effectiveness of the existing quarantine barriers. This suggests the construction risks of the Westport are manageable.

There are three known benthic invasive marine species known in Cockburn Sound that are of concern to DPIRD: *Didemnum perlucidum, D. vexillum* and *Codium fragile fragile*. There are no known populations of other potential pest species in WA, so construction vessels mobilising to Cockburn Sound from other ports within WA would present low risks of introducing new invasive marine species to Cockburn Sound.

5.4.2 Operations

There were 1546 vessel visits to Fremantle Port in 2022-2023, 379 of which were container vessels. The goal of the Westport Project is to move the handling of container vessels from Fremantle Inner Harbour to a new location in Fremantle Outer Harbour at Kwinana to reduce congestion in Fremantle Inner Harbour and provide modern facilities for handling container vessels. As the vessels are already arriving in Western Australia from overseas or interstate, the only increased risk of introducing new invasive marine species would be from any incremental increase in the number of vessels arriving or changes in trade patterns with overseas jurisdictions.

5.5 Relationship with other WAMSI Westport Marine Science Program

While the present WWMSP review is a stand-alone document, it does have links to three aspects of the research objectives of WWMSP Project 2.4 science plan:

- analysis of community establishment on different substrates (Section 4.4.1).
- use of a “green wall” to minimise the establishment of invasive marine species (Section 4.4.2).
- effects of climate change on future invasive marine species risks.

6 Conclusions/recommendations

A detailed literature search identified 70 potential introduced marine species in the Fremantle marine area, 29 of which may have become established in Cockburn Sound and/or Owen Anchorage. Three of these are of concern to DPIRD as invasive marine species and are being actively monitored: the ascidians *Didemnum perlucidum* and *D. vexillum* and the marine alga *Codium fragile fragile*. As Cockburn Sound is a small semi-enclosed basin, all three will potentially be spread more widely in the sound, including any new facilities constructed by the Westport Project. Four possible eco-engineering mitigation procedures are discussed. Two of these are most likely to offer possibilities for the Westport Project:

- modifying the physical and chemical properties of structures to enhance native recruitment marine invasive species.
- pre-seeding structures to enhance their colonisation by native species.

If practicable strategies can be developed, these methods may reduce the risk of the three invasive marine species introducing invasive marine species to the Westport facilities. They would also reduce the risk of any species that are introduced to the Fremantle marine area in future. The accelerated establishment of a natural community on Westport facilities would have other benefits such as improvement in water quality by filtration by mussels.

As eco-engineering is a new field of research some projects have failed but others have succeeded. Project 2.4 is examining both options.

One consistent feature of the literature review is the lack of information on the effects of invasive marine species. Generalities of potential effects are repeated by one author after another, but with little demonstration of actual effects. The three invasive marine species in Cockburn Sound offer an opportunity to develop factual data on their impacts.

There will be an increased risk of invasive marine species to the Westport Project by high-risk construction vessels such as barges, dredges, tugs, etc. especially if they are mobilised from overseas. This risk can be reduced by using construction vessels sourced in WA as much as possible where there are no known additional invasive marine species. Experience in the Pilbara has demonstrated this risk is manageable. The transfer of container vessel arrivals from Fremantle Inner Harbour to Westport will not necessarily increase the risk of invasive marine species introductions to the Fremantle marine area. The only increase would be due to an increase in vessel arrivals or changes to trade patterns.

Invasive marine species are introduced by vessels discharging ballast water or in biofouling on immersed surfaces. Ballast water discharge is managed by the Commonwealth and biofouling by Western Australia through DPIRD. Rigorous procedures have been developed for both transmission pathways. Their requirements and recommendations should be followed by all vessels operating on the Westport Project.

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8 Appendices

8.1 Appendix 1 Introduced marine species in the Fremantle marine area

8.1.1 Marine algae

***Codium fragile fragile* (Suringar) Hariot, 1889**

Records in the Fremantle marine area: Cockburn Sound. **Vouchers:** None. **Range outside WA:** Originally from Japan, now widely distributed in Europe, Mediterranean Sea, North American east and west coasts, and New Zealand; in eastern Australia from New South Wales to South Australia and Tasmania (Florabase 2023). **Range in WA:** Found in Albany in 2007 **(**McDonald et al. 2008; 2015) and in Cockburn Sound in 2019 (CSMC 2022). **Habitat:** Attaches to a range of hard surfaces in intertidal marine and estuarine environments. **WA literature records:** McDonald et al. (2008; 2015); CSMC (2022); Florabase (2023). **Notes:** Listed as a species of concern by DPIRD (2016) but not DAFF (2023).

***Grateloupia imbricata* Holmes, 1896**

Records in the Fremantle marine area: Rous Head, Cottesloe, Cockburn Sound. **Vouchers:** WA Herbarium PERTH 09185887, PERTH 081877789, PERTH 07573316. **Range outside WA:** Native to Japan, introduced to the Mediterranean (Verlaque et al. 2005). **Range in WA:** Rous Head, Cottesloe and Cockburn Sound. **Habitat:** Rocky substrates. **WA literature records:** Huisman et al. (2006; 2008), Wells et al. (2009); Florabase (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Pseudocodium devriesii* Weber van Bosse, 1896**

Records in the Fremantle marine area: Rous Head, Cottesloe, Cockburn Sound. **Vouchers:** WA Herbarium PERTH 07259964, PERTH 07561296, PERTH 08252467. **Range outside WA:** Known from East London, South Africa eastward to Mozambique; Madagascar (Coppejans et al. 2005). **Range in WA:** Rous Head, Cottesloe and Cockburn Sound. **Habitat:** Small clusters in sand associated with rocks. **WA literature records:** Huisman et al. (2008); Wells et al. (2009); Florabase (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Ulva taeniata* (Setchell) Setchell & N.L.Gardner, 1920**
***Ulva fasciata* Delile, 1813**
Native WA species

Huisman et al. (2008) discussed the uncertain taxonomy of the marine algae *Ulva taeniata* and *U. fasciata* in the Fremantle marine area. They concluded that neither species was native to WA, so whichever species was present would be either cryptogenic or introduced. However, Florabase (2023) now lists both species as being native to WA.

8.1.2 Dinoflagellates

***Alexandrium catenella* (Whedon & Kofoid) Balech, 1985**

Records in the Fremantle marine area: Cockburn Sound. **Vouchers:** None available. **Range in WA:** Cockburn Sound. **Range outside WA:** Cryptogenic in the Mediterranean, Spain, New Zealand, east coast of USA and southeast Asia. In eastern Australia from New South Wales to South Australia and Tasmania (Dias et al. 2015; ALA 2023). **Habitat:** Planktonic. **WA literature records:** Dias et al. (2015); ALA (2023). **Notes:** This species is known as a causative agent for paralytic shellfish poisoning. It is listed as a species of concern by DPIRD (2016) but not by DAFF (2023).

***Alexandrium minutum* (Halim, 1960) Balech, 1989**

Records in the Fremantle marine area: Cockburn Sound, Swan River. **Vouchers:** None available. **Range in WA:** Bunbury, Geographe Bay, Mandurah, Peel Inlet, Cockburn Sound, Swan River. **Range outside WA:** Cryptogenic in the Mediterranean, Spain, New Zealand, east coast of USA, southeast Asia and parts of south-east Australia. Introduced to Tasmania., parts of South Australia and southwestern WA (Chang & McClean 1997; Giacobbe et al. 1996). **Habitat:** Planktonic. **WA literature records:** Hallegraeff & Hosja (1993); CRIMP (1997a); Huisman et al. (2008); Wells et al. (2009), Dias et al. (2015). **Notes:** This species is known as a causative agent for paralytic shellfish poisoning. It is **l**isted as a species of concern by DPIRD (2016) but not by DAFF (2023).

8.1.3 Bryozoans

***Bugulina flabellata* (Thompson in Gray, 1848)**

Records in the Fremantle marine area: Fremantle, Cockburn Sound. **Vouchers:** WAM 30812; 32846. **Range in WA:** South coast and lower west coast of WA from Albany to Fremantle. **Range outside WA:** Possibly native to Atlantic and Mediterranean coasts. Widely distributed in warm and temperate seas (Ryland 1965; Ryland & Hayward 1977; Gordon 1986; Gordon & Mawatari 1992); in eastern Australia from New South Wales to South Australia and Tasmania (Allen & Wood 1950; Allen 1953; Brock 1985; Keough & Ross 1999; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Found almost invariably attached to other bryozoans. Common on rocky shores near low water mark and among the epibenthos of inshore waters (Ryland & Hayward 1977); mainly found on stones, shells etc., occasionally on harbour structures, from low water mark and coastal waters (Ryland 1965). **WA literature records:** CRIMP (1997a, 1997b); Huisman et al. (2008); Wells et al. (2009). **Notes:** Huisman et al. (2008) record this species as *Bugula flabellata*. It is listed as cryptic by NIMPIS (2023). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Bugula neritina* (Linnaeus, 1758)**

Records in the Fremantle marine area: Fremantle, Cockburn Sound. **Vouchers:** WAM 4987; 30813. **Range in WA:** Widely distributed in WA ports from Esperance to Port Hedland. **Range outside WA:** Widely distributed throughout most seas worldwide, except in cold polar and subarctic/ subantarctic regions (Osburn 1950; Ryland 1965; Ryland & Hayward 1977; Winston 1982; Gordon 1986; Keough 1989; Gordon & Mawatari 1992); in eastern Australia from Queensland to South Australia and Tasmania (Keough & Ross 1999; Allen & Wood 1950; Black 1971; Vigeland 1971; Vail & Wass 1981; Brock, 1985; Moran & Grant 1993; Parry et al. 1997; Currie et al. 1998; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023; NIMPIS 2023). **Habitat:** Found worldwide in warm water ports and harbours, this is a serious and common fouling organism that grows on a wide variety of substrates (Ryland 1965; Ryland & Hayward 1977; Bock 1982; Winston 1982). **WA literature records:** CRIMP (1997a, 1997b; 1999; 2000); Campbell (2003a; 2003b); Wyatt et al. (2005); Mackie et. al. (2006); Huisman et al. (2008); Wells et al. (2009); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Cryptosula pallasiana* (Moll, 1803)**

Records in the Fremantle marine area: Fremantle. **Vouchers:** WAM 30804; 32803). **Range in WA:** South coast and lower west coast to Fremantle. **Range outside WA:** Widespread around the world, particularly in ports, harbours and estuaries (Ryland 1965; Hayward & Ryland 1979; Winston 1982; Gordon 1989; Gordon & Mawatari 1992); in eastern Australia from New South Wales to South Australia and Tasmania (Bock 1982; Brock 1985; Keough and Ross 1999; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** A common biofouling species that can be found on virtually all solid surfaces in the intertidal or shallow subtidal (Ryland 1965; Hayward & Ryland 1979; Bock 1982; Gordon 1989; Gordon & Mawatari 1992). **WA literature records:** CRIMP (1997a; 1997b; 2000); Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Schizoporella errata* (Waters, 1878)**

Records in the Fremantle marine area: Fremantle, Owen Anchorage. **Vouchers:** WAM 33011. **Range in WA:** South and west coast from Esperance to Shark Bay. **Range outside WA:** Widespread in warm temperate to subtropical seas (Ryland 1965; Hayward & Ryland 1979; Gordon & Mawatari 1992); in eastern Australia known from New South Wales to South Australia and Tasmania (Brock 1985; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023; NIMPIS 2023). **Habitat:** On hard bottoms. **WA literature records:** CRIMP (2000); Campbell (2003a); Wyatt et al. (2005); Huisman et al. (2008); Wells et al. (2009). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Schizoporella unicornis **(Johnston, 1847)**

Records in the Fremantle marine area: Fremantle Harbour. **Vouchers:** None for Fremantle marine area. Other WA vouchers from Esperance (WAM 30567; 30571); Albany (WAM 32633); and Bunbury (WAM 30532; 30534; 32104). **Range in WA:** South coast and lower west coast of WA from Esperance to Fremantle. **Range outside WA:** Cryptogenic in Japan and colder waters of the eastern Atlantic; introduced to the northeast Pacific (including the Hawaiian Is), west Atlantic (Osburn 1952; Ryland 1965; Sutherland 1978; Hayward & Ryland 1979; Winston 1982; Hurlbut 1991; NEMESIS 2023); in eastern Australia from Queensland to South Australia and Tasmania (Allen 1953; Vail & Wass 1981; Brock 1985; Pollard & Hutchings 1990b; Hewitt et al. 2004; Wiltshire et al. 2010). **Habitat:** NEMISIS (2023) reports two growth forms: attached colonies or unattached bryoliths. NEMESIS also reports that it can grow on seagrass. **WA literature records:** Pollard & Hutchings (1990b); CRIMP (1997a; 1997b); Campbell (2003b); Huisman et al. (2008). **Notes:** Literature records of *S. unicornis* may be confused with *S. errata* (Ryland 1965; Hayward & Ryland 1979; Winston 1982). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Tricellaria occidentalis **(Trask, 1857)**

Records in the Fremantle marine area: Fremantle. **Vouchers:** WAM 32702; 30814. **Range in WA:** Known only from Fremantle and Barrow Island. **Range outside WA:** British Columbia to California, Japan, China, New Zealand, Venice, Italy (Osburn 1950; Gordon 1986); in eastern Australia from New South Wales to South Australia (Gordon & Mawatari 1992; Hewitt et al. 2004; Wiltshire et al. 2010); ALA 2023). **Habitat:** A variety of hard substrates. **WA literature records:** CRIMP (2000); Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Watersipora arcuata **Banta, 1969**

Records in the Fremantle marine area: Fremantle. **Vouchers:** WAM 32836. **Range in WA:** South coast and lower west coast of WA from Esperance to Geraldton. **Range outside WA:** Widely distributed in warmer seas (Banta 1969; Winston 1982; Gordon 1989; Gordon & Mawatari 1992); in eastern Australia recorded from Queensland to South Australia (Vail & Wass 1981; Bock 1982; Brock 1985; Pollard & Hutchings 1990b; Moran & Grant 1993; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023; NIMPIS 2023). **Habitat:** A variety of hard substrates. **WA literature records:** Pollard & Hutchings (1990b); CRIMP (1997a; 1997b; 2000); Campbell (2003a, 2003b); Mackie et al. (2006); Huisman et al. (2008); Wells et al. (2009); ALA (2023); NIMPIS (2023). **Notes:** The systematics of this species is complex, but genetic analysis confirmed the identity of the species (Mackie et al. 2012). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Watersipora subtorquata **(d'Orbigny, 1852)**

Records in the Fremantle marine area: Fremantle. **Vouchers:** None in the Fremantle marine area. Albany (WAM 30539); Bunbury (WAM 30527). **Range in WA:** South coast and west coast of WA from Albany to Shark Bay. **Range outside WA:** Widespread in tropical and temperate seas, including Brazil; West Indies, Bermuda, California, Cape Verde Islands, Japan, Mediterranean and New Zealand (Gordon 1989; Zibrowius 1991; Gordon & Mawatari 1992); in eastern Australia from Queensland to South Australia and Tasmania (Gordon & Mawatari 1992); Parry et al. 1997; Currie et al. 1998; Keough and Ross 1999; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Wide variety of hard substrates, copper tolerant. **WA literature records:** CRIMP (1997a; 2000); Campbell (2003a); Wyatt et al. (2005); Mackie et. al. (2006); Huisman et al. (2008); Wells et al. (2009). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

8.1.4 Crustaceans

Cirolana harfordi **(Lockington, 1877)**

Records in the Fremantle marine area: Fremantle, Owen Anchorage, Swan River. **Vouchers:** WAM C23479, C13191. **Range in WA:** Fremantle marine area and the Kimberley. **Range outside WA:** Described from California, distributed in western North America from British Columbia to Baja California, also recorded from Japan, eastern Russia and Malaysia (Johnson 1976; Poore & Storey 1999); in eastern Australia from New South Wales and Victoria (Bruce 1986; Hutchings et al., 1987; Currie et al., 1998; Cohen et al., 2001; Hewitt et al., 2004; ALA 2023) and Waverton, NSW (Bruce, 1986). **Habitat:** Under rocks and amongst mussels, also ship hulls. **WA literature records:** Bruce (1986); Poore & Storey (1999); Furlani (1996); Hass & Jones (2000); Huisman et al. (2008); ALA (2023). **Notes:** Johnson (1976) and Furlani (1996) stated this species is a voracious scavenger that has the potential to be a pest species in high population densities, but it is not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Paracerceis sculpta **(Holmes, 1904)**

Records in the Fremantle marine area: Fremantle, Owen Anchorage, Cockburn Sound. **Vouchers:** WAM C35839; C35846. **Range in WA:** Introduced to south and west coast of WA, including Esperance, Bunbury, Mandurah, Fremantle, Port Denison. **Range outside WA:** Native to California and northern Mexico, now found worldwide in warm temperate and tropical waters (Zibrowius, 1991; NEMESIS 2023); in eastern Australia from Queensland, New South Wales and South Australia (Harrison & Holdich, 1982b; Hutchings et al. 1987; Pollard & Hutchings 1990b; Furlani 1996; Poore & Storey 1999; Hewitt & Campbell 2001; Hewitt et al. 2004; Wiltshire et al. 2010). **Habitat:** Common in sheltered sand and rocky habitats, among algae, under rocks and in fouling communities (NEMESIS 2023). **WA literature records:** Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Paradella dianae **(Menzies, 1962)**

Records in the Fremantle marine area: Fremantle. **Vouchers:** Bunbury: WAM C23302; C16781; C23302. **Range in WA:** Introduced to the lower west coast from Bunbury, Fremantle and the Swan River. **Range outside WA:** Native from Southern California to northern Mexico, now widespread in tropical and warm temperate seas (NEMESIS 2023); in eastern Australia known only from Queensland (ALA 2023). **Habitat:** Amongst barnacles, bryozoans and rock oysters on rocks and artificial structures (Harrison & Holdich, 1982a). **WA literature records:** Harrison & Holdich (1982a); Pollard & Hutchings (1990b); Hass & Knott (1998); Zibrowius (1991); Furlani (1996); Huisman et al. (2008); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Sphaeroma serratum **Fabricius, 1787**

Records in the Fremantle marine area: Swan River. **Vouchers:** Esperance WAM 36953. **Range in WA:** Esperance, Swan River, Jurien Bay. **Range outside WA:** Widespread (Pollard & Hutchings, 1990b); in United Kingdom (BMIG 2023). **Habitat:** Intertidal, found under rocks and in crevices. **WA literature records:** Holdich & Harrison (1983); Hutchings et al. (1987); Pollard & Hutchings (1990b); Hass & Knott (1998); Furlani (1996); Campbell (2003b); Hass (2007); Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Amphibalanus amphitrite **(Darwin, 1854)**

Records in the Fremantle marine area: Cockburn Sound, Owen Anchorage, Fremantle, Swan River. **Vouchers:** WAM C668; C778, C10092; C6926; C12141. **Range in WA:** Esperance area to the Kimberley. **Range outside WA:** Indian Ocean to southwestern Pacific; regarded as an introduced species in New Zealand. Found in all areas of Australia (ALA 2023). **WA literature records:** Lewis (1982); Jones (1990a, 1990b); Jones and Hewitt (2001); Huisman et al. (2008); Wells et al. (2009); CSMC (2022); ALA (2023). **Notes:** It is not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Megabalanus rosa (Pilsbry, 1916)

Recorded, but not established in the Fremantle marine area.

Records in the Fremantle marine area: None. **Vouchers:** WAM C33163; C33165; C33189. **Range in WA:** Shark Bay to the Kimberley. **Range outside WA:** Japan; China; Taiwan (Pollard & Hutchings 1990b); in eastern Australia reported only from New South Wales (Hass & Jones 2000; Jones et al. 1990; ALA 2023). **Habitat:** On hard substrates. **WA literature records:** Jones (1992a); Hass & Jones 2000; Jones et al. 1990; Huisman et al. (2008); Wells et al. (2009); ALA (2023). **Notes:** The species appears to have been a relatively recent introduction to WA, the first specimens being collected in 1981 (Jones 1992a). Huisman et al. (2008) report it from Cockburn Sound based on the three specimens listed above, but these were collected during an inspection of a vessel that had recently arrived from Southeast Asia. No other individuals have been collected from Cockburn Sound and the species is not known from the Fremantle marine area. It is not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Megabalanus tintinnabulum (Linnaeus, 1758)

Records in the Fremantle marine area: Cockburn Sound. **Vouchers:** C12188. **Range in WA:** Albany to the Kimberley. **Range outside WA:** Cosmopolitan in warm temperate and tropical seas (Jones et al. 1990; Furlani 1996); in all Australian states except Tasmania (Jones 1999; Jones et al. 1990; Wiltshire et al. 2010; ALA 2023). **Habitat:** A fouling species on hard substrates. **WA literature records:** Jones (1990a; 1990b; 1991; 1992a) Jones et al. (1990); Jones & Hewitt (1997; 2001); Hass & Jones (2000); Huisman et al. (2008); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Monocorophium acherusicum (Costa, 1857)

Records in the Fremantle marine area: Fremantle, Swan River. **Vouchers:** WAM C35989. **Range in WA:** Bunbury, Fremantle, Swan River. **Range outside WA:** Native range unknown, widespread global distributions in North America, Central America, South America, Europe, Asia, Australia and New Zealand (NEMESIS 2023); in eastern Australia from Queensland to South Australia and Tasmania (Fearn-Wannan 1968; Poore & Storey 1999; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Forms U shaped burrows in soft shallow muddy environments but can also occur on hard surfaces (NEMESIS 2023). **WA literature records:** Poore & Storey (1999); Huisman et al. (2008); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Monocorophium insidiosum (Crawford, 1937)

Records in the Fremantle marine area: Swan River. **Vouchers:** WAM C10271; C49946. **Range in WA:** Swan River and Bunbury. **Range outside WA:** Native range unknown. Widespread in temperate and subtropical regions of both coasts of North and South America, Europe, Australia and Asia (NEMESIS 2023); in eastern Australia from New South Wales to South Australia and Tasmania (Poore & Storey 1999; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Forms U shaped burrows in soft shallow muddy environments but can also occur on hard surfaces (NEMESIS 2023). **WA literature records:** Poore & Storey (1999); Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Monocorophium sextonae (Crawford, 1937)

Records in the Fremantle marine area: Fremantle, Owen Anchorage, Cockburn Sound. **Vouchers:** WAM C49917; C49927; C49928; C49970; C49980. **Range in WA:** Albany, Bunbury, Fremantle, Swan River, Dampier (ALA 2023). **Range outside WA:** Northeast Atlantic (England, Scotland, Ireland, France, The Netherlands, the Mediterranean, Portugal) and New Zealand (Hurley 1954; Costello 1993); in eastern Australia from Queensland to South Australia and Tasmania (Poore & Storey 1999; Hewitt et al. 2004; ALA 2023). **Habitat:** A tube dwelling amphipod, found on kelp holdfasts, sponges and artificial substrata (Costello 1993). **WA literature records:** Poore & Storey (1999); Huisman et al. (2008); ALA (2023). **Notes:** Its natural distribution is uncertain, and it may be native to Australia and New Zealand (Poore & Storey 1999), but NIMPIS (2023) lists the species as cryptogenic. Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Tesseropora rosea* (Krauss, 1848)**

Records in the Fremantle marine area: Cottesloe; Fremantle; Cockburn Sound. **Vouchers:** WAM C17763; C15963; C536-86. **Range in WA:** Albany and Fremantle marine area. **Range outside WA:** Described from South Africa; widespread in eastern Australia from Queensland to Victoria and Tasmania. **Habitat:** On intertidal rocks, where it can be common. **WA literature records:** Jones (1990a; 1990c); Huisman et al. (2008); ALA (2023). **Notes:** Apparently introduced from eastern Australia, where it is common (Jones et al. 1990; Jones 1990a; 1990c). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Carcinus maenas* (Linnaeus, 1758)**

Recorded but not established in the Fremantle marine area.

Records in the Fremantle marine area: None. See notes below. **Vouchers:** WAM C14833. **Range in WA:** None. **Range outside WA:** Native to European coasts, introduced to east and west coasts of North America, Japan and east coast of South America (NEMESIS 2023); widespread in eastern Australia from Queensland to South Australia and Tasmania (Fulton & Grant 1900, 1901; Allen 1953; Zeidler 1978; Rozenweig 1984; Hutchings et al. 1987, 1989; Pollard & Hutchings 1990b; Furlani 1996; Currie et al. 1998; Cohen et al. 2001; Hewitt et al. 2004; Ahyong 2005; Wiltshire et al. 2010; ALA 2023). **Habitat:** Sheltered intertidal and shallow subtidal habitats (NEMESIS 2023). **WA literature records:** Huisman et al. (2008); Wells et al. (2009; 2010). **Notes:** Listed as one of the '100 worst invasive species' with major effects on shell fisheries in the northeastern United States (NEMESIS 2023). In south-eastern states of Australia *C. maenas* out competes native species (Fulton & Grant 1901; Zeidler 1978, 1988; Furlani 1996; Waiters 1996; Ahyong 2005). Listed as a species of concern by DPIRD (2016) and DAFF (2023).
Although the species is widespread in eastern Australia, there is a single specimen in WAM collected in 1965. This was used as stating *C. maenas* occurs in WA by Zeidler (1978); Furlani (1996); Pollard & Hutchings (1990b) and Hass & Jones (2000). The species was not collected in the CRIMP Fremantle port survey causing CRIMP (1997b) to suggest no WA populations have become established. A marine pest survey of the Fremantle marine area in 2007 confirmed the absence of *C. maenas* (Wells et al. 2008).

***Charybdis japonica* (A. Milne-Edwards, 1861)**

Recorded but not established in the Fremantle marine area.

Records in the Fremantle marine area: Lower Swan River. **Vouchers:** None. **Range in WA:** Not established. **Range outside WA:** Native range: China, Japan, Korea, Taiwan, Malaysia and Thailand; introduced to New Zealand, with a single specimen recorded in the Mediterranean (NIMPIS 2023). **Habitat:** Found in a variety of estuarine habitats, including soft sediments, rocky shores, artificial structures and seagrass meadows. WA literature records: DoF (2015a); Hourston et al. 2016; Hewitt et al. 2018; DPIRD 2019; CSMC 2022; Simpson et al. 2023). Notes: Isolated individuals have been found in the lower Swan River and the Peel Harvey system at Mandurah, and in South Australia, but the species is not considered established in Australia. It has not been detected in WA in the last four years (Dr J. McDonald, DPIRD, pers. comm.). Listed as a species of concern by DPIRD (2016) but not on DAFF (2023).

***Pyromaia tuberculata* (Lockington, 1877)**

Recorded but not established in the Fremantle marine area.

Records in the Fremantle marine area: Cockburn Sound. **Vouchers:** WAM C19338. **Range in WA:** Cockburn Sound (not established). **Range outside WA:** Native to west coast of the Americas from California to Colombia; widely distributed in the temperate and sub-tropical Pacific and South Atlantic, Brazil, Japan, New Zealand (Morgan 1990; Poore & Storey 1999); in eastern Australia from New South Wales to Victoria and Tasmania (Hass & Jones 2000; Furlani 1996; Poore & Storey 1999; Hewitt et al. 2004; ALA 2023). **Habitat:** Under stones or on sandy to muddy bottoms. **WA literature records:** Morgan (1990); Furlani (1996); Poore & Storey (1999); Hass & Jones (2000); Huisman et al. (2008); Ahyong & Wilkens 2011. **Notes:** Morgan (1990) reported *Pyromaia tuberculata*, was introduced to Cockburn Sound in 1978 via ballast water, but no further specimens have been collected. Huisman et al. (2008) concluded the species had not become established. Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

8.1.5 Hydroids

Antenella secundaria (Gmelin, 1791)

Records in the Fremantle marine area: Simply listed as Perth. **Vouchers:** Cape Peron, Shark Bay (WAM 2541). **Range in WA:** Perth to Albany, Houtman Abrolhos Is., Shark Bay to Exmouth; Port Hedland (CRIMP 1999). **Range outside WA:** Cosmopolitan in temperate and tropical seas (Boero & Bouillon 1993; Watson 1997, 1999, 2000); in eastern Australia from the Northern Territory, Queensland, New South Wales and South Australia (Pennycuik 1959; Watson 1973; 1994, 1999; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Grows in thick masses on algal and invertebrate substrata in sheltered ocean waters, often amongst sponges and red algae (Bock 1982; Watson 1994). **WA literature records:** Watson (1996; 1997); CRIMP (1999); Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Ectopleura crocea (Agassiz, 1862)

Records in the Fremantle marine area: Cockburn Sound, Owen Anchorage. **Vouchers:** Dunsborough (WAM INV945). **Range in WA:** Known only from the Fremantle marine area and Dunsborough (ALA 2023). **Range outside WA:** Native to Atlantic coast of North America but widely introduced to the west coast of North America, Europe, Mediterranean, South Africa, Australia and New Zealand (NEMESIS 2023); in eastern Australia from Queensland to South Australia and Tasmania (Pennycuick 1959; Ralph 1966; Black 1971; Watson 1980, 1999; Hewitt et al. 2004; ALA 2023). **Habitat:** The hydroid stage grows on a variety of hard substrates; there is no medusa stage (NEMESIS 2023). **WA literature records:** Bock (1982); Watson (1999); CRIMP (2000); Huisman et al. (2008); ALA (2023). **Notes:** Although the species can reduce growth rates of cultured mussels (NEMESIS 2023), it is not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Eudendrium carneum Clarke, 1882

Records in the Fremantle marine area: Fremantle. **Vouchers: Fremantle:** NMV F50724; Bunbury WAM INV30531). **Range in WA:** Albany to Perth (Watson 1996). **Range outside WA:** Circumtropical (Boero & Bouillon 1993); California; Ecuador; Mexico; California; northwest Atlantic (Fraser 1948); in other Australian areas known only from Darwin, Northern Territory and the Sydney area of New South Wales (ALA 2023). **Habitat:** There are two life stages: a hydroid stage which occurs on a variety of natural and artificial hard substrates and a planktonic medusa (NEMESIS 2023). **WA literature records:** Watson (1996); Huisman et al. (2008); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Halecium delicatulum Coughtrey, 1876

Records in the Fremantle marine area: Simply recorded as Perth. **Vouchers:** Bunbury (WAM 30524). **Range in WA:** Albany to the Houtman Abrolhos Islands. **Range outside WA:** Circum global tropical to Antarctic waters (Ralph 1958; Watson 1997); in eastern Australia from southern Queensland to South Australia and Tasmania (Hodgson 1950; Pennycuick 1959; Watson 1975; Ralph 1966; Black 1971; Watson 1973; 1975; 1994; 1999; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** This is a common southern Australian species colonising many invertebrate and algal substrata (Watson 1997). **WA literature records:** Watson (1996; 1997); Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

8.1.6 Molluscs

Batillaria australis (Quoy and Gaimard, 1834)

Records in the Fremantle marine area: Cockburn Sound, Swan River. **Vouchers:** NMV F12818; WAM S13341; MAGNT P054377; P039411. **Range in WA:** Swan River and Cockburn Sound (see notes). **Range outside WA:** Eastern Australia from Queensland to South Australia and Tasmania (ALA 2023). **Habitat:** Subtidal sandflats, seagrass and marine algae. **WA literature records:** Wells (1984); Wells & Bryce (1986); Huisman et al. (2008); Wells et al. (2009); Thomsen (2010); Beechey (2023); ALA (2023). **Notes:** Previously known as *Velacumantus australis.* The species is known in WA only from the Swan River, with a single specimen recorded from Woodman Point, Cockburn Sound. ALA (2023) also shows an INaturalist record from Albany, but there is no voucher specimen. Cotton (1984), Ewers (1967) and Roberts & Wells (1980) all recorded *B. australis* from Albany, based on a single specimen that was shown to be a subfossil (Wells 1984). ALA (2023) also records *B. australis* from Turtle Bay at North West Cape (NMV F148940), but the locality is considered erroneous. *B. australis* is a host of the flatworm parasite *Austrobilharzia,* discharging larvae into the water column where they can "bathers itch" in humans (Ewers, 1965). Thomsen et al. (2010) estimated there are 3.6 billion living individuals in the Swan River.

Godiva quadricolor (Barnard, 1927)

Records in the Fremantle marine area: Cockburn Sound, Fremantle. **Vouchers:** WAM 339-86; S26849. **Range in WA:** Cockburn Sound and Fremantle. **Range outside WA:** Native to South Africa, from the Cape of Good Hope to Port Alfred (Willan 1987b); in eastern Australia from Queensland, New South Wales and South Australia (Macnae 1954; ALA 2023). **Habitat:** Subtidal on hard surfaces. **WA literature records:** Willan (1987b); Wells & Bryce (1993); Furlani (1996); Fisheries WA (2000); Huisman et al. (2008); Wells et al. (2009); CSMC (2022); ALA (2023). **Notes:** Isolated single individuals have been recorded in WA but it is not clear that the species has become established. Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Arcuatula senhousia (Benson in Cantor, 1842)

Range in Records in the Fremantle marine area: Swan River, Fremantle. **Vouchers:** WAM 10748, 12718, 14305, 16462, 16910. **Range in WA:** Swan River and Fremantle. **Range outside WA:** Native to Pacific coast of Asia. An invasive species that has been recorded in Mediterranean, USA, India, and New Zealand; in eastern Australia it has been recorded from Queensland, Victoria, South Australia and Tasmania (Willan 1985a, 1985b, 1987a; Hutchings et al. 1987; Pollard & Hutchings 1990b; Coleman 1993; Furlani 1996; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Sedimentary bottoms and seagrasses. **WA literature records:** Slack-Smith & Brearley (1987); Hutchings et al. (1987); Pollard & Hutchings (1990b); Furlani (1996); Wilson (1998); Fisheries WA (2000); CRIMP (2000); Huisman et al. (2008); Wells et al. (2009); CSMC (2022); ALA (2023); NIMPIS (2023). **Notes:** Previously known as *Musculista senhousia.* Slack-Smith & Brearley (1987) recorded the species in the Swan River. By the late 1980s and early 1990s it was widespread in the estuary and was the most common benthic species but a detailed survey of the Fremantle marine area in 2007 failed to find the species. It was apparently eliminated by an unusually intense rainfall event in January 2000 that overnight reduced the warm, hyposaline waters of the Swan River to a cooler, freshwater system (McDonald & Wells 2009; 2010). The species has recently been detected in the upper half of the Swan-Canning Basin and lower Canning River (Cottingham et al. unpub.)

Not listed as a species of concern by DAFF (2023). Listed as a noxious species in any area of WA except the Swan River and Port of Fremantle (DPIRD 2016).

Mytilus galloprovincialis Lamarck, 1819

Records in the Fremantle marine area: Cockburn Sound, Owen Anchorage, Fremantle, Swan River, Cottesloe. **Vouchers:** WAM N1650. **Range in WA:** Across the south coast to Perth. **Range outside WA:**

Native to the Mediterranean Sea and Atlantic coast of Europe. Widely introduced to North America, South Africa, Asia and other areas (NEMESIS 2023). In eastern Australia from New South Wales to South Australia and Tasmania (ALA 2023). **Habitat:** Forms dense colonies on hard surfaces in protected waters of harbours and estuaries. **WA literature records:** Huisman et al. 2008; Dias et al. 2014. **Notes:** Lamarck (1819) described *Mytilus planulatus* from southern Australia based on specimens collected in King George Sound at Albany. In the same publication he also described the European *M. galloprovincialis*. The taxonomic history of *M. planulatu*s has been controversial, with it variously being recognised as a valid species, a synonym of *M. edulis,* a subspecies of *M. edulis* or as *M. galloprovincialis.* Mussels are abundant in the Fremantle marine area. They were initially fished in Cockburn Sound as a wild caught fishery and a small aquaculture industry later developed. Dias et al. (2014) investigated the genetics of *Mytilus* in several WA ports, including Garden Island. While the shells could not be separated Dias et al. (2014) concluded there were two genetic strains. The more common was *M*. *galloprovincialis* and the less abundant form was a native species which they did not name. However, *M. planulatus* is currently recognised by WoRMS (2023). Ab Rahim et al. (2016) similarly found extensive hybridisation in mussels in a broader examination of the southern Australian coastline.

No *Mytilus* species are listed as being of concern by either DPIRD (2016) or DAFF (2023).

Okenia pellucida Bum, 1967

Records in the Fremantle marine area: Fremantle. **Vouchers:** None. **Range in WA:** Fremantle only. **Range outside WA: Kn**own from the United Arab Emirates, India, Malaysia, New Zealand, Palmyra Atoll and Japan (Rudman 2004); in eastern Australia from Queensland and New South Wales (Willan & Coleman 1984; Rudman 2004; ALA 2023). **Habitat:** Lives and feeds on the bryozoan *Zoobotryon verticillatum.* **WA literature records:** Willan & Coleman (1984); Huisman et al. (2008); Rudman (2004); Wells et al. (2009); ALA (2023). **Notes:** A common fouling species readily distributed by shipping activities. The genus is extremely complex, with numerous new species recently described and others known but not yet described (Paz-Sedano et al. 2021). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Perna viridis

Not established in the Fremantle marine area.

Records in the Fremantle marine area: None. **Vouchers:** None. **Range in WA:** None. **Range outside WA:** Native to the Indo-Pacific from the Persian Gulf to Thailand and Indonesia. Widely introduced by vessels and for aquaculture into China, Japan, the eastern Pacific, Caribbean and southeastern United states (NEMESIS 2023). No populations extant in eastern Australia. **Habitat:** On a range of hard substrates in the intertidal and shallow subtidal. **WA literature records:** Huisman et al. (2008). **Notes:** The Asian green mussel is a key aquaculture species. It is also highly invasive. The species is listed as noxious by DPIRD (2016) and as a priority marine pest by DAFF (2023). However, *P. viridis* is routinely found during vessel inspections in Australian waters. Heersink et al. (2020) estimated the species is brought into Australian waters hundreds of times annually. Both Wells (2017) and Heersink et al. (2020) provided arguments as to why *P. viridis* is not as great a threat to Australia as previously thought.

McDonald (2012) reported a possible spawning on naval vessels in Cockburn Sound that could have been associated with a marine heat wave. Two cohorts were found on the vessel: 4 individuals of 41-47mm and 197 individuals of 3-17mm. Using published tropical growth rates, it was estimated that the smaller individuals were spawned in Cockburn Sound. However, extensive surveys of the local marine environment 6 and 9 months later failed to find *P. viridis.* The vessel on which the *P. viridis* were found had been in both Singapore and New Zealand.

The assessment of the possible spawning date in Cockburn sound was based on published tropical growth rates. These are primarily from aquaculture regions where the mussels are growing rapidly, or they would not be suitable sites for aquaculture. Growth rates in the open sea and cold New Zealand waters would be much lower, so the mussels could have attached to the vessel in Singapore. This in fact happened in a similar vessel inspected in Fremantle (Wells unpublished). An offshore support vessel was cleaned and inspected in drydock in Singapore in July 2013. On re-entering the water, the OSV moved to Dunedin, New Zealand where it remained for a prolonged period in the Austral summer. It was then mobilised to WA and inspected on arrival in Fremantle in early 2014. The hull was well fouled and black mussels (*Mytilus* sp.) were common. Several *P. viridis* up to 17 mm long were also found. The mussels were stunted by the lack of food in the water on the voyage to New Zealand and the cold temperatures they encountered in New Zealand and were far smaller than published growth rates would indicate.

Polycera hedgpethi **Marcus, 1964**

Records in the Fremantle marine area: Cockburn Sound. **Vouchers:** Rockingham (WAM S29806). **Range in WA:** Cockburn Sound. **Range outside WA:** California; Caribbean; Mediterranean; South Africa; New Zealand; Japan; Iberian Peninsula (Gosliner 1982; Pollard & Hutchings 1990b; Gofas & Zenetos 2003); in eastern Australia from New South Wales to South Australia and Tasmania (Willan & Coleman 1984; Hutchings et al. 1987; Furlani 1996; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** On subtidal hard surfaces. **WA literature records:** Wells & Bryce (1993); Furlani (1996); Huisman et al. (2008); Wells et al. (2009); ALA (2023). **Notes:** *Polycera hedgpethi* was abundant on jetty pilings at Quaranup, Princess Royal Harbour, Albany in the 1980s (Wells & Bryce 1993), but subsequent searches of the pilings did not record any individuals. A single specimen was later collected at Rockingham in Cockburn Sound (Huisman et al. 2008). It is not clear that the species has become established in WA. It is not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Scaeochlamys livida **(Lamarck, 1819)**

Records in the Fremantle marine area: Swan River, Fremantle Harbour, Owen Anchorage, Cockburn Sound. **Vouchers:** WAM S14964, S33048-S33051. **Range in WA:** Fremantle marine area, Rottnest Island, Whitfords. **Range outside WA:** Eastern Australia from Queensland and New South Wales. Note that ALA (2023) has numerous records of the species in northern Australia and other parts of WA, but these are misidentifications. **Habitat:** Attached to hard substrates**. WA literature records:** CRIMP (2000); Huisman et al. (2008); Morrison and Wells (2008); Wells et al. (2009); CSMC (2022). **Notes:** This scallop was recorded in the CRIMP (2000) survey of Fremantle Harbour and Cockburn Sound but as an eastern Australian species did not attract any attention. Morrison & Wells (2008) provide full details on the species in Fremantle Harbour and Cockburn Sound. lt first appeared in about 1985 and is now well established. More recently it has been recorded from Minden and Roe Reefs off Fremantle (Richards et al. 2016). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Theora lubrica **Gould, 1861**

Records in the Fremantle marine area: Cockburn Sound, Swan River. **Vouchers:** Geraldton: MAGNT P055278. **Range in WA:** Cockburn Sound and Swan River; also Geraldton. **Range outside WA:** Asia, California, New Zealand (Chalmer et al. 1976; Pollard & Hutchings 1990b); in eastern Australia from New South Wales to South Australia and Tasmania (Coleman 1993; Furlani 1996, as *Theora fragilis;* Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** In soft sediments. **WA literature records:** Chalmer et al. (1976); Slack-Smith & Brearley (1987); Hutchings et al. (1987); Pollard & Hutchings (1990b); Furlani (1996); CRIMP (1997a); Huisman et al. (2008); Wells et al. (2009); ALA (2023). **Notes:** This is a small (<10mm) species with a thin, fragile shell in a poorly known group of species. The numerous literature references in WA are based on a small number of specimens that are simply repeated by subsequent authors. The presence of *Theora lubrica* in Western Australia requires confirmation. Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Mitrella bicincta **(Gould, 1860)**

N**ot established in the Fremantle marine area**

Records in the Fremantle marine area: Cottesloe. **Vouchers:** AMS C.209869. **Range in WA:** Known only from Cottesloe based on a dead shell. **Range outside WA:** Japan; in eastern Australia from southern Queensland to Victoria (Beechey & Willan 2007; ALA 2023). **Habitat:** On rocky shores. **WA literature records:** Beechey & Willan (2007); ALA (2023). **Notes:** This species was recorded from a single specimen washed up on Cottesloe beach in 1994. Extensive surveys of the molluscs of the intertidal platform at Cottesloe have not detected the species (Wells et al. 2023; submitted) and is not considered to have become established. Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Family Teredinidae

Commonly known as shipworms, the family Teredinidae is in fact a group of bivalve molluscs. There are about 18 genera and nearly 100 species (WoRMS 2023). The planktonic larvae settle onto wood, or less commonly other soft objects, and burrow into them. Individual species burrow into live or dead wood, or even both. The body and shell are highly modified for their unusual habitat, which gave rise to the common name of shipworms. Individual species have been transported around the world by wooden boats, rafts and other human devices, and they readily colonise artificial wooden structures in the ocean. Over the centuries individual species have become widespread and their native ranges obscured. The limited number of DNA studies of species such as *Teredo navilis* have failed to determine their native ranges. Information on teredinid species in Australia was developed by Turner (1966, 1971a, 1971b) and Marshall & Turner (1974). Brearley et al. (2003) worked on the species occurring near the port of Dampier, WA and provided a table showing the known distribution of individual species in Australian waters. Six species were recorded in the Fremantle marine area. Marshall & Turner (1974) recorded one additional species for a total of seven:

- *Teredo navalis* Linnaeus, 1758
- *Teredo furcifera* E. von Martens, 1894
- *Teredo bartschi* Clapp, 1923
- *Lyrodus pedicellatus* (Quatrefages, 1849)
- *Lyrodus medilobatus* (Edmonson, 1942)
- *Nototeredo edax (*Hedley, 1895)
- *Bankia australis* (Calman, 1920)

Notes: None of these species is listed as a species of concern by DPIRD (2016) or DAFF (2023).

Eumarcia fumigata **(G.B. Sowerby II, 1853)**

Records in the Fremantle marine area: Lower Swan River. **Vouchers:** WAM S71351 to S71372. **Range in WA:** Swan River (Brearley & Wells 2019). **Range outside WA:** Restricted to eastern Australia from Queensland to South Australia and Tasmania (ALA 2023). **Habitat:** On intertidal and shallow subtidal sand. **WA literature records:** Brearley & Wells (2019). **Notes:** This is a rare example of a species introduced to WA from eastern Australia. Is it unique in having lived in WA during the Pleistocene, became extinct in WA and having been recently reintroduced. The first living specimen from Point Walter in the Swan River was collected on 25 November 2012. ALA (2023) lists specimens in MuseumsVictoria from Emu Point, Albany and Wilson Inlet, but these are likely to be subfossils or misidentifications. Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

8.1.7 Polychaetes

Alitta succinea **(Leuckart, 1847)**

Records in the Fremantle marine area: Swan River. **Vouchers:** None. **Range in WA:** Swan River. **Range outside WA**: Thought to be native to the north Atlantic. Introduced to west coast of North America, Hawaii, Japan, Korea, China and Australia (NEMESIS 2023); in eastern Australia from Victoria, South Australia and Tasmania (Hutchings & Murray 1984; Wilson 1999; Wiltshire et al. 2010; ALA 2023). **Habitat:** Occupies a range of habitats, including soft sediments, rocky reefs, oyster beds and artificial surfaces (NEMESIS 2023). **WA literature records:** Monroe (1938); Wilson (1984); Cohen et al. (2001); Hewitt et al. (2004); Huisman et al. (2008). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Boccardia proboscidea Hartman, 1940

Records in the Fremantle marine area: Fremantle. **Vouchers:** None. **Range in WA:** Fremantle. **Range outside WA:** Chile, Panama; in eastern Australia from New South Wales to South Australia (Blake & Kudenov 1978; Hartmann-Schroder 1982, 1989; Carlton 1985; Hutchings et al. 1987; Pollard & Hutchings 1990b; Furlani 1996; Wilson 1999; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Wide variety of intertidal and shallow subtidal habitats, including rocky shores and sandflats and tide pools (Furlani 1996). **WA literature records:** Hartmann-Schroder (1982); Hutchings et al. (1987); Pollard & Hutchings (1990b); Furlani (1996); Huisman et al. (2008). **Notes:** This species was first recorded in Fremantle Harbour in 1975 and was probably introduced through ballast water or hull fouling (Hartmann-Schroder 1982). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Ficopomatus enigmaticus (Fauvel, 1923)

Records in the Fremantle marine area: Swan River. **Vouchers:** AMS W.51880; W.51884. **Range in WA:** Albany to Shark Bay (ALA 2023). **Range outside WA:** Native distribution unknown; apparently of subtropical or temperate origin. Also known in the Mediterranean, Europe, Black Sea, Japan, North and South America; in eastern Australia from Queensland to South Australia (Monroe 1938; Allen 1953; ten Hove & Weerdenburg 1978; Hutchings & Murray 1984; Hutchings et al. 1987; Pollard & Hutchings 1990b; Zibrowius 1991; Cohen et al. 2001; Hewitt et al. 2004; ALSA 2023). **Habitat:** Calcareous tubeworm that forms dense intertidal habitats. **WA literature records:** Monroe (1938); Allen (1953); ten Hove & Weerdenburg (1978); Hutchings & Murray (1984); Hutchings et al. (1987); Pollard & Hutchings (1990b); Huisman et al. (2008); Styan et al. (2017); ALA (2023). **Notes:** Described from France, where it was thought to have been introduced, widespread populations in southern Australia were rapidly reported. Huisman et al. (2008) listed the species as introduced in accord with the prevailing view, but there were also papers suggesting it was a native species. Styan et al. (2017) used molecular techniques to answer the question of whether the species was introduced or native. Unexpectedly, they found three cryptic species in southern Australia that often co-occurred in the same mass of individuals. It is now considered to be cryptogenic. Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Genus Hydroides

The genus *Hydroides* contains small tubeworms that occur widely in tropical and subtropical shallow waters. They live on a variety of hard structures and are notorious biofoulers. Identification requires a detailed knowledge of the taxa. Sun et al. (2015) reviewed the genus in Australia, recognising 20 species.

The following species were recorded in the Fremantle marine area by Sun et al. (2015):

- ***H. amri* Sun et al., 2015:** Southern Queensland to South Australia. In WA: several specimens from Cottesloe and City Beach and one from Point Quobba.
- ***H. dirampha*** Mörch, 1863: Probably native to the tropical Pacific coast of Central America, but now widespread in the Mediterranean, Indo-West Pacific, East and West Atlantic, South Africa and New Zealand. In eastern Australia from New South Wales, Victoria and Tasmania. The distribution map of Sun et al. (2015) shows the species in Cockburn Sound, but the text shows these records were from vessel inspections.
- ***H. elegans* Haswell, 1883:** Widespread in the Mediterranean-Atlantic, Indo-West Pacific, tropical Pacific America, East and West Atlantic and South Africa. Sun et al. (2015) record the species “all around Australia” but there are only two localities in WA: Dampier and Cockburn Sound. Some, and probably all, came from vessel inspections.

- ***H. minax* (Grube, 1878):** Indo-West Pacific, from East Africa to Japan and Polynesia, Australia. Across northern Australia from North West Cape, WA to Queensland. There is a single record from City Beach.

No *Hydroides* are listed as a species of concern by DAFF (2023). DPIRD (2016) lists *Hydroides dianthus* as noxious from any area of the state.

Sabella spallanzanii (Gmelin, 1791)

Records in the Fremantle marine area: Fremantle, Cockburn Sound. **Vouchers:** WAM 4613; 4053; AMS W.22249; W.48877. **Range in WA:** South coast to Perth. **Range outside WA:** Native to the Mediterranean and European coast to the English Channel, introduced to South-East Asia and Brazil; in eastern Australia from New South Wales to South Australia and Tasmania (Carey & Watson 1992; Clapin & Evans 1995; Furlani 1996; Currie et al. 1998, 2000; CRIMP 2000; Cohen et al. 2001; Pollard & Rankin 2003; Hewitt et al. 2004; Wiltshire et al. 2010; Murray & Keable 2013; Ahyong et al. 2017; NIMPIS 2023; ALA 2023). **Habitat:** A large (up to 50 cm) tubeworm that can live on both rocky and muddy substrates and can be common on jetty pylons. **WA literature records:** Clapin & Evans (1995); CRIMP (1997a, 1997b, 2000); Campbell (2003b); Huisman et al. (2008); Wells et al. (2009); CSMC (2022); NIMPIS (2023); ALA (2023). **Notes:** *Sabella spallanzanii* is widespread in ports across southern Australia. The first record in WA was a specimen in the WA Museum collected in Albany in 1965. The species was first observed in Cockburn Sound in 1994 (Clapin & Evans 1995) but may have been there earlier. There has been significant recent work on the species in eastern Australia (Murray & Keable 2013; Ahyong et al. 2017; Wood et al. 2017; Daffe et al. 2021). Not listed as a species of concern by DAFF (2023). DPIRD (2016) lists *S. spallanzanii* as noxious in any area of the State except in the West Coast Region and South Coast Region.

8.1.8 Ascidians

Ascidiella aspersa (Müller, 1776)

Records in the Fremantle marine area: Swan River, Fremantle. **Vouchers:** WAM 30507. **Range in WA:** South coast and lower west coast to Fremantle. **Range outside WA** Native to the Mediterranean and Atlantic coast of Europe as far north as Norway. Introduced to the east coast of the USA, New Zealand and Australia (ALA 2023); in eastern Australia from Victoria, South Australia and Tasmania (Black 1971; George & George 1979; Kott 1985; Furlani 1996; Currie et al. 1998; Keough & Ross 1999; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** On intertidal and shallow subtidal rocks and other hard surfaces (George & George 1979). **WA literature records:** Kott (1985); CRIMP (1997a; 1997b; 2000); Furlani (1996); Huisman et al. (2008); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Botrylloides leachii (Savigny, 1816) Cryptogenic

Records in the Fremantle marine area: Cockburn Sound, Fremantle. **Vouchers:** WAM 9583; 9584; QM G9663, G9399. **Range in WA:** Found throughout the state (ALA 2023). **Range outside WA:** Northeastern Atlantic, Europe, British Isles, North Sea, western Mediterranean, Adriatic Sea, Black Sea, Indonesia, western Indian Ocean, Red Sea, South Africa, New Zealand; found throughout Australia (Herdman 1899; Kott 1985; Furlani 1996; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Grows on rocks, other hard substrates, seaweed, and on sand and detritus. **WA literature records:** Hartmeyer & Michaelsen (1928); Kott (1985); Campbell (2003b); CRIMP (1997a; 1997b); Wyatt et al. (2005); Huisman et al. (2008); Wells et al. (2009); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

Botryllus schlosseri (Pallas, 1766)

Records in the Fremantle marine area: Fremantle, Swan River, Cockburn Sound. **Vouchers:** AMS Y.1586. **Range in WA:** On all WA coasts (ALA 2023). **Range outside WA:** Native range unknown. Widespread on temperate coasts of both sides of North America, South America, Asia and New Zealand

(NEMESIS 2023). On all Australian coasts (Kott 1985; Furlani 1996; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** Encrusting species on intertidal and shallow subtidal rocks, seagrasses and oysters (Furlani 1996). **WA literature records:** Hartmeyer & Michaelsen (1928); Kott (1985); Sabbadin & Graziani (1967); Furlani (1996); Huisman et al. (2008); ALA (2023). **Notes:** Recent DNA evidence suggests *B. schlosser*i may in fact be a complex of five closely related species (Brunetti et al. 2017). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Ciona robusta* Hoshino & Tokioka, 1967**

Records in the Fremantle marine area: Fremantle, Swan River. **Vouchers:** WAM 30765. **Range in WA:** South coast to Fremantle. **Range outside WA:** Southern Europe, the Mediterranean, the North Pacific, and in the Southern Hemisphere (NEMESIS 2023). In eastern Australia from Queensland to South Australia and Tasmania (Herdman 1899; Van Name 1945; AlIen & Wood 1950; Black 1971; Kott 1990, 1997; Furlani 1996; Currie et al. 1998; Keough & Ross 1999; CRIMP 2000; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023). **Habitat:** A fouling species that colonises hard structures, including mussel lines and impeding mussel growth. **WA literature records:** Kott (1985; 1990); Furlani (1996); CRIMP (1997a; 1997b; 2000); Campbell (2003b); McDonald (2004); Huisman et al. (2008); CSMC (2022). **Notes:** *Ciona intestinalis* (Linnaeus, 1767) was previously regarded as a widespread fouling species spread by shipping to all six of the occupied continents. Genetic work determined that there were in fact four species, with the species occurring in the southern hemisphere being confirmed as *C. robusta* by Brunetti et al. (2015). All published Australian records cited above use the original name of *C. intestinalis*, and ALA (2023) continues to use that name.

***Didemnum perlucidum* Monnoit, 1983**

Records in the Fremantle marine area: Cockburn Sound, Fremantle. **Vouchers:** None. **Range in WA:** Throughout WA from Esperance to the Kimberley. **Range outside WA:** Described from Guadeloupe in the Caribbean in 1983, the native range of the species is unknown. Following the original description, *D. perlucidum* was rapidly reported in a wide range of localities, including Brazil, West Africa, and the Indo-Pacific (NEMESIS 2023). In eastern Australia it is known from the Northern Territory and northern Queensland. **Habitat:** Occurs on a wide range of hard substrates, where it can rapidly overgrow other organisms. **WA literature records:** Smale & Childs (2012); Bridgwood et al. (2014); Muñoz et al. (2014; 2015); Dias et al. (2016; 2021); Simpson et al. (2016; 2017); CSMC (2022). **Notes:** *D. perlucidum* was first recorded in the Fremantle marine area in 2010 as part of a study of the community structure of organisms growing on test plates. Intensive research rapidly recorded the species throughout WA. Not listed as a species of concern by DAFF (2023). Considered to be noxious in the Montebello Marine Park by DPIRD (2016).

***Didemnum vexillum* Kott, 2002**

Records in the Fremantle marine area: Cockburn Sound. **Vouchers:** None. **Range in WA:** Cockburn Sound. **Range outside WA:** Native to Japan, introduced to Europe, North America and New Zealand (ALA 2023); not present in eastern Australia (NIMPIS 2023). **Habitat:** Attaches to hard structures, including aquaculture and port infrastructure and can become established on gravel surfaces (NIMPIS 2023). **WA literature records:** DPIRD (2023). **Notes:** First detected at HMAS Stirling at Garden Island in April 2021, the species spread to Henderson, where it was found in January 2023 (DPIRD 2023). It is currently subject to a level 2 incident (DPIRD 2023). Not listed as a species of concern by DAFF (2023). Considered to be noxious in any area of WA by DPIRD (2016).

***Styela plicata* (Lesueur, 1823)**

Records in the Fremantle marine area: Swan River, Owen Anchorage, Cockburn Sound**. Vouchers:** QM G9646. **Range in WA:** All areas of WA. **Range outside WA:** Native range unknown, cryptogenic in various widespread locations in the Mediterranean and. warmer parts the Pacific, Indian and Atlantic Oceans, introduced to Atlantic South America**;** all Australian coasts except the Northern Territory (Allen & Wood 1950; Kott 1952, 1985; Hutchings et al. 1987, 1989; Pollard & Hutchings 1990b; Furlani

1996; Currie et al. 1998; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; Torkkola et al. 2013; ALA 2023; NIMPIS 2023). **Habitat:** A solitary ascidian attached to hard substrates. **WA literature records:** Kott (1952; 1985); Hutchings et al. (1987); Pollard & Hutchings (1990b); Furlani (1996); CRIMP (1997a); Campbell (2003b); Wyatt et al. (2005); Huisman et al. (2008); Wells et al. (2009); ALA (2023); NIMPIS (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Styela clava* (Herdman, 1881)**

Records in the Fremantle marine area: Cockburn Sound. **Vouchers:** None. **Range in WA:** Albany, Cockburn Sound and Shark Bay. **Range outside WA:** Native to the northwest Pacific from Shanghai, China to the Bering Sea, introduced to both coasts of North America, Europe and New Zealand NEMESIS 2023) in eastern Australia from New South Wales, Victoria and Tasmania (Kott 1985; Pollard & Hutchings 1990b; Currie et al. 1998; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023; NIMPIS 2023). **Habitat:** A solitary ascidian with a long stalk. **WA literature records:** Kott (1985); Huisman et al. (2008); ALA (2023); NIMPIS (2023). **Notes:** Can affect aquaculture and native communities (NEMESIS 2023). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

8.1.9 Fish

***Acentrogobius pflaumii* (Bleeker, 1853)**

Records in the Fremantle marine area: Swan River; Owen Anchorage, Cockburn Sound. **Vouchers:** WAM P33852.002. **Range in WA:** Fremantle marine area. **Range outside WA:** Native to Japan, Korea and China, introduced to New Zealand; in eastern Australia from New South Wales and Victoria (Lockett & Gomon 1999, 2001; Cohen et al. 2001; Hewitt et al. 2004; ALA 2023). **Habitat:** Open soft silt substrate (Madden & Morrison 2011). **WA literature records:** Lockett & Gomon (1999); Mead-Hunter (2005); Huisman et al. (2008); Wells et al. (2009); Madden & Morrison (2011); CSMC (2022); Hogan-West K (2015); Hogan-West et al. (2019); ALA (2023). **Notes:** Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Sparidentex hasta* Valenciennes, 1830**
Not established in the Fremantle marine area

Records in the Fremantle marine area: Swan River. **Vouchers:** WAM 28437. **Range in WA:** Not established. **Range outside WA:** Arabian Sea, west coast of India, Persian Gulf (Pollard & Hutchings 1990a). **Habitat:** Free swimming in shallow water. **WA literature records:** Bodeker (1985); Harvey & Beard (1985); Anon. (1985); Hutchings et al. (1987); Pollard & Hutchings (1990a); Huisman et al. (2008). **Notes:** Bray (2023) states that only one individual has been collected in Australia, the WAM record. It is believed to have been introduced by ballast water from a vessel originating in the Persian Gulf. All literature references after Bodeker (1985) simply repeat the original record. The species is not listed by ALA (2023) or NIMPIS (2023). Not listed as a species of concern by DPIRD (2016) or DAFF (2023).

***Tridentiger trigonocephalus* (Gill, 1859)**

Records in the Fremantle marine area: Swan River, Fremantle Harbour, Cockburn Sound. **Vouchers:** WAM 26037; 27679; 27690. **Range in WA:** South coast and lower west coast to Fremantle. **Range outside WA:** Native to Japan, China and Korea, introduced to California; in eastern Australia from New South Wales to South Australia (Friese 1973; Hoese 1973; Bodeker 1985; Paxton & Hoese 1985; Hutchings et al. 1987; Pollard & Hutchings 1990a; Gomon et al. 1994; Furlani 1996; Lockett & Gomon 1999, 2001; Cohen et al. 2001; Hewitt et al. 2004; Wiltshire et al. 2010; ALA 2023; NIMPIS 2023). **Habitat:** Occurs in a variety of substrates, including seagrass; it is common around ports (Pollard & Hutchings 1990a; Lockett & Gomon 2001). **WA literature records:** Chubb et al. (1979); Bodeker (1985); Paxton & Hoese (1985); Pollard & Hutchings (1990a); Gomon et al. (1994); CRIMP (1997a; 2000); Lockett & Gomon (1999, 2001); Huisman et al. (2008); Wells et al. (2009); ALA (2023); NIMPIS (2023). **Notes:** Not listed as a species of concern by DAFF (2023). Considered to be noxious by DPIRD (2016) for any area of the State except the Port of Bunbury, the Port of Fremantle and the Swan River.

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