Marine Biosecurity Indicators

Port Phillip Bay Environmental Management Plan

August 2022

VICTORIA State Government

Energy, Environment and Climate Action

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A single Northern Pacific seastar, *Asteria amurensis* (Lutken, 1871) specimen as found in its natural surrounds. Source: Copyright notice: John Lewis, ES Link Services Pty Ltd. https://nimpis.marinepests.gov.au/species/species/105

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Contents

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List of Acronyms

APMPL	Australian Priority Marine Pest List
CCIMPE	Consultative Committee on Introduced Marine Pest Emergency
CM	Confidence Metric
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DJPR	Department of Jobs, Precincts and Regions
EMP	Port Phillip Bay Environmental Management Plan 2017-2027
HELCOM	Helsinki Commission, protection of Baltic marine environment
MACA	Marine and Coastal Act 2018
MACKF	Marine and Coastal Knowledge Framework
MERI	Monitoring, Evaluation, Reporting and Improvement strategy
NIS	Non-indigenous species
OSPAR	Oslo/Paris convention for the Protection of the Marine Environment of the North-East Atlantic
PPB	Port Phillip Bay

Acknowledgements

Dr Richard Stafford-Bell, Department of Jobs, Precincts and Regions (DJPR)

1. Purpose

This document has been created for the Port Phillip Bay (PPB) Environmental Management Plan 2017-2027 (EMP). It identifies an evaluation methodology for marine biosecurity that can be used for reporting and to drive continuous improvement in monitoring and management of marine life. That said, the approach described is relevant for other marine and coastal regions. The presented method is embedded within the Victoria's Marine and Coastal Knowledge Framework (MACKF), a recommended mechanism for addressing knowledge gaps, reducing uncertainties, and forming the future evidence base for assessing management interventions and environmental outcomes in PPB and Western Port. The method provides clear linkages between the MACKF's core pillars of "Outputs" and "Applications"; whereby data and information products are synthesised to support management and planning decisions, evaluation and reporting purposes.

2. Introduction

The EMP was authorised under the Marine and Coastal Act (MACA) 2018 and the State Environment Protection Policy (Waters) 2018. The MACA, section 55 (1) specifies environmental management plans must be reviewed within five years of making the plan.

The EMP's Monitoring, Evaluation, Reporting and Improvement strategy (MERI) will guide the five-yearly evaluation through an assessment of the effectiveness and efficiency of the EMP's strategies (Figure 1). As part of this, the EMP MERI will assess the effectiveness of the EMP in delivering on its overarching goal of 'The Bay's habitats and marine life are thriving', and priority area of 'Marine biosecurity'. Managing marine biosecurity is fundamental to the prosperity of all Victorians. Marine pests present a risk and can have a significant impact upon maritime industries, the marine environment, and the community.

VISION	A healthy Port Phillip Bay that is valued and cared for by all Victorians						
GOALS	Stewardship of the Bay is fostered across community, industry and government		Water quality is improved to ensure environmental health and community enjoyment of the Bay			The Bay s habitats and marine life are thriving	
PRIORITY AREAS	Connect and inspire	Empower action (work together)	Nutrients and pollutants	Litter	Pathogens (human health)	Habitat and marine life	Marine biosecurity
STRATEGIES	Improve appreciation and understanding of Bay values and connections to catchment	Improve collaboration and partnerships across community, industry and government	Ensure nutrient and sediment loads do not exceed current levels and pollutant loads are reduced where practicable	Reduce litter loads to the Bay	Minimise risks to human health from pathogens	Conserve and restore habitats and marine life	Manage risks from marine pests
PRIORITY ACTIONS	**1.1** Work with Aboriginal groups to improve understanding of Aboriginal cultural values and interests in the Bay and support connections to Country	**2.1** Build capacity and knowledge within community and industry networks	**3.1** Effectively maintain existing stormwater infrastructure and programs to mitigate loads to the Bay, or secure via equivalent means	**4.1** Establish a baseline estimate of the volume of litter entering the Bay and support clean up activities	**5.1** Improve understanding of links between pathogen concentrations and human health for swimming and consumption of shellfish	**6.1** Monitor indicator species and key habitats at priority locations	**7.1** Prevent introduction and dispersal of marine pests
	1.2 Develop and deliver programs to inspire greater appreciation of the Bay's values	**2.2** Empower the broader community to get more actively involved in caring for the Bay	**3.2** Prevent increases in nutrient loads from wastewater systems and where practicable reduce loads of other pollutants	**4.2** Support capability and capacity building programs that target litter prevention, including reduction of microplastics	**5.2** Adopt a risk-based approach to mitigate sources of pathogens found in the Bay	**6.2** Improve understanding of ecological processes, threats and pressures	**7.2** Monitor priority locations for early detection of marine pest introductions
	1.3 Build understanding of management responsibilities and programs for the Bay and its catchments	**2.3** Support stronger partnerships across community, industry and government to ensure aims and outcomes are aligned	**3.3** Ensure all urban and rural land use effectively controls impacts from stormwater and runoff, and that controls are in place to manage increases in loads	**4.3** Identify and prioritise litter sources and pathways, and take actions to prevent litter entering the Bay	**5.3** Improve monitoring and reporting to better detect and communicate human health risks from pathogens	**6.3** Improve overall extent and condition of the Bay's natural ecosystems	**7.3** Respond rapidly to new introductions of marine pests

Figure 1. The placement of the marine biosecurity priority area (teal box) under the broader goal of 'The Bay's habitats and marine life are thriving' and within the broader EMP framework.

There are currently 237 activities listed in the EMP's Delivery Plan. Of these 6 activities are delivering the marine biosecurity goal. To evaluate the effectiveness of this work and the state of the Bay in terms of marine biosecurity, the proposed outcome is to ensure non-indigenous species do not adversely alter the ecosystem. For PPB indicators and composite indicators (i.e., index) are proposed for evaluating marine biosecurity (Figure 2). Indexes enable simplified reporting on complex information for broad audiences (McIntosh et al 2019) and are used worldwide for reporting on environmental condition and management actions (Logan 2020).

3. Biosecurity indicators

3.1. Defining marine biosecurity species

Below are definitions to describe marine species relating to biosecurity indicators of PPB's EMP.

3.1.1. Non-indigenous species (NIS)

Non-indigenous species (NIS), which are also known as non-native, alien, or exotic organisms, are species introduced outside of their natural range or dispersal potential (Rotter et al. 2020). Natural changes to a species distribution range such as climate change, or ocean current dispersal does not qualify the species as a NIS. The introduction of these species is caused by human activities that are either intentional or unintentional (Jeschke et al. 2014). If a NIS subsequently reproduces and spreads within its new environment threatening the native biodiversity or causing economic damage, the species is defined as an invasive species or marine pest (Molnar et al. 2008). However, not all NIS become invasive (i.e., have the potential to cause negative impacts).

3.1.2. Marine pests

***'Marine pests are highly invasive, non-native animals and plants that can cause significant harm to Victoria's marine environment'* (DJPR 2022).**

Marine pests in our bays and waterways can adversely affect aquatic habitats, food chains, the ecosystem and our enjoyment of the marine environment. Specific effects include impacts on human heath, competition and predation of native species, damage to coastal areas and structures, restricted areas to ports, waterways and marinas, and the spread of diseases. The arrival of marine pests (or also known as invasive species) into Victoria from other parts of the world occur through a variety of avenues such as aquarium trade, larvae in ballast water, and attachment to ship hulls. Australia has over 400 introduced and cryptogenic (unknown origin) marine species, including plants, animals and algae, and PPB has confirmed records of at least 100 introduced and 61 cryptogenic marine pests, although some estimates put the number at more than 300.

3.1.3. Overabundant natives

In some cases, native species can cause pest-like environmental changes. Native species can become too numerous or 'overabundant', beyond sustainable levels, and cause negative impacts on the surrounding environment. Changes in native species biomass, particularly rapid increases, or phase-shift dynamics (Kriegisch et al. 2016), along with evidence of environmental damages to other native species and habitats can signify an overabundant marine species. Native species are only managed when a particular population threatens the survival of rare and threatened species or communities, becomes a significant contributor to environmental damage and habitat degradation, prevents habitat recovery or is itself suffering disease or poor health due to overcrowding or confinement. Currently no formal policy addresses the recognition of an overabundant native species, however such species may trigger an impact management plan and active interventions. For example, the rapid increases of the native purple sea urchin *Heliocidaris erythogramma* in PPB (Kriegisch et al. 2016; Carnell & Keough 2019) has correspondingly led to significant decreases in kelp cover and reef damage across major sites across PPB. While overabundant natives are recognised as an important environmental issue for PPB, they will be reported on in the Marine Biodiversity Index (MBI) and excluded from marine biosecurity reporting. The reason for their exclusion is due to 1) alignment with biosecurity reporting by other government agencies, and 2) the absence of formal processes to identify overabundant natives.

3.2. Overview of biosecurity indicators in Port Phillip Bay

The below diagram (Figure 2) illustrates the indicators used to examine marine biosecurity in PPB. These include 1) the number of arrivals of new non-indigenous species (NIS) in the Bay, and 2) the Marine Biosecurity Index (MBSI) which is a composite indictor comprising of information on species abundance, spatial distribution, and impacts. Such indicators and indices help managers determine the spread and threats of marine biosecurity species in PPB and hence the likely management actions to control their invasion and mitigate future damage.

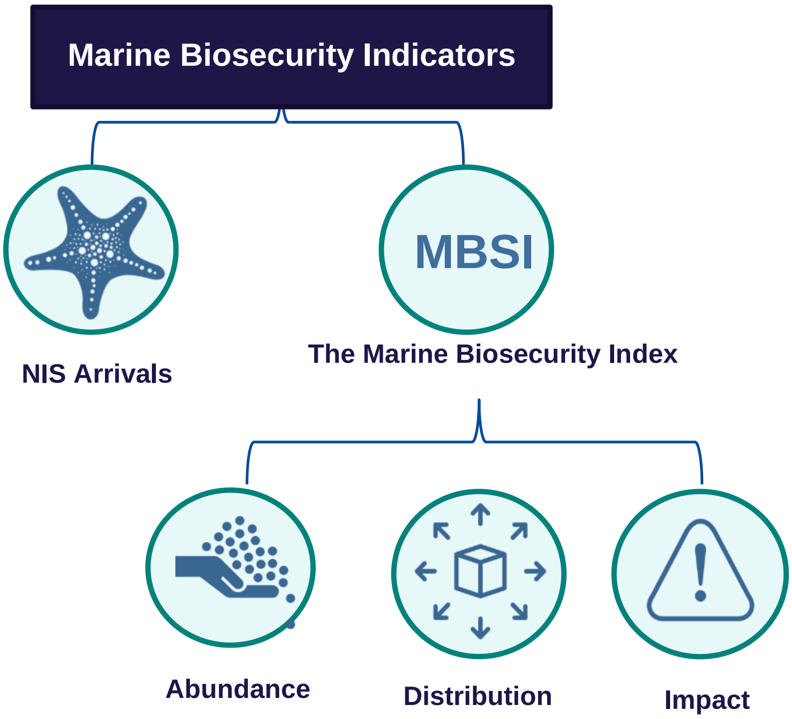

Figure 2. Diagram of the core biosecurity indicators used for the PPB EMP.

4. NIS Arrivals indicator

The first core indicator assesses the number of arrivals of new non-indigenous species (NIS) (primary introductions) in PPB across time. This indicator is widely used across the globe (Wilson et al. 2018); adopted by HELCOM (2018) for use in the Baltic Sea region, applied in the UK Marine Strategy (HM Government, 2012), recognised as a common indictor agreed by OSPAR in the North-East Atlantic (OSPAR Commission 2017), and achieving the European Commission Good Environmental Status for non-indigenous species (European Commission, 2010; Tsiamis et al. 2019).The objective is that there should be no primary introductions of NIS due to human activities during a 5-year assessment period (adapted from the Core Indicator Report; HELCOM 2018) and aligning with the EMP 5-yearly reporting framework and objectives. Hence, this indicator assesses the success of management actions to abate potential marine pest arrivals.

4.1. Calculating the NIS Arrivals indicator

This indicator reconstructs data from previous reported arrival events provided by the Department of Jobs, Precincts and Regions DJPR (Figure 3; see Appendix Table A1 for a list of species and sources) to monitor the rate of introduction of NIS and whether it has increased or decreased in recent decades. Reported arrivals are those that have been reported to occur in PPB and do not include those that may be attached to boat hulls on transient vessels. Not all introduced marine species become invasive (i.e., have the potential to cause negative impacts), but monitoring the arrival of NIS is an important step to help mitigate potentially invasive species that could pose threats and impacts on the surrounding environment (Hewitt et al. 2004; Tsiamis et al. 2019). Importantly, this indicator depends on the monitoring effort and early detection and documentation of NIS. Hence, the arrival of some species may have occurred earlier but were not reported or detected until a later date. The NIS arrivals indicator may be revised and updated due to receipt of new information on marine species arrival dates.

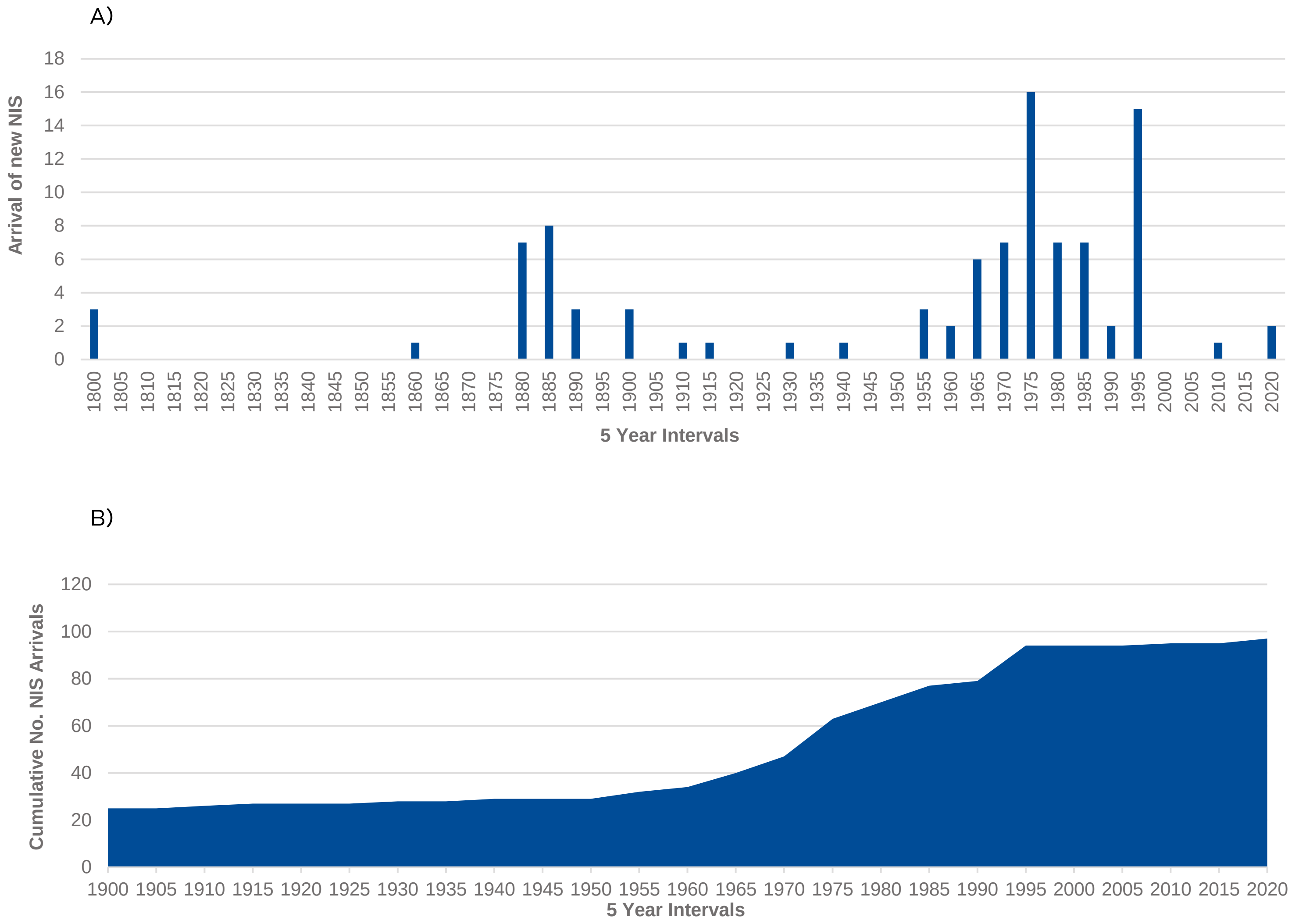

Figure 3. PPB arrival of new non-indigenous species (NIS), see Appendix Table A1 for full details. Some species were not included due to their unknown date of arrival in PPB.

4.2. Status assessment

To align with the EMP reporting framework, status categories for the NIS arrivals indicator in Table 1 have been developed in collaboration with DJSIR. The 'Very Good' category aligns with successful prevention and biosecurity mitigation of the arrival of NIS, compared to the 'Very Poor' category which reflects a state where many NIS have arrived, and biosecurity measures are ineffective.

Table 1. The five status categories use to report in the PPB EMP and the description relating to indicator 1. The indicator value in brackets is used to align with reporting across other PPB EMP themes where status is scored from 0 - 100.

Status Categories	NIS Arrivals Indicator
Very Good	Zero NIS arrivals during 5-year period (will be charted as a value of 90)
Good	1 NIS arrivals during 5-year period (will be charted as a value of 70)
Fair	2 NIS arrivals during 5-year period (will be charted as a value of 50)

Poor	3 or 4 NIS arrivals during 5-year period (will be charted as a value of 30)
Very Poor	≥5 NIS arrivals during 5-year period (will be charted as a value of 10)
Data Deficient	Not Assessed due to not enough data available to define a status

A 'Status trend' will also be reported. This will indicate if the 'NIS arrivals' indicator is improving (i.e., less arrivals are reported), is stable or is declining (i.e., more arrivals are reported) since the last 5-year assessment period.

4.3. Confidence assessment

A confidence status is integrated into the approach to evaluate the method and data that the indicator is derived from, also aligning with other reported themes of PPB's EMP. Confidence of the indicator to accurately represent the arrival of NIS is defined by DJSIR, where the confidence is categorised as high, intermediate, or low as per Table 2.

Table 2. Confidence status categories and their description in reporting indicator NIS Arrivals.

Confidence status	Description
High	Monitoring and reporting new NIS arrivals is frequent and consistent
Intermediate	Monitoring and reporting new NIS arrivals is regular
Low	Reporting new NSI arrivals is ad-hoc with no regular monitoring

5. The Marine Biosecurity Index (MBSI)

The Marine Biosecurity Index (MBSI) is a composite indicator which aims to integrate available information to assess NIS and determine marine biosecurity species of concern across PPB. The index adopts HELCOM's 'Biopollution level index' (Olenin et al. 2012), developed by Olenin et al. (2007) and applied by Zaiko et al. (2011). The Biopollution level index considers the adverse effects of NIS which lower environmental quality and are therefore termed "biopollution". This index has been endorsed by the European Union Marine Strategy Framework Directive as a practical method for assessing NIS and their potential to become invasive (Olenin et al. 2012). The index is based upon classification of the abundance and distribution range of NIS as well as their impacts on native communities, habitats, and ecosystem function. Given that only a small portion of NIS cause negative impacts on the surrounding environment the number of NIS alone cannot be a sufficient basis (i.e., Indicator 1). The MBSI enables monitoring changes across NIS to best understand the spread and damage that may be caused to the surrounding environment. It also offers a scientifically robust way to prioritise the threats among NIS (Zaiko et al. 2011).

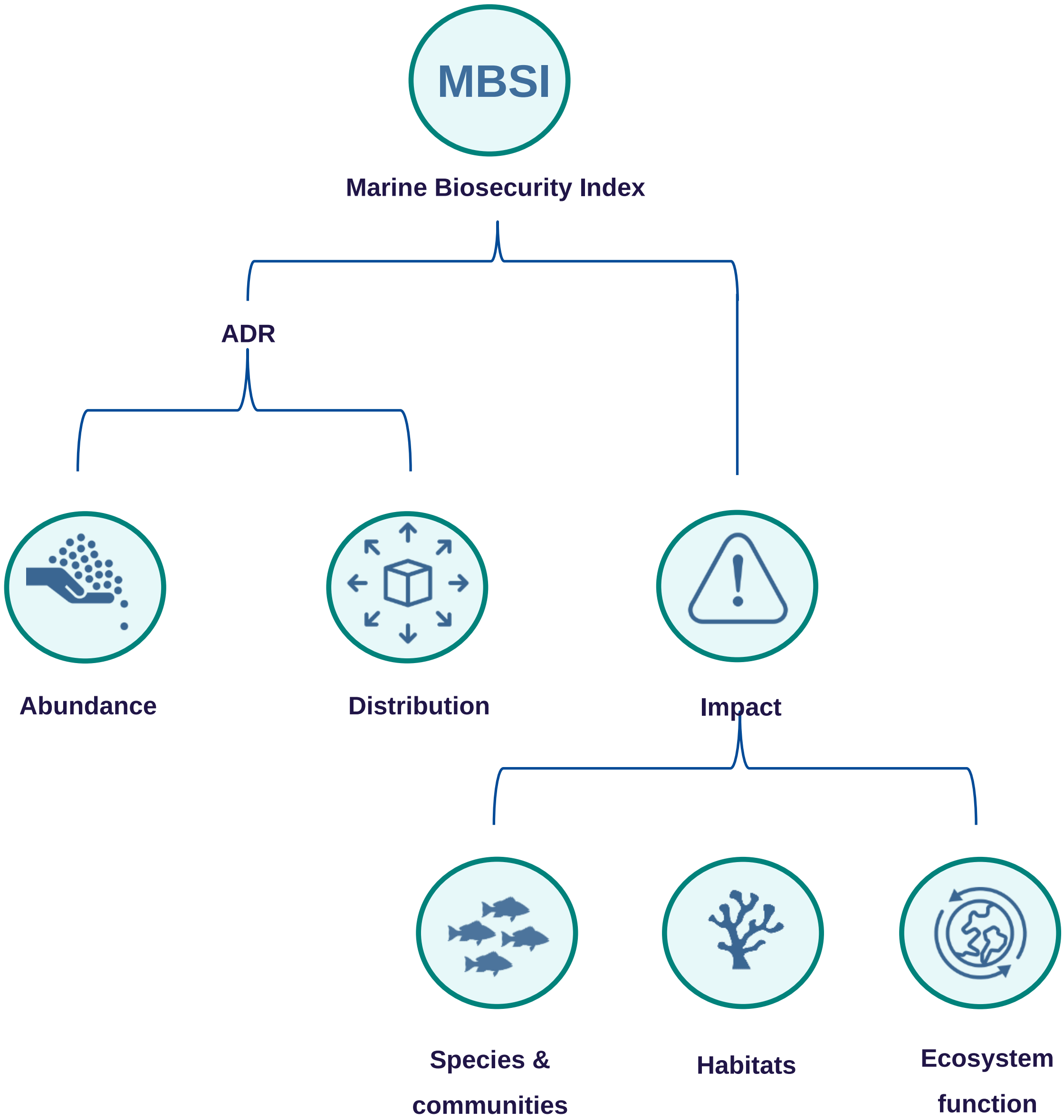

Figure 4. Diagram of the Marine Biosecurity Index (MBSI) and its components. Species abundance and distribution is combined into an Abundance Distribution Range (ADR), and environmental impacts are examined in three different categories: native species and communities, habitats, and ecosystem function. These indicators are all combined to provide an MBSI.

5.1. MBSI assessment units

One of the first steps of the MBSI is to determine the study area and assessment units. The division of PPB into five regions by Hewett et al. 2004 will be used for consistency with previous marine pest monitoring (Figure 5). These regions will be referred to as 'assessment units' as per Olenin et al. (2007).

A)

B)

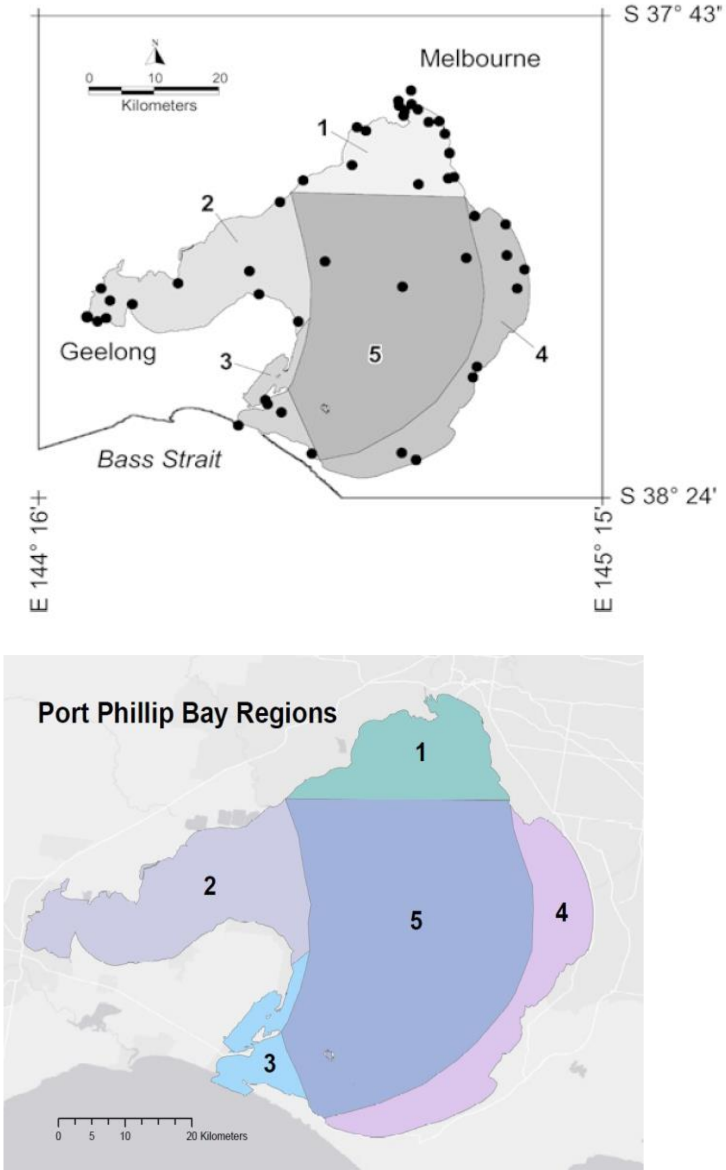

Figure 5. The five PPB assessment units used for the MBSI from Hewitt et al. 2004. A) Black circles represent the Centre for Research on Introduced Marine Pests (CRIMP) sampling stations. (Figure Credit: Hewitt et al. 2004), B) Five PPB assessment units represented in different colours.

5.2. MBSI assessment species

Australia has over 250 established NIS (Thresher, 1999), but few have displayed invasive or pest-like tendencies. In Port Phillip Bay, Victoria, which has two international shipping hubs, approximately 160 NIS have been found (Hewitt et al. 2004). The MBSI initially assesses 12 priority NIS found in Port Phillip Bay, recommended by DJSIR, and assessed in Victoria's regional ports monitoring program (Colin et al. 2021). These species comprise of listings under the Consultative Committee on Introduced Marine Pest Emergency (CCIMPE) trigger and watch lists, the Ballast water decision support system, as well as the Australian Priority Marine Pest List (APMPL). For more details on the 12 species see Appendix Figure A1.

Table 3. List of 12 NIS that are assessed in the MBSI

Common Name	Scientific Name
1. Asian Shore Crab	*Hemigrapsus sanguineus*
2. Dead Man's Fingers	*Codium fragile*
3. Wakame / Japanese Kelp*	*Undaria pinnatifida*
4. Northern Pacific Sea Star*	*Asterias amurensis*
5. European Clam	*Varicorbula gibba*
6. European Fan Worm	*Sabella spallanzanii*
7. Asian Bag Mussel	*Arcuatula senhousia*
8. Stalked Ascidian	*Styela clava*
9. Vase Tunicate	*Ciona intestinalis*
10. Pacific Oyster	*Magallana gigas*
11. Pleated Sea Squirt	*Styela plicata*
12. European Shore Crab*	*Carcinus maenas*

**Australian Priority Marine Pest List (APMPL).*

5.3. Calculating the MBSI

To derive the MBSI three indicator components (Figure 4) are integrated: 1) species relative abundance, 2) species distribution range and 3) the adverse impacts the species has on the environment. These three indicators are commonly reported as useful measures of biosecurity species (Catford et al. 2012; DEW 2018; Froese et al. 2021) and align with strategies from the 'Australian marine pest monitoring guidelines' as well as other methods that examine invasiveness and impacts of pests (DPI 2008; DAFF, 2010; National Land & Water Resources Audit and Invasive Animals Cooperative Research Centre 2008). A ranking method (Olenin et al. 2007; Zaiko et al. 2011) is used to calculate the MBSI of NIS across PPB's assessment units. The results of expert elicitation will be used to determine ranks for each indicator component and support the evaluation of NIS applying the MBSI method described below.

5.3.1. Abundance Distribution Range (ADR)

The scale of relative abundance and the scale of distribution range are combined, providing 12 possible combinations (Table 4) and a total of five classes (Table 5; Olenin et al. 2007). These Abundance Distribution Range (ADR) classes largely relate to the different stages of invasion (Figure 6; Table 4); arrival (Class A), establishment (Class B), expansion (Class C, Class D and in extreme cases Class E) and adjustment. In the later post-expansion phase, the ADR Class could vary between Class B and Class D, however, it is possible that a population may become reduced (Class A) or evolve to form a new outbreak (Class E). Where possible the ADR will be based upon available literature, reports and data such as abundance graphs and distribution maps, however expert evaluation will be used where data are unavailable.

Abundance: Species abundance (measured as the number of individuals, biomass, percent cover or density) is reported to be a useful surrogate for invasiveness, invasion level, or even for impact (Pearson et al. 2016; Fleming et al. 2017; DEW 2018; Wilson et al. 2018; O'Loughlin et al. 2019). Monitoring initiatives often examine changes in species abundance and hence provide a comparable indicator across different species. The units of abundance for a given species are ranked in relation to the abundance of its relevant ecological group (i.e., phytoplankton, macroalgae, zoobenthos, fish).

Distribution: The distribution rank provides an indication of the stage of spread a NIS has reached (DPI 2008). The distribution is assessed for a given spatial area, in this case assessment units of PPB (Figure 5). Available data on the current location of the biosecurity species in PPB are examined as well as potential habitat that exists for the species to further inhabit. The rank will represent the current proportion of habitat that the species inhabits in PPB versus the available habitat the species could potentially spread to.

Table 4. For a given NIS the relative abundance (low, moderate, and high) and distribution range (local, several localities, many localities, all localities) are ranked and combined, providing 12 possible combinations and a total of five classes (Table 4; Olenin et al. 2007).

Abundance	Distribution			
	Local *Found only in one place within the assessment unit (Figure 5)*	**Several localities** *Spread beyond one locality but present in less than half of the available localities*	**Many localities** *Extends to more than a half of the available localities*	**All localities** *All, or nearly all, available habitats are colonised*
Low *A species that makes up only a small part of the relevant community: i.e., when a population of an alien invertebrate forms a minor portion (few %) of the benthic macrofauna community*	**A**	**A**	**B**	**C**

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Moderate *A species constitutes less than a half of abundance of the native community*	**B**	**B**	**C**	**D**
High *If a species exceeds half, i.e., quantitatively dominates in the invaded community.*	**B**	**C**	**D**	**E**

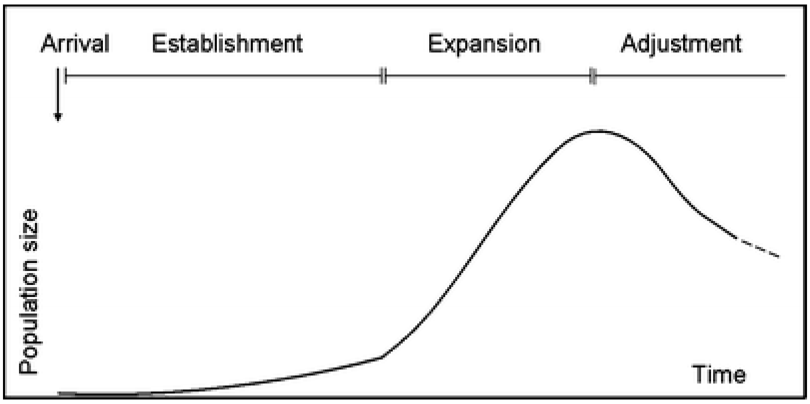


Figure 6. Stages of invasion during the introduction of invasive species (Credit: Reise et al., 2006).

Table 5. Five classes of the Abundance Distribution Range (ADR), which largely relate to the different stages of invasion (Figure 6; Table 4). Methods from Olenin et al. (2007).

ADR Class	Description
A	An NIS occurs in low numbers in one or several localities.
B	An NIS occurs in low numbers in many localities or in moderate numbers in one or more several localities or in high numbers in one locality
C	An NIS occurs in low numbers in all localities, or in moderate numbers in many localities, or in high numbers in several localities
D	An NIS occurs in moderate numbers in all localities or in high numbers in many localities
E	An NIS occurs in high numbers in all localities

5.3.2. Impacts

The MBSI assess three categories of impacts caused by NIS. These categories include impacts on native species and communities (C), impacts on habitats (H) and impacts on ecosystem functioning (E). For each NIS these three categories of impacts are scored from no-impact to massive impact (0 to 4; Table 6), and an impact code is reported. Impacts currently caused by NIS in PPB are derived from examining scientific literature, reports, data, documented evidence of impacts and expert evaluation.

Table 6. Categories of impacts caused by NIS from Olenin et al. (2007). A code is selected for each impact type, communities (C0 to C4), habitat (H0 to H4), and ecosystem functioning (E0 to E4). For assessment units see Figure 5.

Impact type	Code	Impact	Description
Native species & communities	C0	None	No displacement of native species, although NIS may be present. Ranking of native species according to quantitative parameters in the community remains unchanged. Type-specific communities are present.
	C1	Weak	Local displacement of native species, but no extinction. Change in ranking of native species, but dominant species remain the same. Type-specific communities are present.
	C2	Moderate	Large scale displacement of native species causes decline in abundance and reduction of their distribution range within the assessment unit; and/or type-specific communities are changed noticeably due to shifts in community dominant species.
	C3	Strong	Population extinctions within the ecosystem. Former community dominant species still present but their relative abundance is severely reduced; alien species are dominant. Loss of type-specific community within an ecological group.
	C4	Massive	Population extinction of native keystone species. Extinction of type-specific communities occurs within more than one ecological group.
Habitats	H0	None	No habitat alteration.
	H1	Weak	Alteration of a habitat(s), but no reduction of spatial extent of a habitat(s).
	H2	Moderate	Alteration and reduction of spatial extent of a habitat(s).
	H3	Strong	Alteration of a key habitat, severe reduction of spatial extent of habitat(s); loss of habitat(s) within a small area of the assessment unit.
	H4	Massive	Loss of habitats in most or the entire assessment unit, loss of a key habitat.
Ecosystem functioning	E0	None	No measurable effect.
	E1	Weak	Measurable, but weak changes with no loss or addition of new ecosystem function(s).
	E2	Moderate	Moderate modification of ecosystem performance and/or addition of a new, or reduction of existing, functional group(s) in part of the assessment unit.

	E3	Strong	Severe shifts in ecosystem functioning in part of the assessment unit. Reorganisation of the food web because of addition or reduction of functional groups within trophic levels.
	E4	Massive	Extreme, ecosystem-wide shift in the food web and/or loss of the role of a functional group(s).

5.3.3. MBSI

Once all components above have been scored a resulting MBSI can be achieved. The MBSI is obtained by combining the ADR class (Table 4; Table 5) along with the three impact magnitude scores (Table 6) following the matrix in Table 7. Three values are obtained from Table 6, with 50 possible combinations (see Olenin et al. 2007 for an explanation of the 25 highly unlikely cases which are removed from the matrix). The MBSI is determined by the greatest impact level (i.e., highest value from matrix in Table 7), as described by Olenin et al. 2007.The diagram in Figure 7 provides a general decision framework of the steps involved in deriving the MBSI. The MBSI assessment is performed for each NIS in the assessment unit (Figure 5), and for a given time period. The first assessment will provide a baseline assessment (as undertaken in Olenin et al. 2007) to summarise all existing information on NIS and evaluate the MBSI level across units of PPB. A subsequent management assessment will follow on a 5-year basis to reveal changes in the MBSI across PPB since the baseline assessment.

Table 7. Matrix of 50 possible situations that combine the Abundance Distribution Range (ADR) and the impact (magnitude) categories. Three values are obtained for each NIS and the highest value is used to determine the MBSI following Figure 7.

		Impact														
		Species & Communities					Habitat Function					Ecosystem Function				
		C0	C1	C2	C3	C4	H0	H1	H2	H3	H4	E0	E1	E2	E3	E4
ADR	A	1	2				1	2				1	2			
	B	2	2	3			2	2	3	4		2	2	3		
	C	2	2	3			2	3	3	4	5	2	3	3		
	D		3	3	4	5		3	4	4	5		3	3	4	5
	E			4	4	5		3	4	4	5		3	4	4	5

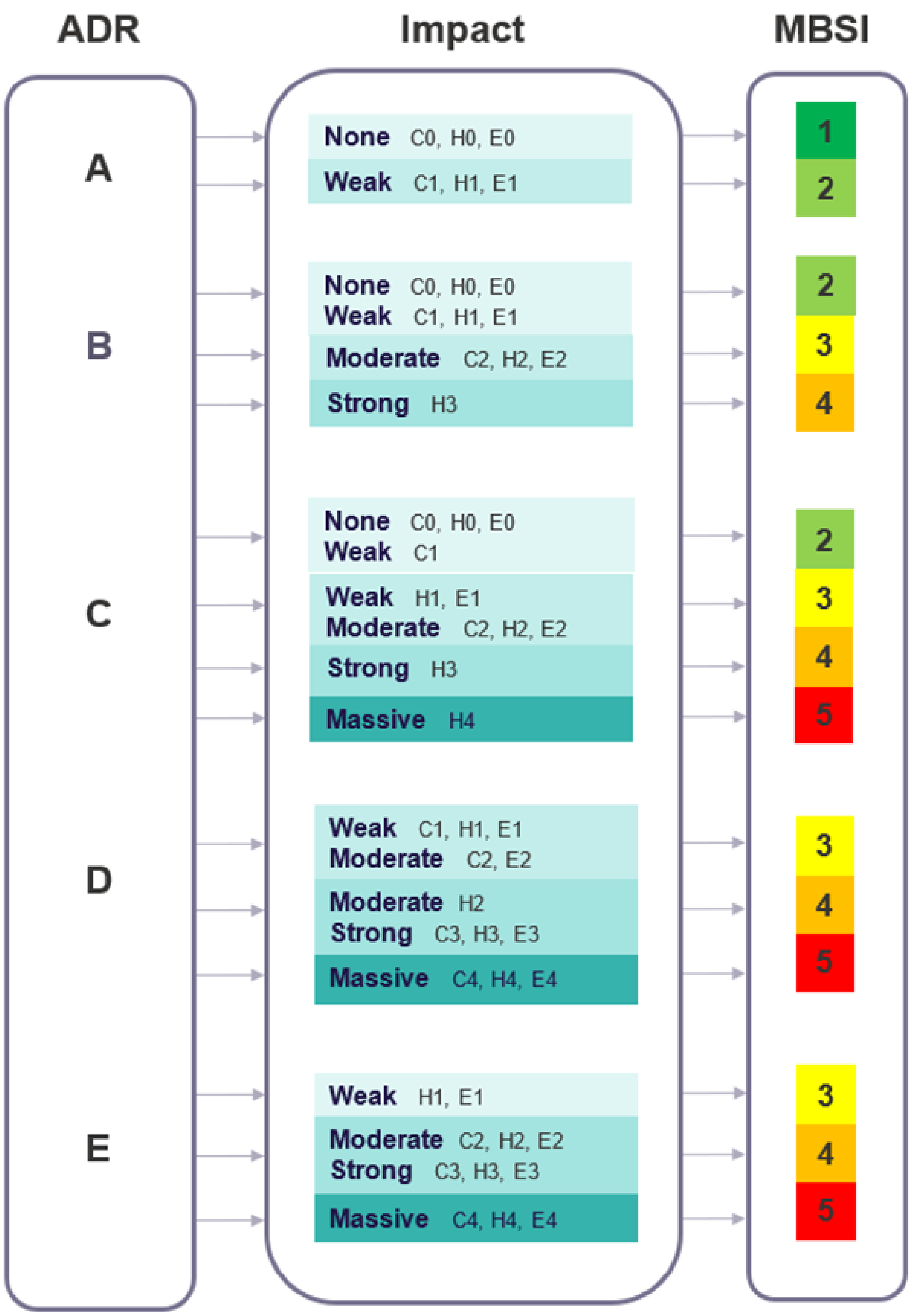


Figure 7. Diagram of the general decision framework for deriving the MBSI (figure adapted from Olenin et al. 2007). First, the Abundance Distribution Range (ADR) is scored (Table 4; Table 5), Impact is calculated in three categories (Table 5), and a final MBSI is achieved (Table 8).

5.4. Status assessment

To align with the EMP reporting framework, status categories for the MBSI are outlined in Table 8. The 'Very Good' category (MBSI = 1) aligns with successful marine pest mitigation in PPB or very low levels with no impacts, compared to the 'Very Poor' category (MBSI = 5) which indicates NIS are widespread with high impacts and of great concern in PPB. The MBSI will be reported on for each NIS within each assessment unit of PPB (Figure 5). Summary values will be calculated to report on 1) NIS – average MBSI across all PPB assessment units for each NIS assessed 2) PPB assessment units – average MBSI across all NIS for each assessment unit, 3) PPB – average MBSI across all NIS and all assessment units.

Table 8. The five status categories use to report in the PPB EMP and the description relating to the MBSI. The status if comprised of the abundance distribution range ADR and impact scores following the decisions framework in Figure 7. The indicator value in brackets is used to align with reporting across other PPB EMP themes where status is scored from 0 - 100.

Status categories	Marine Biosecurity Index (MBSI)
Very Good	MBSI = 1 (will be charted as a value of 90)
Good	MBSI = 2 (will be charted as a value of 70)
Fair	MBSI = 3 (will be charted as a value of 50)
Poor	MBSI = 4 (will be charted as a value of 30)
Very Poor	MBSI = 5 (will be charted as a value of 10)
Data Deficient	Not Assessed due to not enough data available to define a status

A 'Status Trend' will also be reported. This will indicate if the MBSI indicator is improving (i.e., the MBSI Status is increasing), is stable or is declining (i.e., the MBSI Status is decreasing) since the last assessment. For the first assessment, which is the baseline assessment, a trend will not be reported.

5.5. Confidence assessment

A parallel confidence assessment is integrated into the approach to evaluate the underlying data that the MBSI is derived, also aligning with other reported themes of PPB's EMP. Confidence of each indicator is measured in three ways to include the abundance trend (ConfA), distribution ratio (ConfD), and impact score (ConfI) as outlined in Table 9. Confidence metrics are defined by consulted experts, where confidence metric components are categorised as high, intermediate, or low, and thereafter assigned categorical values (1, 0.5 and 0, respectively).

Table 9. Confidence Metric (CM) components and their classification within the high, intermediate, and low categories.

Confidence Metric (CM) components		High (value = 1)	Intermediate (value = 0.5)	Low (value = 0)
ConfA	Confidence in the assessment based on the **abundance**	Abundance data are consistent and of high scientific quality. Data were available across the reporting period.	Abundance data are available for more than half of the assessment period years. Monitoring methods and data are of mixed methods and sources with moderate scientific quality and guidance by expert opinion.	Abundance data are scare, methods and data (not quality assured) are low quality. Expert opinion is relied upon.
ConfD	Confidence in the assessment based on the **distribution**	The distribution ratio was calculated from modelled or mapped distribution ranges	The distribution ratio was determined by a combination of maps/spatial data and expert opinion	The distribution ratio was determined by expert opinion with little to no spatial data
ConfI	Confidence in the assessment based on the **impact score**	The impact scores are derived from reported scientific studies and/or reported quantitative evidence.	The impact score was developed with a combination of scientific literature and reports, as well as expert opinion.	The impact score was determined solely by expert opinion.

Confidence Metric (CM) components are then combined into an overall Confidence Metric (CM):

Confidence Metric (CM) = (1/3*ConfA) + (1/3*ConfD) + (1/3*ConfI)

An overall CM is calculated for each indicator by equally weighting the confidence metric components and summing these to produce a value between 0 and 1. Confidence status is defined by the CM value as per Table 10.

Table 10. Confidence Status as determine by the Confidence Metric (CM) value

Confidence status	CM Value
High	> 0.75
Intermediate	0.5 - 0.75
Low	< 0.5

5.6. Management assessment

Eradicating marine pest incursions is very challenging and difficult to achieve (Wittenberg & Cock 2001; Arthur et al. 2015). For the great majority of marine pest cases, eradication will likely remain impossible (Arthur et al. 2015). However, key features of some successful eradications have been where species have been detected in small (less than 1 ha), isolated populations in relatively contained areas (Wittenberg & Cock 2001). Another way of expressing plausible management strategies to undertake is by examining the relative position of the species on its invasion curve (Figure 8; Agriculture Victoria, 2021; Invasive species council 2021). Therefore, species which are widespread, and eradication is not possible, may require asset-based protection. The MBSI Status is reported along with the appropriate management category: Prevention, Eradication, Containment and Asset-based Protection. This assessment provides important context around the potential management actions and strategies that can be achieved for a species.

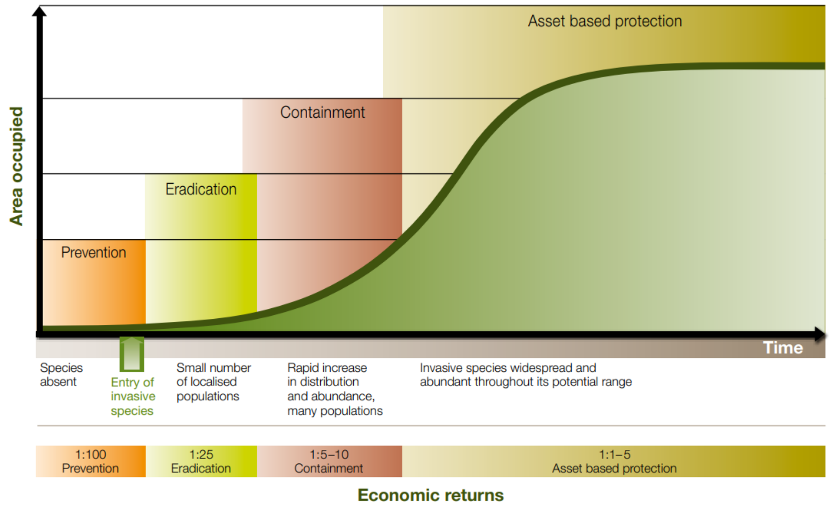
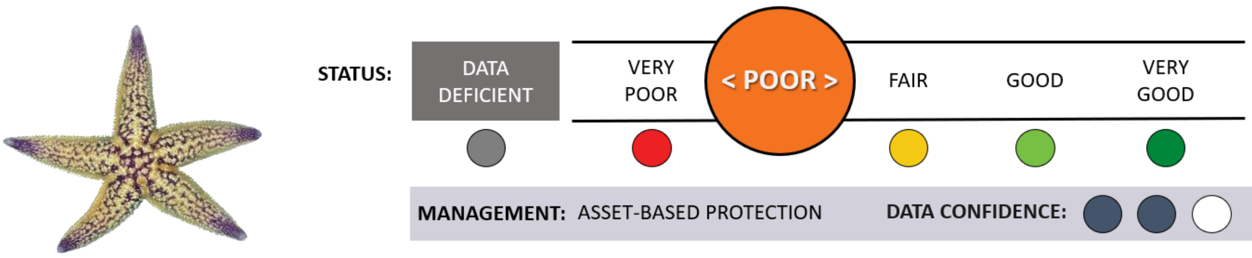


Figure 8. The invasion curve describes the arrival and spread of a new invasive species and the management actions required at each stage (i.e., prevention, eradication, containment, asset-based protection). The diminishing economic return on biosecurity investment is shown alongside the invasion time axis (Agriculture Victoria, 2021; Invasive species council 2021).

5.7. Worked example of the MBSI

This is a worked example of calculating the MBSI for the Northern Pacific seastar *Asterias amurensis*. In this example, experts have not been consulted and scores and calculations are estimated from the below data. When undertaking the MBSI, subject matter experts will evaluate each biosecurity species. The below example provides a simple illustration of the type of data and information that could be used to derive the MBSI Status, Confidence Status and Management Category (Figure 9). Note that this example has been applied to the whole of PPB, whereas for actual reporting PPB assessment units (Figure 5) will be applied.



OFFICIAL

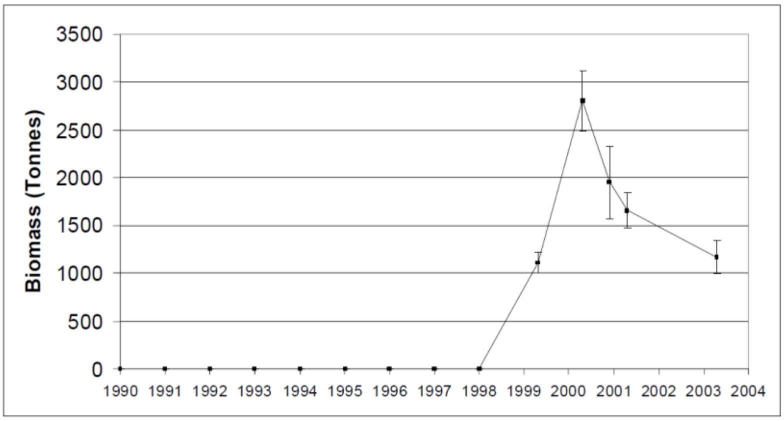
Assessment species	Northern Pacific seastar *Asterias amurensis* (Lutken, 1871)
First identified in PPB	1995 (O'Hara 1995)
Data sources	Parry and Cohen (2001); Parry et al. 2004; Parry and Hirst 2016
ADR	D
Impact scores	C3, H2, E2
MBSI status	4 = Poor
Status trend	(NA for baseline assessment)
Confidence status	Intermediate
Management category	Asset-based protection

Figure 9. Northern Pacific seastar (photo credit: Commonwealth Scientific and Industrial Research Organisation (CSIRO) and summary table for the MBSI status, status trend, confidence status, and management category.

ADR = D

The ADR for the Northern Pacific seastar was classed "D" - *an NIS occurs in moderate numbers in all localities* (Table 3; Table 4). The abundance level 'moderate' is based upon field sampling undertaken between 1990 to 2011 by scollop dredge and trawl catches in sites across PPB (Parry and Cohen 2001; Parry et al. 2004; Parry and Hirst 2016; Figure 10). *Asterias amurensis* was first detected in 1995 with rapid increases in biomass in 2000 to ~2800 tonnes, abundance was 165 million (Parry and Cohen 2001; Parry et al. 2004). However, the abundance of the seastar has decreased since 2000, with detected decrease to 36 million and biomass to 1200 tonnes by 2003. This detected decrease has been suggested to be due to benthic resources, specifically the decline in food availability (bivalves) which have limited the *A. amurensis* population growth. Population densities overseas have generally subsided following major outbreaks. In comparison, densities in Australia are often reported at more than seven seastars per m^2 in areas where there is an abundant supply of food (i.e., around wharf piles, shellfish beds and shellfish aquaculture facilities; DSE 2001). The available data indicates an established population that has spread rapidly during the first years of arrival, resources have now limited its rapid spread, however the risk and potential invasiveness in the future remains with abundance data supporting a current stable trend.

a)



b)

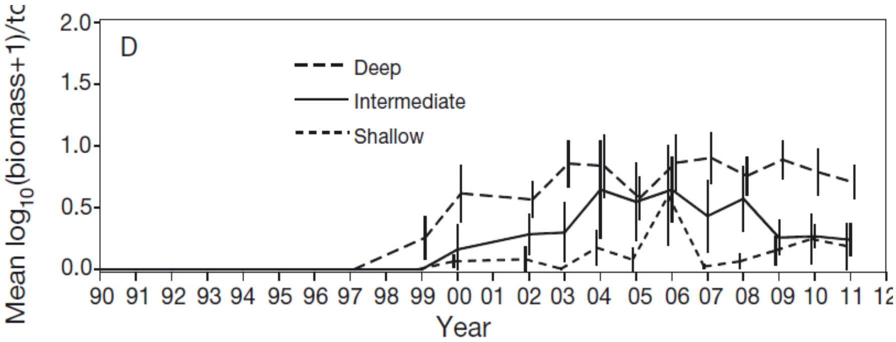


Figure 10. Abundance time-series data to support the abundance trend. **a)** Changes in biomass of *A. amurensis* between 1990 and 2003. Field surveys were performed with a scallop dredge across 12 sites in PPB. Error bars are std errors. The first spawning occurred in 1997 (Figure Credit: Parry et al. 2004). **b)** Index of abundance for *A. amurensis* based on trawl catches, for 3 regions of PPB between 1990 and 2011 (Figure Credit: Parry and Hirst 2016).

The distribution has been estimated from the below map (Figure 11) and classed as 'all localities' (All, or nearly all, available habitats are colonised; Table 3). The seastar infestation has remained in the north-east of the Bay in waters deeper than 15m. The seastar's absence in shallow water has been hypothesised to be related to the competition of the native seastar *Coscinasterias muricata* (Parry and Cohen 2001). The initial spread of the seastar was achieved by water movement influencing the spread of larvae (Parry et al. 2004). The low density and infestation of *A. amurensis* in Corio Bay is poorly understood, however potentially linked to the limiting exchange of water flow to the rest of the Bay and subsequent supply of larvae, or similarly the competition with the native seastar species in this area (Parry et al. 2004; Parry 2017).

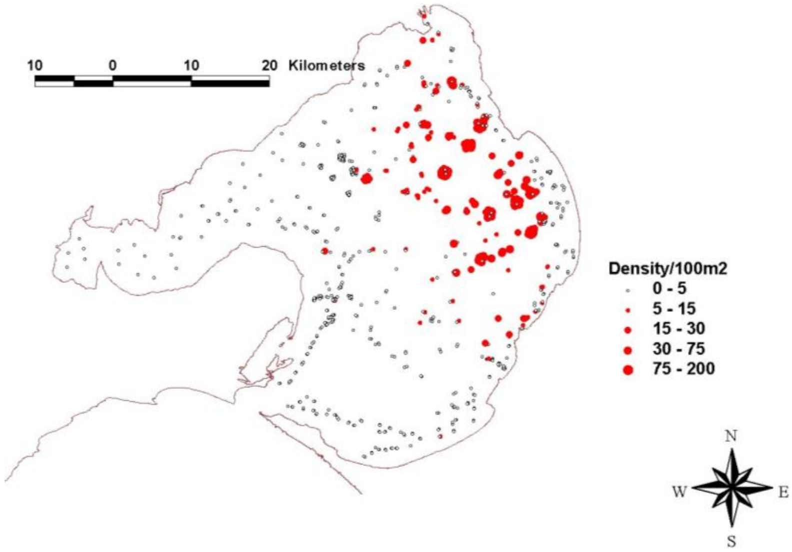


Figure 11. Distribution and density of *A. amurensis* between 1990 and 2003 in PPB (Figure Credit: Parry et al. 2004).

Impact scores = C3, H2, E2

The impact scores for *Asterias amurensis* were based upon several sources, the Marine Pest Sectoral Committee (2020), *Rapid response manual for 'Asterias amurensis'* which provide an absence and presence of the impacts to investigate, combined with expert evaluation to further rank the impact in the context of PPB. *Asterias amurensis* is a generalist, voracious predator that can severely alter benthic assemblages by consuming a large variety and quantity of bivalve species. *A. amurensis* can alter food webs and reduce the abundance of native species (Marine Pest Sectoral Committee 2020).

MBSI status = Poor (4)

The resulting ADR (D) and Impacts scores (C3, H2, E2) are used in the decision framework (Figure 7), resulting in an MBSI status of 4 or Poor (Table 7).

Confidence status = Intermediate (0.67)

The confidence values are input into the weighted CM equation.

Confidence Metric (CM) = (1/3*0.5) + (1/3*0.5) + (1/3*1).

Management category = Asset-based protection

The northern Pacific seastar is widely distributed and established in PPB. The current management category is therefore asset-based protection. Earthcare St Kilda has been removing Northern Pacific seastars by hand from the seagrass beds in St Kilda Harbour since 2008. This activity has expanded to include removal at Brighton Sea Baths, starting in 2012.

6. Applications

6.1 Reporting

The PPB Marine Biosecurity indicators presented in this report will be incorporated into the EMP Experience Builder platform. The NIS Arrivals indicator will be presented with a time-series chart and status bar, and the MBSI will be reported for each PPB assessment unit as well as for each NIS along with a status bar and a map (regions coloured by their status). The MBSI provides synthesised semi-quantitative evidence to depict the status and management stage of marine biosecurity species across PPB. While many of the species assessed are likely to be already established in PPB, the MBSI approach is most useful for monitoring changes in biosecurity species as well as prioritising established species (based upon the MBSI Status) for asset-based protection (section 5.3). This approach can also be applied and adopted in other areas across Victoria. The reporting frequency will be limited by ongoing monitoring and data; however, updates will be assessed on a 5-yearly basis. For the MBSI updates will include a management assessment and comparisons to the baseline assessment (first assessment).

6.2 Limitations and improvements

Limitations are inherent in biological datasets. There are data gaps, inconsistent or an absence of monitoring data across time and in some cases inconsistency in survey methods and survey effort. The presented indicators aim to compile and standardise quantitative information where possible to support the assessment of PPB's biosecurity and report on its status. The indicators are limited in its ability to assess and determine appropriate management actions for biosecurity. However, they aim to build quantitative evidence to help monitor and highlight the status of potential marine pests and marine biosecurity species of concern which helps direct further research and investigation into priority biosecurity species. Limitations in the approach includes an absence of population models, growth rates, spatial distribution models and predictions of suitable habitat, as well as the reliance upon consulted experts to score impacts and evaluate missing data and knowledge gaps. Future expansion of the MBSI to address specific management actions and questions may be possible with improved data on abundance, distribution, impacts and cost benefit analysis of management actions.

7. Conclusion

The biosecurity indicators in this report will enable efficient reporting and evaluation of the delivery of the EMP's goal (to conserve and restore habitats and marine life; Figure 1). The method and its outputs are embedded into the Victoria's MACKF, supporting the need for forming the future evidence base for assessing management interventions and environmental outcomes. It will help support informed decision-making to ensure a purposeful and systematic approach is taken to assessing marine biosecurity species. While developed for the EMP, the methods can be applied in other environmental management settings and applied more widely across the Victorian coast or other priority marine regions. The indicators support the *Marine Pest Plan 2018–2023* Australia's national strategic plan for marine pest biosecurity by providing assessments to assist management of the risks posed by marine pests and minimising their potential harm to marine industries, communities and the environment (Department of Agriculture and Water Resources 2018).

It is recommended that the NIS Arrival indicator and MBSI be adopted for ongoing use in evaluation of the EMP, and the results for the first MERI evaluation be used as a benchmark to identify marine biosecurity priorities in PPB and set targets for the future.

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9. Appendix

Table A1. List of NIS arrivals in PPB and associated details.

Scientific name	Common name	Detection year	Known distribution	Presumed origin	Vectors	Source
Acanthogobius flavimanus	Yelowfin goby	1/01/1990		NW Pacific	hull fouling, ballast water	Parry et al.1995; Hewitt et al. 2004
Acentrogobius pflaumi	Striped sand goby	1/01/1996		NW Pacific	hull fouling, ballast water	Lockett and Gomon 1999; Hewitt et al. 2004
Aetea anguina	Snake head coralline	1/01/1887		Cosmopolitan	hull fouling	MacGillivray 1887, Hewitt et al. 2004
Alexandrium catenella	Toxic dinoflagellate	1/01/1988		Cosmopolitan	ballast water	Hallegraeff et al. 1988, Hewitt et al. 2004
Alitta succinea (Neanthes succinea)	Pile worm	1/01/1978		NE Atlantic	hull fouling; mariculture; ballast water	Wilson 1984, Hewitt et al. 2004
Amathia distans	Bryozoan	Unknown		Cosmopolitan	hull fouling	Campbell and Hewitt 1999b, Hewitt et al. 2004
Amathia spp. (Bowerbankia)	Bryozoan	1/01/1977		Cosmopolitan	hull fouling	Russ 1977, Hewitt et al. 2004
Amathia verticillata (Zoobotryon verticillatum)	Bryozoan	Unknown		Cosmopolitan	hull fouling	Russ and Wake 1975, Hewitt et al. 2004
Amphibalanus amphitrite	Acorn barnacle	Unknown		Cosmopolitan	hull fouling, ballast water	see Keough and Ross 1999
Amphisbetia operculata	Wiry hydroid	1/01/1884		Cosmopolitan	hull fouling; mariculture; ballast water	Bale 1884, Hewitt et al. 2004
Antennella secundaria	Sessile hydrozoan	1/01/1910		Cosmopolitan	hull fouling; mariculture; ballast water	Mulder and Trebilcock 1910, Hewitt et al. 2004

Antithamnionella spirographidis	Red alga	1/01/1976		Mediterranean	hull fouling	Lewis 1977, MELUa, Hewitt et al. 2004
Aplysilla rosea	Sponge	1/01/1981		Mediterranean,	hull fouling; mariculture	Weidenmayer 1989
Aplysiopsis formosa	Beautiful formosa	1/01/1994		NE, NW and S Atlantic	ballast water	Harris et al. 1996; Hewitt et al. 2004
Arcuatula senhousia	Asian bag mussel	1/01/1980	Corio Bay	NW Atlantic	hull fouling; mariculture; ballast water	Coleman 1993
Ascidiella aspersa	European sea squirt	Unknown		Baltic Sea	hull fouling	Kott 1985; Hewitt et al. 2004
Asperococcus compressus	Brown alga	1/01/1976		NE and NW Atlantic	hull fouling	Kraft 1976, MELUa, Hewitt et al. 2004
Asterias amurensis	Northern pacific seastar	1/01/1995	Bay wide	NW Pacific	hull fouling; mariculture; ballast water	O'Hara 1995
Boccardia proboscidea	Tube worm	1/01/1978		NE and NW Pacific	mariculture; ballast water	Blake and Kudenov 1978; Hewitt et al. 2004
Botryella micromora (Sorocarpus micromorus)	Brown alga	1/01/1970	Mornington	NE and NW Atlantic	hull fouling	Clayton 1970, MELUa; Hewitt et al. 2004
Botrylloides leachii	Sea squirt	1/01/1901		Baltic Sea	hull fouling; mariculture	MV collections; Hewitt et al. 2004
Botryllus schlosseri	Star tunicate	1/01/1977		NE Atlantic	hull fouling; mariculture	Russ 1977; Hewitt et al. 2004
Bougainvillia muscus (ramosa)	Cnidarian, Hydroid, jellyfish	1/01/1971		Cosmopolitan NE Atlantic	hull fouling; mariculture; ballast water	Southcott 1971; Hewitt et al. 2004
Bugulina flabellata (Bugula flabellata)	Bryozoan	1/01/1982		NE Atlantic	hull fouling	Holmes 1982, Hewitt et al. 2004
Bugulina neritina	Bryozoan	1/01/1881		NE Atlantic	hull fouling	MacGillivray 1881; Hewitt et al. 2004
Bugulina simplex	Bryozoan	1/01/1982		NE Atlantic, Australia, New Zealand, NE Pacific	hull fouling	Holmes 1982; MacGillivray 1881; Hewitt et al. 2004

Bugulina stolonifera	Bryozoan	1/01/1880		NE Atlantic, Australia, New Zealand, Mediterranean and Baltic	hull fouling	MacGillivray 1880's; Hewitt et al. 2004
Bugulina calathus (Bugula)	Colonial arborescent bryozoa	1/01/1978		NE Atlantic, Mediterranean	hull fouling	Watson 1978
Carcinus maenas	European shore crab	1/01/1800		Baltic Sea	hull fouling; SDB; ballast water	Uncertain; Campbell and Hewitt 1999b; Hewitt et al. 2004
Celleporaria albirostris	Bryozoan	1/01/1888		NW Atlantic; Wider Caribbean	hull fouling	MacGillivray 1888; Hewitt et al. 2004
Celleporella hyalina	Bryozoan	1/01/1889		NE, NW, South Atlantic, NE, NW, South & SE Pacific	hull fouling	MacGillivray 1889; Hewitt et al. 2004
Chondria arcuata	Red alga	1/01/1975		NE and NW Pacific	hull fouling	Kraft 1975, MELUa, Hewitt et al. 2004
Ciona intestinalis	Vase tunicate	1/01/1958	Widesprea d	NE and NW Atlantic	hull fouling; mariculture; ballast water	Miller 1966, Hewitt et al. 2004
Cirolana harfordi	Harford's isopod	1/01/1996		NE Pacific	mariculture; ballast water	Campbell and Hewitt 1999b; Hewitt et al. 2004
Cladophora prolifera	Green alga	1/01/1964		Mediterranean	hull fouling	Ducker 1964, MELUa, Hewitt et al. 2004
Clavelina lepadiformis	Lightbulb sea squirt	27/01/2021	Blairgowrie, Mornington			DJPR
Clytia hemisphaerica	Cnidarian, Hydroid, jellyfish	1/01/1980		Cosmopolitan	hull fouling; mariculture; ballast water	Watson 1999; Hewitt et al. 2004
Clytia paulensis	Cnidarian, Hydroid, jellyfish	1/01/1985		E Africa, NE Atlantic, NW Atlantic	hull fouling; mariculture; ballast water	Watson 1999; Hewitt et al. 2004
Codium fragile subsp fragile	Dead man's finger/oyster thief	1/01/1997	Northern	NE and NW Atlantic	hull fouling	Parry 1997, MELUa, Hewitt et al. 2004
Conopeum reticulum	Bryozoan	1/01/1879		Cosmopolitan	hull fouling; ballast water	MacGillivray 1879, Hewitt et al. 2004

Conopeum seurati	Bryozoan	Unknown		Mediterranean and NE Atlantic	hull fouling; ballast water	Gordon and Mawatari 1992
Coryne eximia (Sarsia eximia)	Athecate hydroid	1/01/1884		Cosmopolitan	hull fouling; mariculture; ballast water	von Lendenfeld 1884
Cryptosula pallasiana	Bryozoan	1/01/1800	1800*	NE and NW Atlantic; Cosmopolitan	hull fouling	MV collections, Hewitt et al. 2004
Cyclicopora longipora	Bryozoan	Unknown		NE Pacific	hull fouling	MacGillivray 1883
Deucalion levringii	Red alga	1/01/1975		S Pacific	hull fouling	Kraft et al. 1975, MELUa, Hewitt et al. 2004
Dysidea avara	Pink sponge	1/01/1889		Mediterranean, NE and SE Pacific	hull fouling; mariculture	von Lendenfeld 1889
Dysidea fragilis	Brittle horny sponge	1/01/1996		Arctic, NE Atlantic and Mediterranean	hull fouling; mariculture	Bergquist (unpublished); Campbell and Hewitt 1999b
Ectopleura crocea	Pink-hearted hydroid	1/01/1884		NE Atlantic	hull fouling; mariculture	Bale 1884, Hewitt et al. 2004
Electra pilosa	Bryozoan	1/01/1860			hull fouling; ballast water	MacGillivray 1869, Hewitt et al. 2004
Euchone limnicola	fan worm	1/01/1984		NE Pacific	hull fouling; mariculture; semi-dry ballast, ballast water	McArthur 1997, Hewitt et al. 2004
Euplana gracilis	Slender flatworm	1/01/1982		NW Atlantic	hull fouling; mariculture	Prudhoe 1982
Fenestrulina malusii	Bryozoan	1/01/1879		Cosmopolitan	hull fouling; ballast water	MacGillivray 1879; Hewitt et al. 2004
Ficopomatus enigmaticus	Tube worm	1/01/1975		NE Atlantic or Central Indian Ocean?	hull fouling; mariculture; ballast water	Russ and Wake 1975, Hewitt et al. 2004
Filellum serpens	Sessile hydrozoan	1/01/1984		Cosmopolitan	hull fouling; ballast water	Watson 1999; Hewitt et al. 2004
Forsterygion lapillum	Common triplefin	1/01/1996		Australia and New Zealand	ballast water	Lockett and Gomon 1999, Hewitt et al. 2004
Grateloupia turuturu	Devil's tongue weed	1/01/2010	Point cooke, Williamstown, Port Melb			Yamada (1941)

Gymnogongrus crenulatus	Norwegian fan weed	1/01/1969	NE and NW Atlantic	hull fouling	King 1969, MELUa, Hewitt et al. 2004
Halecium delicatulum	Cnidarian, Hydroid, jellyfish	1/01/1966	Cosmopolitan	hull fouling; ballast water	Ralph 1966; Hewitt et al. 2004
Haliclona (Rhizoniera) rosea (Haliclona heterofibrosa)	Sponge	1/01/1996	Arctic and NE Atlantic	hull fouling; mariculture	Bergquist (unpublished); Campbell and Hewitt 1999b
Halisarca dujardini	Dujardin's slime sponge	1/01/1996	NE Atlantic	hull fouling; mariculture	Bergquist (unpublished); Campbell and Hewitt 1999b
Hemigrapsus sanguineus	Asian shore crab	1/01/2020	Widespread - N,E 31 October 2020 but further investigation reveals presence since 2018 at least		De Haan, 1835
Hydroides norvegica	Tube worm	1/01/1975	Arctic	mariculture; ballast water	Russ and Wake 1975, Hewitt et al. 2004
Janolus hyalinus	Nudibranch	1/01/1986	NE Atlantic and Mediterranean	hull fouling; ballast water	Miller and Willan 1986
Jassa marmorata	Amphipod	1/01/1997	Mediterranean, NE and NW Pacific, East Africa and NE, NW and S Atlantic	hull fouling; mariculture, ballast water	Conlon 1990, Hewitt et al. 2004
Magallana gigas	Pacific oyster	1/01/1940	NW Pacific	hull fouling; ballast water, I	Coleman and Hickman 1986, Hewitt et al. 2004
Medeiothamnion lyalli	Red alga	1/01/1962	Australia and New Zealand	hull fouling	Halder 1962, MELUa, Hewitt et al. 2004
Membranipora membranacea	Bryozoan	1/01/1879	Cosmopolitan	hull fouling; ballast water	MacGillivray 1879; Hewitt et al. 2004
Metacarcinus (Cancer) novaezelandiae	Pie crust crab	1/01/1930	Australia and New Zealand	hull fouling; SDB, ballast water	McNeil and Ward 1930; Hewitt et al. 2004
Microporella ciliata	Bryozoan	1/01/1879	Cosmopolitan	hull fouling; ballast water	MacGillivray 1879; Hewitt et al. 2004
Molgula manhattensis	Sea grapes	1/01/1967	NE and NW Atlantic	hull fouling; ballast water	Kott 1976; Hewitt et al. 2004

Monocorophium acherusicum (Corophium)	Tube-building amphipod	1/01/1968		Cosmopolitan	mariculture; ballast water	Fearn-Wannan 1968; Hewitt et al. 2004
Monocorophium insidiosum	Amphipod	1/01/1996		Cosmopolitan	mariculture; ballast water	Storey 1996
Monocorophium sextonae	Mudshrimp	1/01/1995		NE Atlantic	mariculture; ballast water	Campbell and Hewitt 1999b
Obelia dichotoma (australis)	Sea plume	1/01/1966		Cosmopolitan	hull fouling; mariculture, ballast water	Ralph 1966; Hewitt et al. 2004
Paracerceis sculpta	Marine slater	1/01/1995		NE Pacific	ballast water	Campbell and Hewitt 1999b
Phialella quadrata	Hydroid	1/01/1915		Cosmopolitan	hull fouling; mariculture, ballast water	Mulder and Trebilcock 1915; Hewitt et al. 2004
Plumularia (Monotheca) obliqua	Hydroid	1/01/1884		Cosmopolitan	hull fouling; mariculture, ballast water	Bale 1884
Plumularia setacea	Little seabristle	1/01/1885		Cosmopolitan	hull fouling; mariculture, ballast water	von Lendenfeld 1885, Hewitt et al. 2004
Polysiphonia brodiei	Red alga	1/01/1959		NE and NW Atlantic	hull fouling; ballast water	Womersley 1959, Ada, Hewitt et al. 2004
Polysiphonia senticulosa (pungens)	Red alga	1/01/1969		NE and NW Pacific	hull fouling; ballast water	King 1969, MELUa, Hewitt et al. 2004
Pseudopolydora paucibranchiata	Elkhorn Slough Spionid	1/01/1978		NE and NW Pacific	mariculture, ballast water	Blake and Kudenov 1978, Hewitt et al. 2004
Pyromaia tuberculata	Fire crab	1/01/1995		NE Pacific	hull fouling; ballast water	Parry et al. 1995, Hewitt et al. 2004
Raeta pulchella	Clam	1/01/1991	limited(?)	NW Pacific	hull fouling; SDB, ballast water	J Watson (personal comment); Campbell and Hewitt 1999b
Sabella spallanzanii	European fan worm	1/01/1984	Widesprea d	Mediterranean and NE Atlantic	hull fouling; mariculture, ballast water	Carey and Watson 1992, Hewitt et al. 2004
Schizoporella unicornis	Bryozoan	1/01/1800	1800*	Cosmopolitan, NW Pacific	hull fouling	Hincks 1880, Hewitt et al. 2004

Schottera nicaeensis	Shaded weed	1/01/1975		Mediterranean	hull fouling	O'Brien and Kraft 1975, MELUa, Hewitt et al. 2004
Scruparia ambigua	Bryozoan	1/01/1881		Cosmopolitan	hull fouling; mariculture	MV collections, Hewitt et al. 2004
Scrupocellaria bertholettii	Bryozoan	1/01/1900		Cosmopolitan	hull fouling; mariculture	Vigeland 1971; Hewitt et al. 2004
Scrupocellaria scrupea	Bryozoan	1/01/1887		Cosmopolitan	hull fouling; mariculture	MacGillivray 1887; Hewitt et al. 2004
Scrupocellaria scruposa	Bryozoan	1/01/1900	1900s	Cosmopolitan	hull fouling; mariculture	Vigeland 1971; Hewitt et al. 2004
Solieria filiformis	Red alga	1/01/1957		NE and NW Atlantic	hull fouling	Womersley 1966, Hewitt et al. 2004
Stictyosiphon soriferus	Brown alga	1/01/1969		NE and NW Atlantic	hull fouling	King 1969, MELUa, Hewitt et al. 2004
Styela clava	Stalked sea squirt	1/01/1976		NW Pacific	hull fouling; ballast water	Holmes 1976, Hewitt et al. 2004
Styela plicata	Pleated sea squirt	1/01/1966		East Asian Seas	hull fouling; ballast water	Miller 1966, Hewitt et al. 2004
Theora lubrica	Asian Semele	1/01/1958		NW Pacific	ballast water	Macpherson 1966
Tricellaria occidentalis	Bryozoan	1/01/1889		NE Pacific, NW Pacific, Australia, New Zealand	hull fouling	MacGillivray 1889, Hewitt et al. 2004
Tridentiger trigonocephalus	Trident goby	1/01/1977		NW Pacific	hull fouling; ballast water	Paxton and Hoese 1985; Hewitt et al. 2004
Turritopsis nutricula	Immortal jellyfish	1/01/1982		Cosmopolitan	hull fouling; mariculture, ballast water	Southcott 1982; Hewitt et al. 2004
Ulva fasciata	Sea lettuce	1/01/1978		Mediterranean	hull fouling; mariculture	Parish 1978, MUCVa, Hewitt et al. 2004
Undaria pinnatifida	Wakame	1/01/1996	Widesprea d - N, E, SW	NE and NW Pacific	hull fouling; ballast water	Campbell and Burridge 1998, Hewitt et al. 2004
Varicorbula gibba	European clam	1/01/1987		East Asian Seas	hull fouling; ballast water	Coleman 1993
Watersipora arcuata	Bryozoan	1/01/1973	1973-76	NE Pacific	hull fouling	Holmes 1982, Hewitt et al. 2004

Watersipora subtorquata	Bryozoan	1/01/1973	1973-76	NE Pacific	hull fouling	Australia and NZ, NW Pacific, Wider Caribbean, S Atlantic

Figure A1. Description and images of 12 key marine species assessed in the MBSI.

Key Species	Description	Photo
Asian Shore Crab *Hemigrapsus sanguineus*	The Asian shore crab is native to North-western Pacific and was reported in Australia in 2020. It is most commonly found on rocky intertidal and subtidal shores. The crab has a rapid geographical expansion and may affect access for Australian seafood products in international markets. *H. sanguineus* has replaced the introduced European Shore Crab in some locations and has the high potential to displace native crabs, fish and shellfish either by outcompeting or direct predation.	 Photo Credit: Ondřej Radosta – some rights reserved (CC BY-NC)
Dead Man's Fingers *Codium fragile*	Considered native to North-western Pacific and spread to Australia in 1985 and first reported in Victoria in 1995. Codium fragile is a seaweed of great biomass and replaces kelp beds after disturbance and prevents re-colonisation by the native species for extended periods of time. It has been assessed for APMPL and is listed on CCIMPE trigger list although not on their watch list.	 Photo Credit: Saryu Mae – some rights reserved (CC BY-NC)

Wakame / Japanese Kelp *Undaria pinnatifida*	Introduced to Australia in 1988 and then detected in Victoria in 1996. High nitrogen availability and low light adapted physiological characteristics have provided a competitive advantage over other fast-growing macroalgae. Currently there is no evidence to suggest that Japanese kelp can displace native algal species through direct competition. Listed as one of the world's 100 worst invasive alien species and one of the five most dangerous invasive seaweed species. It has been assessed for APMPL and is listed on CCIMPE trigger list although not on their watch list.	 Photo Credit: MPSC
Northern Pacific Sea Star *Asterias amurensis*	The Northern Pacific Sea star is native to cold and temperate nearshore waters of the north and North-eastern Pacific ocean. The species was identified in Port Phillip Bay in 1995 and early eradication attempts were unsuccessful. Following identification, the sea star became the dominant invertebrate predator. The sea star has a high fecundity with individuals producing between 5-20 million eggs with a high dispersal potential. The native eleven-arm star preys upon the northern pacific sea star however declines in Port Phillip Bay of eagle ray, globefish and eastern shovelnose stingaree populations have been attributed to direct competition with the sea star. It has been assessed	 Photo Credit: Justin McDonald

	for APMPL and is listed on CCIMPE trigger list although not on their watch list and is on the Marine Pest Monitoring Target Species list.	
European Clam *Corbula (Varicorbula) gibba*	The European clam has a native range of the eastern Atlantic and Mediterranean although has more recently been updated as a range from Norway to Senegal. The first records in the Southern Hemisphere were from Port Phillip Bay in 1988 due to domestic shipping. It flourishes in habitats with low salinity or oxygen where it is prevalent within its natural range. As of July 2021, there were no published records of environmental impact in Australia. It has been assessed for APMPL and is listed as Stage One. The clam is listed on CCIMPE trigger list although not on their watch list and is on the Marine Pest Monitoring Target Species list.	 Photo credit: Museums Victoria, Photographer: Blair Patullo
European Fan Worm *Sabella spallanzanii*	The European fan worm is native to the Mediterranean Sea and was first found to be abundant in Corio Bay, Victoria in 1991. It has been classified as a 'medium priority species' with reasonably high impact and/or invasion potential. It competes with infauna and can modify epifaunal recruitment on hard substrates. It can biotransform non-toxic organic molecules into toxic forms. Protocols to	 Photo credit: Justin McDonald

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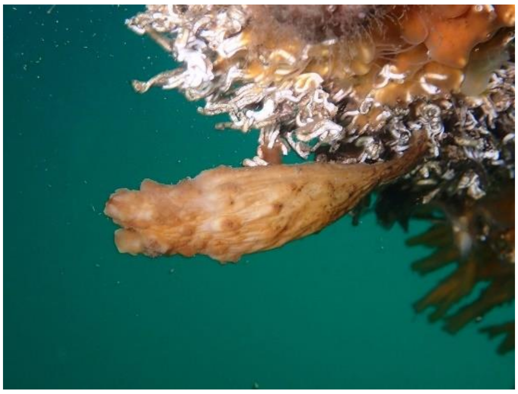
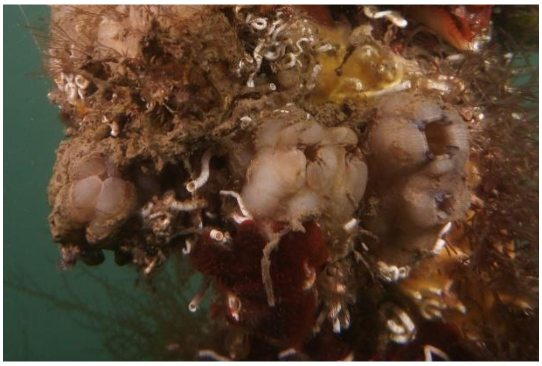
	minimise translocation involve multiple effects of freshwater immersion and air drying. It has been assessed for APMPL and is listed on CCIMPE trigger list although not on their watch list and is on the Marine Pest Monitoring Target Species list.	
Asian Bag Mussel *Arcuatula senhousia*	The Asian Bag Mussel's native range is coastal north-western Pacific Ocean. It is believed to have established in Australia in late 1970s or early 1980s with populations going through periods of flux. It has not been known to displace existing species however it acts as an opportunistic coloniser of disturbed habitats. The mussel's high fecundity, combined with rapid growth rate and gregarious habit results in its exceedingly high population densities. They grossly modify the character of a substrate by forming mats that are so dense they smother the underlying biota. However, because of their population flux, their impacts are not long-term and do not last long enough in ecosystems affect irreversible environmental damage. It has been assessed for APMPL and is listed on CCIMPE trigger list although not on their watch list and is on the Marine Pest Monitoring Target Species list.	 Photo Credit: Marine Pest Photo album, ID confirmed by S. Grove, TMAG

Stalked Ascidian *Styela clava*	Native to North-western Pacific. It is suspected to have been introduced in Australia in early 1970s. It is found in fouling assemblages and thought to have been introduced via fouling or within aquaculture stock. It is most commonly found on artificial structures in ports and harbours but can also colonise rocky reefs or soft sediments. It is suggested that the Stalked Ascidian may facilitate recruitment and survival of Japanese kelp by increasing habitat complexity and/or providing protection from grazers. No social impacts have been found in Australia however in Japanese oyster shuckers, *S. clava* has been implicated in increased asthma symptoms. It has been assessed for APMPL and is listed on CCIMPE watch list but not on their trigger list.	 Photo Credit: Sylvain Le Bris – some rights reserved (CC BY-NC)
Vase Tunicate *Ciona intestinalis*	The Vase Tunicate is believed to be native to the North East Atlantic. In early 2000s, it was reported to have only been found in marinas in Port Phillip Bay. It is considered moderately abundant and prefers the underside of artificial and natural substrates. The tunicate is commonly found in dense aggregations and has a high clearance rate which can reduce turbidity and food availability when present in large numbers and outcompetes other species. CSIRO review has	 Photo Credit: Museums Victoria Photographer: Patrick Honan

	listed it as 'extreme' to environment however has not assessed for APMPL and is listed as tier two.	
Pacific Oyster *Magallana gigas*	The Pacific Oyster is believed to have Japanese origin and was spread in modern times for aquaculture and is now known as a cosmopolitan species. The oyster was deliberately introduced in Australia for cultivation on several occasions and was first introduced in Victoria in 1953. It is considered a pest due to it competing with and overgrowing commercial Sydney rock oysters and for perceived environmental impacts. The NSW government has control measures in place. However, no impacts or effects have been noted in Victoria. It has not been assessed for APMPL or is listed on CCIMPE trigger list or not on their watch list however it is listed on the Marine Pest Monitoring Target Species list.	 Photo credit: Thesupermat, some rights reserved (CC BY-SA), http://commons.wikimedia.org/wiki/File:Magallana_gigas_-_Huitre_creuse_-_007.jpg
Pleated Sea Squirt *Styela plicata*	The Pleated Sea Squirt origin is uncertain but believed to be native to North-western Pacific/North-east Atlantic. It is widely distributed in sheltered waters along southern Australian coast. It's rapid growth and reproductive rate allows large populations of *S. plicata* to colonise substrates quickly and densely. It competes for food and predates on oyster and mussel larvae in the water column. CSIRO review has listed it as 'extreme' to economic however has not been	 Photo credit: Dan Monceaux – some rights reserved (CC BY-NC)

	assessed for APMPL and is listed as tier two.	
European Shore Crab *Carcinus maenas*	The European Shore Crab was first formally reported in 1900 however suspected to be first introduced in the 1850s. Studies in Australia have indicated that the presence of the shore crab can impact and influence the feeding behaviour of native prey species. It depends on the overlap of distribution, but it has also been shown to have an impact and cause reduction in seagrass cover. CSIRO review has listed it as 'extreme' to environment and economic rankings and it has been assessed for APMPL and is listed on CCIMPE trigger list although not on their watch list and is on the Marine Pest Monitoring Target Species list.	 Photo credit: Alex Chalupa PIRSA