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Monitoring for marine pests: A review of the design and use of Australia's national monitoring strategy and identification of possible improvements

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Contents

Summary	iv
Findings and recommendations	iv
1 Introduction	1
Purpose of this report	1
2 Marine Pest Monitoring	3
Background for development of the current National Monitoring Strategy (NMS)	3
Description and review of the current National Monitoring Strategy	4
Other systems used around the world	15
Use of citizen science programs	16
Emerging technologies	17
3 Stakeholder consultation	20
4 Possible changes to a monitoring framework	23
Appendix A: Stakeholder Consultation	31
Glossary	51
References	53

Tables

Table 1 Locations monitored according to the National Monitoring Strategy manual and guidelines	14
---	----

Figures

Figure 1 Effect of a clumped distribution (specified by the aggregation parameter k of a negative binomial distribution) on survey sensitivity for a given sample size	10
Figure 2 Simulated clumped distribution of 400 individuals. Dividing this area in 3,600 sample units (that is 60 x 60), results in a k of about 0.015.	11

Maps

Map 1 Current National Monitoring Network priority locations	7
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Summary

The Australian Government is currently reviewing the biosecurity arrangements designed to safeguard Australia's marine environment from invasive pests. The existing national system, the National System for the Prevention and Management of Marine Pest Incursions, commenced in 2005, following development by the National Introduced Marine Pests Coordination Group (NIMPCG), which was comprised of representatives from the Australian governments (Commonwealth, state and territory), industry, marine scientists and environmental organisations. Underpinning this system is a National Monitoring Strategy (NMS) designed to provide standardised monitoring to detect high risk species at priority locations around Australia.

As part of the broader Review of National Marine Pest Biosecurity, ABARES was commissioned to:

1. Review the existing national marine pest monitoring strategy.
2. Make recommendations on the scope and elements of change that could be made to achieve a simpler and more cost-effective monitoring framework.

The study involved a detailed review of the science underpinning the existing strategy, exploration of alternative and emerging methods for monitoring, and extensive consultation with stakeholders to identify impediments to adoption of the current strategy and possible improvements.

Findings and recommendations

There has been limited adoption of the NMS. Only five of 18 priority and seven other locations have been surveyed (several of these have been monitored twice) using the NMS guidelines during and subsequent to its development. Many jurisdictions indicated that future monitoring based on the NMS is unlikely. This is mainly because of a lack of clarity around the purpose of the NMS and the high cost of carrying out a survey according to existing guidelines.

Any monitoring strategy should have clearly defined objectives that will then determine the nature of the monitoring required to satisfy those objectives. This point was raised by numerous stakeholders as a serious limitation of the NMS. To its credit the NMS attempted to articulate objectives, but unfortunately (i) they were not defined tightly enough, and (ii) only one monitoring strategy was developed to satisfy a range of objectives. We recommend consideration of different systems for the following objectives, and present recommendations for the types of systems that would address them. Whether these systems are adopted will depend on considerations beyond the scope of this report. Considerations for the design of each system are described in more detail in the body of this report.

1. Monitoring to detect marine pest incursions as soon as possible (early warning)

Many stakeholders felt early warning is an important objective. Early warning could be implemented to improve the likelihood of successful eradication, although recognising that in many cases eradication may still not be feasible; to improve the likelihood of slowing spread to other domestic ports; and/or to allow time to prepare to deal with impacts of a new pest. Clear articulation of the goal would be required, as this would have implications for the design.

The NMS is not appropriate as an early warning system. Effective early warning systems are likely to have more frequent monitoring and tighter targeting within each port, than required in the NMS. They may also use other techniques, for example settlement arrays and DNA-based tools such as assays. This tighter targeting and use of other techniques has allowed existing early warning systems (outside the NMS) to be implemented more cheaply than the current NMS, but there is still a question around the cost-effectiveness of these systems for early warning - there is not yet evidence of whether these systems increase the chances of finding marine pests at an earlier stage of invasion that makes a difference relative to having no system, in order to justify their expense. This is likely to become clearer as systems are implemented.

Recommendation

If an early warning system is developed, clear articulation of the goals is required. Development should also explicitly consider the cost-effectiveness of that system.

2. Monitoring to support a domestic ballast water management system aimed at reducing the risk of port-port spread within Australia

The aim of the Australian domestic ballast water management information system (ABWMIS) is to reduce the likelihood of pests being spread from one Australian port to another via ballast water, while minimising the costs incurred by ballast water exchange. The system focuses on pests already present in Australia that are thought to have potential for large impacts, with new pests to be added once found in Australia. Many stakeholders believed that supporting a domestic ballast water system was the main reason the NMS was developed in its current form.

Full implementation of the current ABWMIS requires some form of monitoring at ports and many stakeholders agreed that some form of comparability between monitoring in different ports would be required. While this has been considered an attribute of the NMS, in reality there is too much scope for variation in the monitoring that can be carried out in any port. For example, the size of sub-locations to sample can be varied.

Other stakeholders have questioned whether a domestic ballast water management system that relies on port surveys is practical, because of the challenges of carrying out meaningful port surveys, and because they rely on targeted species when risk may also occur from other, non-target species. They have proposed a system that requires exchange based on some geographical separation of ports. Whether this would be more appropriate comes down to whether this would be more cost effective and/or practical for dealing with risk (including risk posed by known target species), relative to a targeted approach.

If ABWMIS is to rely on port surveys, we recommend that a more tightly focussed, standards based approach be considered. A system that directly targets the risk by focussing on the concentration of pests in the water where ballast water uptake occurs has a far greater chance of generating consistency between ports, and has the potential to be a lot cheaper because it focuses on a much smaller area within any port compared with the NMS. The use of a DNA based detection standard should be explored as one way of setting a standard.

Recommendation

A standards based monitoring system focussed on areas of ballast water uptake should be considered if a domestic ballast water management system is to focus on targeted marine pest species.

3. Monitoring to record changes to the marine environment, including the presence of Invasive Marine Species (IMS)

There are many drivers of change to the marine environment, including the establishment of invasive marine species. Intensive monitoring would be required to document changes, so it would be more tractable to focus on a smaller set of locations around Australia than the 18 currently in the NMS, to achieve this. This type of monitoring would give some insights into changes occurring, but clearly attributing these changes to various management approaches would be difficult. This falls more in the domain of research and would also have the advantage of maintaining capacity in the marine pest area. It would also be addressing broader issues than just IMS.

Recommendation

Consider developing a detailed monitoring program at a small number (for example, around 6) of Australian ports to underpin our understanding of changes to marine environments in Australia, including changes in invasive marine species.

4. Monitoring to determine how well our prevention measures are working

There is considerable uncertainty about many aspects of marine pest biosecurity, including the effectiveness of measures to prevent incursions. Broader objectives for the use of NMS data suggested that the data could help address this issue. However, monitoring designed to help address this question will be challenging and is likely to be expensive – relying on detailed monitoring spread over many ports is unlikely to be achievable for addressing this question.

If there is a desire to attribute changes in risk to specific management practices, then monitoring systems that focus more on risk agents may be more appropriate. For example, a monitoring system focussing on the state of vessels arriving in Australia before and after proposed new biofouling rules are introduced would allow some inference about whether the rules resulted in a change to the proportion of vessels fouled, or to the nature of fouling on those vessels.

However, inference from this type of monitoring would still be compromised by the fact that any changes could also be as a result of other drivers (for example, changing international practices). Also a focus on monitoring vessels does not address the problem that there is limited understanding of the relationship between the proportion of arriving vessels carrying IMS and establishment rates of IMS. Combining results from vessel monitoring with more intensive port monitoring (above) could partly address this.

Recommendations

Consider developing vessel monitoring systems to provide some understanding of whether management practices aimed at preventing introductions of IMS are affecting the proportion of vessels carrying IMS.

Consider linking results from vessel monitoring with results from long-term intensive monitoring at a smaller number of ports (above) to increase the understanding about arrival of vessels that may contain IMS and establishment of IMS.

5. Monitoring to measure the biodiversity outcomes of new port developments

New port developments or significant changes to existing ports present new opportunities for pests to arrive and establish. If a more detailed understanding of the marine pest implications

from these is required, before (baseline)–after (post-development) monitoring may be considered to assess the outcomes of these types of changes and could potentially be broadened to not only focus on marine pest implications, but broader biodiversity consequences of any development.

This type of monitoring program would likely draw on many of the principles in the current NMS, for example setting a target survey sensitivity, but should also consider more clearly defining the required extent and target pest densities required. If pre- and post-development monitoring is conducted at exactly the same points within the area, this should increase the ability of the system to detect any change. In order to help attribute any observed changes to the development, pre and post monitoring at nearby un-manipulated areas should also occur.

Recommendation

Consider before–after monitoring for new port developments or if there are significant changes to existing ports.

1 Introduction

Purpose of this report

The Australian Government is currently reviewing the biosecurity arrangements designed to safeguard Australia's marine environment from invasive pests. The existing national system, the National System for the Prevention and Management of Marine Pest Incursions, was developed in 2005 by the National Introduced Marine Pests Coordination Group (NIMPCG), which comprised representatives from the Australian governments (Commonwealth, state and territory), industry, marine scientists and environmental organisations (Department of Agriculture, 2014). The objectives of the system are to:

- prevent marine pests from arriving in Australian waters and spreading around the coastline
- provide a coordinated emergency response should a new pest arrive in Australian waters
- control and manage established marine pests in Australia, where eradication is not feasible.

Underpinning this system is a National Monitoring Strategy designed to provide standardised monitoring to detect high risk species at priority locations around Australia.

As part of the broader review, ABARES was commissioned to:

- review the existing national marine pest monitoring strategy
- make recommendations on the scope and elements of change that could be made to achieve a more simple and cost-effective monitoring framework with appropriate detection sensitivity.

In this report we:

- Review the existing strategy, including:
 - the criteria for determining national monitoring network locations
 - the justification for the current monitoring approach within a port
 - whether the current tool to aid in designing monitoring (the Monitoring Design Excel Template – MDET) is the most appropriate tool
 - the suitability of the current 80 per cent detection sensitivity threshold.
- Review other monitoring approaches used to monitor for marine pests.
- Present results from consultations with stakeholders (federal, state and territory jurisdictions; companies/consultants that have undertaken monitoring; scientific experts in marine pest surveillance), to identify the characteristics of the existing strategy considered impediments and to identify improvements.
- Identify new or emerging monitoring technologies and approaches that could be incorporated into monitoring to achieve simpler and cheaper monitoring designs.
- Outline the scope and elements of an alternative monitoring framework

Section 2 provides a technical review of marine pest monitoring, covering the current system, systems applied elsewhere, and emerging approaches, and incorporates relevant stakeholder

feedback where appropriate. Section 3 extracts key additional findings from the stakeholder consultations, while outcomes from stakeholder consultations are presented in full in Appendix A. Section 4 outlines potential changes to marine pest monitoring that could improve the system.

2 Marine Pest Monitoring

Background for development of the current National Monitoring Strategy (NMS)

Scientific concern about the possible introduction and impact of introduced marine pests grew throughout the late 1980s and 1990s, resulting in a comprehensive set of port surveys led by the Centre for Research on Introduced Marine Pests (CRIMP). More than 30 port locations were surveyed between 1996 and 2002, according to standards developed by CRIMP (Hewitt, 1996, Hewitt and Martin, 2001); commonly referred to as the 'baseline surveys'. In the March 1999 CRIMP survey of Darwin Harbour, black-striped mussel (*Mytilopsis sallei*) was detected in Cullen Bay Marina (Willan et al., 2000). The population had grown extremely quickly, and eradication was rapidly planned and successfully executed (Ferguson, 2000).

The black-striped mussel event highlighted to Australian governments that marine pests could have severe impacts, yet no nationally consistent system for marine biosecurity existed (Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions, 1999). In response to this issue, the National Taskforce on the Prevention and Management of Marine Pest Incursions was established. The National Introduced Marine Pests Coordination Group (NIMPCG) was established in 2000 on recommendation from this taskforce, with NIMPCG developing detailed reform measures that comprise the National System for the Prevention and Management of Introduced Marine Pest Incursions (the National System) (Department of Agriculture, 2014). A High Level Officials Working Group (HLG) was also formed to help advise on the most appropriate governance, funding and legislative arrangements for the National System (Department of Agriculture, 2014). In 2005, the Intergovernmental Agreement on a National System for the Prevention and Management of Marine Pests Incursions (Marine IGA) was signed. The Australian Government, all state governments and the Northern Territory government signed the marine IGA (with the exception of NSW), with all agreeing on the management measures to be implemented under the National System (Department of Agriculture, 2014). The National System comprises three elements: prevention, emergency response, and ongoing management and control of introduced marine pests; the National Monitoring Strategy (NMS) is one component of the National System.

In 2010, the Australian Marine Pest Monitoring Manual (the manual) and the Australian Marine Pest Monitoring Guidelines (the guidelines) were released, outlining nationally agreed processes and standards for marine pest monitoring in Australia. A Monitoring Design Package, to assist survey designers in their work, was produced to accompany the manual and the guidelines. The package included a Monitoring Design Excel Template (MDET), a report template, and other features discussed further in section 2. The National Biosecurity Committee and the Marine Pests Sectoral Committee (formerly NIMPCG) now oversee the implementation of the National System, and the Intergovernmental Agreement has been superseded by the Intergovernmental Agreement on Biosecurity 2012 (IGAB).

During the development of the NMS, the risk of pest translocations via both domestic and international ballast water exchange was, as it is today, a high profile issue in marine biosecurity. Regulations to prevent discharge of internationally-sourced ballast water in Australian ports were introduced in 2001, and reinforced by Australia's signing in 2005 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (Department of Agriculture, 2014), which is due to come into force later this decade. Domestically sourced ballast water was also discussed as a risk, as domestic shipping could

allow the spread of marine pests between Australian ports. The potential for domestic spread was assessed based on the baseline data from CRIMP surveys, which showed several known pests to be present in some Australian ports. After the release of a regulation impact statement which analysed the possible effects of regulating domestic ballast water exchange (CIE, 2007), it was decided that ongoing monitoring to identify which pests were present in ports would be needed, to support the ballast water regulation system and reflect any changes in pest status. Victoria introduced legislation regulating the discharge of domestic ballast water into Victorian ports in 2004 (Environment Protection Act Vic, 1970). No other jurisdiction has legislation regulating domestic ballast water, nor is there a national domestic ballast water system, though new legislation before parliament makes provisions for one to be implemented (Biosecurity Bill, 2014).

Description and review of the current National Monitoring Strategy

The NMS is described in the *Australian marine pest monitoring guidelines* (DAFF, 2010a), hereafter referred to as 'the guidelines', and the *Australian marine pest monitoring manual* (DAFF, 2010b), hereafter referred to as 'the manual'. The current NMS is a 'species targeted ongoing National Monitoring Strategy' which 'provides for standardised monitoring to detect high risk species at priority locations around Australia'. In essence, the intent was that 18 prioritised locations are to be monitored for a target list of 55 species every two years, with other ports also monitored regularly and every two years if possible.

The guidelines and manual describe a structured process for designing monitoring, with the following elements:

- determine objectives
- identify vectors and nodes for marine pests
- collate previous data on marine pests at the location
- collate environmental data, e.g. tides, currents, wind, waves, water temperature and salinity
- identify and spatially represent sub-locations and habitat types within the sub-location
- identify and consult with all relevant stakeholders, e.g. different levels of government; the Port Authority; marina operators; etc, and obtain required permissions, permits, etc.
- identify target species with reference to the Australia-wide target species list
- determine number of samples to achieve the required survey sensitivity
- select sites to monitor within each sub-location
- approval process.

Below we discuss some of the critical elements of this process.

Objectives

The objectives of the NMS are articulated in slightly different ways both within and between the guidelines and the manual.

In the monitoring manual, the primary monitoring objectives are described as:

- to detect new incursions of established target species at a given location i.e. species already established elsewhere in Australia but not recorded at that location
- to detect target species not previously recorded in Australia that are known to be pests elsewhere

with a secondary monitoring objective:

- to detect introduced species that appear to have clear impacts or invasive characteristics.

The manual states that monitoring plans must, at a minimum, satisfy these objectives.

Other objectives for the use of monitoring data are described in the Executive Summary and Introduction of both documents. The descriptions are consistent between documents, but vary slightly between two sections within documents. In the introductions they were presented as:

- inform the risk assessment of vectors to inform National System prevention measures (pre-border controls)
- provide earliest detection possible to trigger and inform emergency response arrangements in the event of an incursion
- inform decision making for the ongoing management and control of established marine pest populations, including informing risk assessments
- inform broader policy decisions on marine pest management

with the first point captured more broadly in the Executive summary as:

- review and improve other measures that form part of the National System

The presentation and wording of the objectives creates confusion about the purpose of the NMS, a view reflected by many of the stakeholders consulted during this project (see section 3). For example, there is no explicit mention of monitoring to support a domestic ballast water risk management system, despite this featuring heavily in considerations when the NMS was being developed.

The design of any monitoring system is critically dependent on the objectives of monitoring and any constraints to carrying out the monitoring; one system is unlikely to properly satisfy many different objectives. For example, a system aimed at earliest possible detection of new pests would have different requirements from one designed to inform a domestic ballast water management system. Hence the current NMS would benefit from considering a discrete set of very explicit objectives, with different monitoring systems tied to each. This is discussed in more detail in section 4.

Target species, priority locations and survey sensitivity are critical considerations for the design of any monitoring system, and are likely to vary depending on the particular objective. Hence in the following sections we describe and review more generally these attributes of the current NMS, before revisiting them in section 4.

Target Species

Under the current NMS, an Australia-wide target species list for monitoring was derived by screening existing lists and applying criteria outlined in the guidelines. During the survey design process, the target list for a monitoring location is narrowed further by matching known salinity and temperature tolerances of each species with the conditions at the location, but survey designers are able to include species that would otherwise be excluded by this process if they wish.

The lists screened for the Australia-wide target monitoring list included:

- A list of species for which domestic ballast water management would be required (currently seven species).
- The priority pest list (domestic list) in *National Priority pests: part II. Ranking of Australian Marine Pests. Final Report for the Department of Environment and Heritage*. (Hayes et al., 2005a).
- The priority pest list (international list) in *National Priority pests: part II. Ranking of Australian Marine Pests. Final Report for the Department of Environment and Heritage*. (Hayes et al., 2005a).
- The Trigger List of Introduced Marine Pests used in emergency management by CCIMPE (CCIMPE trigger list).

The original list of 55 species determined from this process is shown in Attachment D of the manual. According to the guidelines, the strategy, including the target species list, is due for review every four years, along with a comprehensive review of the manual. However, to date, there has not been a review of the target list (or the manual). The CCIMPE trigger list is currently under review, with the criteria likely to change so that they are consistent with the National Environmental Biosecurity Response Agreement (NEBRA) and with the Framework for Management of Established Pests and Diseases of National Significance (EPDNS). The new 'trigger' list will be known as the Australian Priority Marine Pest List.

During consultations with stakeholders the basis of the current monitoring target list was questioned: should monitoring target lists take into account any species that could be introduced by means other than ballast water or biofouling (for example, by aquaculture)?; and should the lists exclude species that cannot be easily managed? A concern from taxonomists was that some of the target species are difficult to identify even for trained taxonomists. It was suggested that taxonomists should be involved in the selection of target species, to prevent the inclusion of cryptogenic or otherwise unidentifiable species. Stakeholders also questioned whether the process of narrowing the list based on temperature and salinity tolerances presented in the Monitoring Design Excel template should be enhanced by including the expert opinion of local taxonomists. The current NMS does not preclude changes to which subset of species should be monitored, but this would require approval from the Monitoring Design Assessment Panel (MDAP; see below). Details of these issues are discussed further in the section on monitoring approaches for specific objectives (section 4). While the current NMS takes a target list approach, it also recognises that we cannot predict all pests that may become invasive in Australia. For this reason, the NMS also considers species not on the target list and covers this specifically with the secondary objective in the manual. Attributes of these species to look for were listed as:

- tendency towards monoculture or high local abundance
- association with degraded habitats
- sudden appearance in this monitoring location
- strong association with artificial substrate
- rapid increase in abundance.

Stakeholders felt that target lists can help focus the attention of those carrying out monitoring, but may also result in them ignoring species not on the list (see also Bishop and Hutchings, 2011). Regardless, a common theme that emerged was that the likelihood of invasive species being detected improved as the experience of field staff developed. This approach is formalised in New Zealand’s monitoring strategy, where survey teams are designed to include several members who have visited the survey site repeatedly.

An alternative to a target species approach raised by stakeholders is a whitelist approach, where all new organisms are assumed to be harmful until they are shown to be otherwise and ‘whitelisted’. However, a surveillance system that is based on attempting to detect all non-native species is not likely to be achievable, because (i) it would require detailed taxonomic experience of every location to operate, and (ii) many native species have not been identified and classified.

Priority Locations

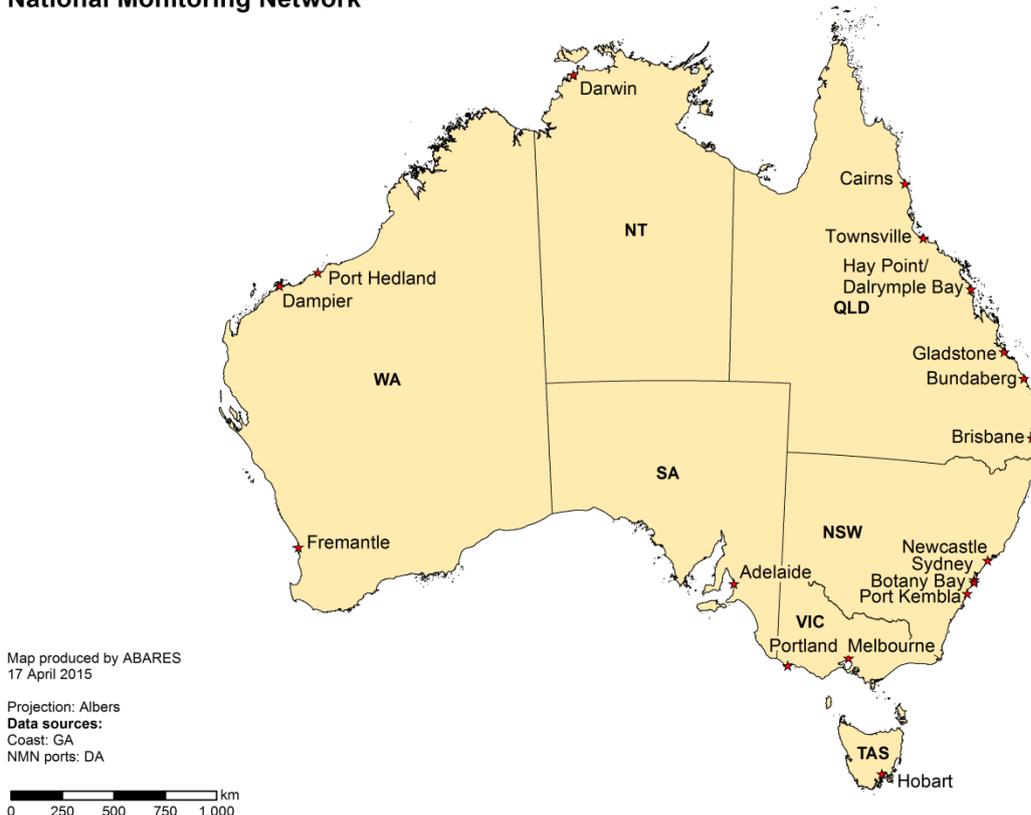
The current National Monitoring Network (NMN) is based on the principle that effort needs to be targeted at locations where invasion is most likely. When the NMS was established, 18 locations around Australia (shown in Map 1) were identified as the minimum sites for ongoing monitoring every two years based on them being high risk locations for:

- introductions and translocations of new pests
- translocations of existing pests.

The NMS also recommends that other locations are monitored regularly and every two years if possible.

Map 1 Current National Monitoring Network priority locations

National Monitoring Network



Data used to develop the priority locations included:

- a) number of international ship visits
- b) estimated international ballast water discharged
- c) number of international yacht visits
- d) number of international fishing vessel visits
- e) a connectivity score that represents the degree to which each location in Australia is connected to all other locations in Australia
- f) environmental data to identify locations with a mean temperature difference of greater than 8 °C between international source and domestic destination locations. The 8 °C was based on the approximate difference that exists between temperate and subtropical locations. This was used to restrict arrival data to those where the 'previous overseas port' was within 8 °C of the Australian destination port.
- g) domestic shipping traffic patterns to develop a translocation risk score.

These data were used in a principal component analysis to establish ranks for the different ports.

While any prioritisation should rely on the specific objective of the monitoring, a point made by many stakeholders, and one discussed in more detail in section 4, the general idea that risk rankings are based at least on a combination of vessel movement data and some form of environmental matching is sound and is generally supported. There was a perception among stakeholders that prioritisation was focussed largely on ballast water discharge, but the list of criteria at least includes a number of potential biofouling carriers that would not present a ballast water risk (for example, international yachts). Other factors stakeholders thought should be considered in prioritising locations included asset prioritisation (giving higher weight to locations containing assets of higher value to be protected from marine pests) and local environmental suitability for marine pests beyond just temperature and salinity requirements.

Identification of sub-locations

The current monitoring strategy recognises that many locations are so large it is unlikely to be feasible to properly sample the entire location to achieve the desired survey sensitivity. Hence the location can be divided into sub-locations 'on the basis of *homogenous environmental* conditions (turbidity, temperature, salinity, pollution level e.g. enclosed marina, commercial port, open coastal environment)' (DAFF, 2010b p30). The NMS is based on sampling of five broad habitat types: soft sediment, epifauna; soft sediment, infauna; hard horizontal/vertical; pelagic horizontal vertical; plankton horizontal/vertical. Further criteria for the selection of sub-locations include:

- each of the identified habitat types are included in at least one sub-location
- each of the identified vector nodes are included in at least one sub-location
- consideration has been given to areas of previous incursions
- local factors such as prevailing currents, larval pooling areas and vector pathways are considered.

The criteria for selecting sub-locations emphasise that the NMS is focussed on sites most likely to have been invaded and colonised by invasive species, consistent with the original CRIMP protocols (Hewitt and Martin, 1996, Hewitt and Martin, 2001)(see section on Other systems used).

Required survey sensitivity

Underlying theory

The current NMS is based on presence/absence surveys (not surveys of abundance). Underpinning the design is that surveys have an 80 per cent chance of detecting a pest if it is present *at an assumed population size and with an assumed underlying spatial distribution*. Any deviation from this sensitivity has to be justified and approved during the survey design phase.

The fundamental equation for calculating sample sizes in the current NMS was presented in Hayes et al. (2005b):

$$n = \frac{-A \times \log_e(1 - \gamma)}{N \times \Phi \times a} \quad \text{eq. 1}$$

Where:

n = sample size; N = population size to be detected; A = area (m^2) of appropriate habitat in a sub-location (determined by the designers); γ = survey sensitivity, set to 0.8; Φ = sample method efficiency (to be determined by the designers); and a = sample method area (area captured by one unit of sample method; to be determined by the designers).

The equation is based on the assumption that pests (or clumps of pests like mussels for example) are independently distributed at constant density $\rho = N/A$. Hence, the zero in an individual sample unit occurs either because no pest is present ($x = 0$, where x is the number of pests detected in a sampling unit) with probability $e^{-\rho a}$, or because a pest is present ($x = 1, 2, 3, \dots$) but not detected, where probability of detecting one pest that is present = Φ .

Hence, $\text{Pr}(\text{no detection of presence in an individual sample unit}) =$

$$e^{-\rho a} + \sum_{x=1}^{\infty} \frac{e^{-\rho a} \rho a^x}{x!} (1 - \Phi)^x = \sum_{x=0}^{\infty} \frac{e^{-\rho a} \rho a^x}{x!} (1 - \Phi)^x$$

Overall sensitivity is then $1 - (\sum_{x=0}^{\infty} \frac{e^{-\rho a} \rho a^x}{x!} (1 - \Phi)^x)^n \quad \text{eq. 2}$

This simplifies to the Hayes et al. (2005b) equation: $\gamma = 1 - \exp(-\rho \times a \times \Phi \times n)$. Rearranging this equation after substituting N/A for ρ , gives the equation to calculate sample size for a desired sensitivity (eq. 1 above).

If species are not independently distributed in space (for example their distribution is patchy), the required sample size to achieve the desired level of sensitivity will increase. One way of representing an aggregated distribution is by the negative binomial, where an extra parameter, k , indicates the degree of aggregation. For rare species, the Poisson based estimate of required

sample size will be about 95 per cent of the estimate of the negative binomial based estimate when $\rho a/k < 0.1$ (Green and Young, 1993). This observation has been used to justify the adoption of the Poisson based equation in the current NMS, but Hayes et al. (2005b) did caution that ‘marine organisms are usually aggregated spatially, particularly in the early stages of an invasion’ and ‘There is clearly a pressing need for further research on the spatial distribution of invasive species as they arrive and colonise new habitats in order to allow scientists to design effective early warning systems’. To date, this issue has not been addressed and it remains unclear whether the approximation is generally likely to be valid.

If the pest is distributed according to a negative binomial distribution with mean ρ (expected number is ρa) and overdispersion parameter k (where k is sampling frame size specific), then the probability that no detections are made in one sampling unit is either because the pest is not present:

$$\frac{\Gamma(k+0)}{\Gamma(k)0!} \left(\frac{k}{k+\rho a}\right)^k \left(\frac{\rho a}{k+\rho a}\right)^0 = \left(\frac{k}{k+\rho a}\right)^k,$$

or is present but is not detected,

$$\sum_{x=1}^{\infty} \frac{\Gamma(k+x)}{\Gamma(k)x!} \left(\frac{k}{k+\rho a}\right)^k \left(\frac{\rho a}{k+\rho a}\right)^x (1 - \Phi)^x$$

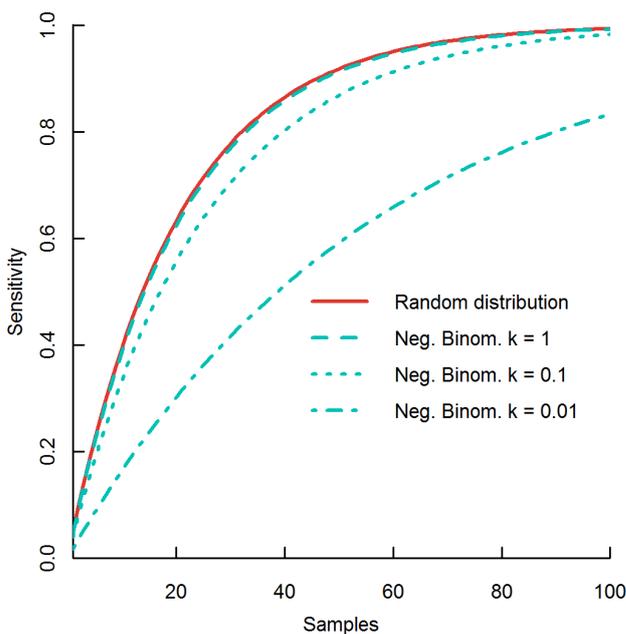
Hence, Pr(no detection of presence in an individual sample unit) =

$$\left(\frac{k}{k+\rho a}\right)^k + \sum_{x=1}^{\infty} \frac{\Gamma(k+x)}{\Gamma(k)x!} \left(\frac{k}{k+\rho a}\right)^k \left(\frac{\rho a}{k+\rho a}\right)^x (1 - \Phi)^x = \sum_{x=0}^{\infty} \frac{\Gamma(k+x)}{\Gamma(k)x!} \left(\frac{k}{k+\rho a}\right)^k \left(\frac{\rho a}{k+\rho a}\right)^x (1 - \Phi)^x$$

Overall sensitivity is then $1 - \left(\sum_{x=0}^{\infty} \frac{\Gamma(k+x)}{\Gamma(k)x!} \left(\frac{k}{k+\rho a}\right)^k \left(\frac{\rho a}{k+\rho a}\right)^x (1 - \Phi)^x\right)^n$ eq. 3

The effect of a clumped distribution on survey sensitivity for a given sample size from a population with a density of 0.1 is shown in Figure 1.

Figure 1 Effect of a clumped distribution (specified by the aggregation parameter k of a negative binomial distribution) on survey sensitivity for a given sample size



For context, Figure 2 shows a simulated clumped distribution of 400 individuals with a measured k of about 0.015. Assuming a random distribution for this example would result in a significant overestimate of survey sensitivity (or underestimate of required sample size to achieve a desired sensitivity).

Figure 2 Simulated clumped distribution of 400 individuals. Dividing this area in 3,600 sample units (that is 60 x 60), results in a k of about 0.015.



Survey sensitivity in practice

For the Poisson based estimate of sample size, n , required to achieve a desired survey sensitivity, we see from the fundamental equation that n is directly proportional to the total area of the survey, A , and inversely proportional to the target population size, N . It's also inversely proportional to the sample method efficiency, Φ . Target population sizes are fixed in the Monitoring Design Excel Template (MDET; a tool used to aid monitoring design) based on expert opinion (originally ranging from 1 000 to 1 000 000 for macroscopic and microscopic individuals respectively, depending on the taxon and lifestage) and in the current NMS these values must be used when calculating sample sizes. There is no documented justification for these target population sizes, but during consultations with those involved in developing the NMS it was suggested that target population densities were considered, and they were estimated at 5 per cent of pest densities obtained from literature searches. It is not clear how these densities were then changed to population sizes in MDET.

Sub-location area is defined by the survey designer, and can be altered if the required sample sizes are deemed logistically or financially unachievable. Clearly because target population size is fixed, target density will be different for different sub-location sizes. This raises two important

issues that are tied to the purpose of any monitoring system that considers survey sensitivity in survey design: (1) should survey sensitivity be based on a target population size or a target population density?; and (2) because survey sensitivity is conditional on the total area of 'interest', it is important to clearly define how that area of interest is delineated for any estimate of survey sensitivity to be meaningful. These issues are discussed in more detail in section 4.

The current NMS is based on achieving a desired survey sensitivity, but it is currently unclear at what level this sensitivity is applied. Both the manual and the MDET user guide (Anon, draft) imply that the aim should be to achieve this level of sensitivity for each species for every life stage, for every habitat type, within every sub-location. Different survey designers have taken different approaches. For example, in one design the aim was to achieve this level of sensitivity for one life stage, for every habitat type, within every sub-location. Even with the latter approach, this will create varying levels of survey sensitivity at the species level, depending on what habitat was available to sample. For example, consider a sub-location that has two habitat types, say hard horizontal where adults occur and an adjacent water column where planktonic larvae would be found. If we survey for the adults (with an 80 per cent survey sensitivity), and for the larvae (with an 80 per cent sensitivity), then one interpretation is that the overall sensitivity for that species in that sub-location is $1 - 0.2^2 = 0.96$, that is, there is only a 4 per cent chance of missing the species if it is present. With this simple example we see that the interpretation of survey sensitivity is not necessarily straightforward, and will depend on combinations of survey targets.

Another complication with estimation of survey sensitivity in the current NMS is that for some methods it assumes sensitivity is based solely on the sampling process and ignores sensitivity and specificity in processing the samples, a point made by stakeholders during consultation. While the sensitivity of processing samples is partly covered by Φ (equations and some parameters for estimating Φ are fixed in MDET, but in some cases final values will change depending on input from designers, for example, turbidity will alter detectability for visual method), generally Φ in MDET does not incorporate things like misidentification. This can be a problem in marine monitoring systems with large target pest lists and extensive native biodiversity, particularly if expert taxonomic expertise is not employed (Bishop and Hutchings, 2011). Any reduction in Φ increases the sample size required to achieve a target survey sensitivity.

While the Φ parameter in MDET attempts to account for things like turbidity, other impacts on sample method efficiency are not accounted for. For example, the ability of divers to detect marine pest species is not perfect even in ideal conditions. Divers self-report tiredness or uncomfortable water temperatures as having a negative effect on their performance (Kanary et al., 2010). The level of experience of the observers may affect the probability that a small population of a pest will be detected (Fitzpatrick et al., 2009). The size of clusters of the pest may also influence whether it will be detected. In experiments with synthetic *Caulerpa taxifolia*, a single frond was only around half as likely to be detected as a 1m² patch (Kanary et al., 2010). Survey timing is also very important, particularly for detecting the larval life stage of a species. While not comprehensive, these examples demonstrate that the limitations of any claims about the ability of a survey design model to account for factors affecting sensitivity must be explained and understood.

All of these issues mean that focussing a system on survey sensitivity with the current approach will not achieve comparability between ports, despite this being a desirable outcome, and one that many stakeholders incorrectly perceived could be achieved by the current NMS (see Appendix A).

Current approval/accreditation process

The Monitoring Design Assessment Panel (MDAP) approves the survey design for National Monitoring Network locations. The panel typically consists of four members: an Australian Government member, an ABARES member, and at least one jurisdictional member. Membership of the jurisdictions is rotated with each survey design, but a jurisdiction submitting a design cannot be on the panel of assessment.

After accreditation of the survey design the MDAP, in consultation with the relevant jurisdiction, needs to approve the implementation plan, which deals with the practical components of the monitoring program. When monitoring is completed, a report on the results must then be submitted to the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) for endorsement. According to the guidelines, 'Any monitoring data, regardless of source, that does not meet the requirements outlined in the manual cannot be used in national decision making processes' (DAFF, 2010a), although it seems this can be overridden by CCIMPE.

Monitoring results from monitoring programs that meet the agreed minimum requirements are deemed to be valid for three years. While this was also supposed to apply to the original baseline surveys, their validity was extended until 2009, making some surveys up to 12 years old while still considered valid for demonstrating likely absence.

Templates and tools for monitoring designers

The Monitoring Coordination Point in the Department of Agriculture provides a toolkit to aid in survey design which includes both optional and mandatory components. The toolkit includes:

- Monitoring design Excel template (MDET) and user guide – optional
- Monitoring design report template (MDRT) – optional
- Boxplots and documentation guide for use of boxplots – optional
- Observation system methods. Field guide – optional
- Standard sampling log sheet – mandatory
- Monitoring data input sheet – mandatory.

The use of MDET, while optional, has been problematic, and MDET has continued to be refined, with an updated version currently being trialled. MDET has the goal of providing a tool to help survey designers address the complicated monitoring strategy that currently exists, but the tool itself is complicated to use and unlikely to be easily used by people who design surveys occasionally. The tool is complicated because the NMS is complicated. MDET's highest level goal is to help people design a survey recognising that many of the methods employed will detect many of the different target species. The costs of different methods were included to try and help designers achieve required survey sensitivity for the least cost. MDET also attempts to provide many of the critical parameter values and calculations required by the current NMS. These include:

- Life stage specific temperature and salinity thresholds for all target species so that location target lists can be refined based on temperature and salinity data for the location.
- Species specific parameters that are used in the calculation of Φ (sample method efficiency) and for deciding which sampling methods are appropriate and when sampling should occur to account for seasonal differences in availability of different life stages.
- Sampling method specific default parameters that cover the approved sampling methods in the NMS.

- Species specific calculation of Φ using equations that take account of things like probability of fleeing and residence time in a particular life stage.
- Calculation of required sample sizes to achieve the hard-coded level of survey sensitivity (currently 0.8), for each combination of species/life stage/sub-location/habitat type for each monitoring method that is appropriate, taking into account user inputted areas/volumes for each sub-location/habitat type combination.
- A way of selecting and displaying preferred techniques taken from the dot point above so that a user can see which species could be surveyed by a common technique.
- For situations where the user deems the indicated sample size is not logistically or economically achievable, the sample size can be adjusted and a new survey sensitivity provided.

Use of the existing NMS

Since the introduction of the NMS only five of the 18 priority locations have been surveyed using the NMS guidelines (Table 1). In addition, seven other locations have been monitored according to the guidelines (Table 1). MDET was used to aid in the design of monitoring for the locations. Monitoring according to the guidelines and the manual has resulted in detections of target species, which have either been new detections of a target species in that particular location (first primary monitoring objective), or detections of target species which have been previously recorded at that location. Monitoring has not detected an incursion of a target species which is previously unrecorded in Australia (second primary monitoring objective). The cost of monitoring at those priority NMN locations reportedly varied between \$175,000 – 355,000 per location (CSIRO, 2013).

Table 1 Locations monitored according to the National Monitoring Strategy manual and guidelines

Location	Monitoring date/s
NMN	
Darwin, Northern Territory	2010
Adelaide, South Australia	2011
Portland, Victoria (partial)	2011
Dampier, Western Australia	2011, 2013, 2015*
Fremantle, Western Australia	2011, 2013, 2015*
Port Hedland, Western Australia	2011, 2013, 2015*
Non- NMN	
Skardon River, Queensland	2008, 2011
Thursday Island, Queensland	2008
Albany, Western Australia	2007
Cape Lambert Port B, Western Australia	2011, 2013
Christmas Island, Western Australia	2010, 2012
Geraldton, Western Australia	2013
Garden Island, Western Australia	2013

*planned

Other systems used around the world

Marine pest surveillance is challenging. The environment can be large and complex; access can be difficult and visibility low; and the system often biologically diverse and not fully understood. This generally makes marine pest surveillance logistically challenging, expensive and puts significant constraints on what can be achieved. However, despite the conduct of limited monitoring in-line with the national strategy, other forms of marine pest monitoring are commonly used throughout Australia, signalling that there is a need and a will to collect some information on marine pests.

The different survey approaches most commonly used around the world to explicitly detect introduced marine species were reviewed in Campbell et al. (2007), these include: the Hewitt and Martin (CRIMP) protocols (Hewitt, 1996, Hewitt and Martin, 2001); the Rapid Assessment Survey (RAS) protocols (e.g. Cohen et al., 2005); the Bernice P. Bishop Museum (BPBM) protocols (Coles and Eldredge, 2002); and Passive Sampling protocols (e.g. Wyatt et al., 2005). Here we provide a brief outline of these methods.

The CRIMP protocols aim to detect introduced, cryptogenic and native species, but focus on habitats and sites most likely to have been invaded and colonised by invasive species. There is a strong emphasis on quantitative methods, but some qualitative methods are also included. CRIMP protocols were used for the baseline surveys of Australian ports (McEnnulty et al., 2005), and most of the methods form the basis of the current Australian NMS (see section 2), but with modifications to overall design to improve overall survey sensitivity (Hayes et al., 2005b). CRIMP style surveys with some modifications also form the basis of port surveys in many other nations, including baseline marine pest surveillance in New Zealand (Gust et al., 2001). Baseline surveys have a higher per-sample cost than some other survey types, because of the need to identify all species present in a sample, rather than a small target list. The often prohibitive cost of increasing the sample numbers for baseline surveys can mean that they are likely to miss species that are very rare or which have restricted distributions in ports. For example, a second baseline survey of the Port of Wellington in New Zealand (Inglis et al., 2008) indicated only 69 per cent of non-indigenous species (9 of 13), 64 per cent of native species and 42 per cent of cryptogenic species found, were found in the first baseline survey (Inglis et al., 2006a). This 'snapshot' effect was typical of the relative detection from 1st and 2nd baseline surveys conducted at all New Zealand ports, but the use of repeat surveys was found to increase the number of species detected by around 25 per cent (G Inglis [National Institute of Water and Atmospheric Research] 2015, pers. comm., 26 February).

Rapid Assessment Surveys (RAS) are qualitative and rely on collecting fouling specimens from substrates that are within arms-reach. Deeper (>1m) sub-tidal structures are sampled less frequently. RAS also use benthic sleds, shovels, benthic grabs, plankton nets and scrapers, but in contrast to CRIMP protocols divers are not used. The surveys tend to rely on time restricted visual searches with haphazard search patterns. Because RAS tend to rely on active search, Campbell et al. (2007) suggest their outcomes are more affected by the taxonomic expertise of the field team than CRIMP methods.

The Bernice P. Bishop Museum (BPBM) protocols use quantitative and qualitative sampling approaches similar to CRIMP protocols, but were developed to be less destructive than some of the sampling techniques developed by CRIMP. They took advantage of the high level of taxonomic expertise of museum staff, and hence tend to rely on taxonomic expertise in the field. The Chile aquaculture surveys (Hewitt et al., 2006), also described in Campbell et al. (2007), involve diver transects radiating out from introduced abalone aquaculture facilities aimed at

detecting escaped abalone. The method is similar to the diver observation technique used in BPBM protocols.

Passive sampling methods use artificial substrates such as settlement trays, settlement plates (also known as fouling plates) and rope mops, to detect fouling organisms. They are placed at various locations and at various depths in the water column and collected after various periods of immersion (usually months). Species can be identified by observation of the fouled surfaces, or by the use of DNA technology, although the latter still requires development for use in operations. They often have a variety of different surfaces to provide different types of habitat for settlement.

Understanding the relationship between species density and likelihood of detection on settlement plates is critical for determining how effective settlement plates are likely to be for early detection of invasive species. A study of this type was attempted by Floerl et al. (2012), who modelled likely detection of marine pests on settlement arrays at different adult population densities. Results were encouraging for some species that were modelled as likely to be detected at low adult population densities, but results were highly sensitive to parameters whose values were highly uncertain. Floerl et al. (2012) also found that the settlement array surfaces used in their experiments were probably unsuitable for some pest species, with no detections of *Styela clava* (Clubbed tunicate) or *Undaria pinnatifida* (Asian kelp) on surfaces in lab experiments, or in the field despite sizeable populations of these pests in the surrounding port. In contrast, in a survey of Albany, settlement arrays detected the same introduced fouling species (the bryozoans *Bugula flabellata*, *B. neritina*, the solitary ascidians *Ciona intestinalis*, *Styela plicata* and the polychaete *Sabella spallanzanii*) that were detected using survey techniques currently available in MDET (McDonald et al., 2009). In 2010, the first detection of *Didemnum perlucidum* in Western Australia, and likely in Australia, was found on settlement panels during an experiment on fouling responses to simulated climate change (Smale and Childs, 2011, as cited in (Bridgwood et al., 2014). More work is required to properly understand the role settlement arrays can play in early detection.

Use of citizen science programs

Information about marine pests may also be collected through citizen science programs. Some systems take advantage of chance observations of suspicious species, which are reported and may be investigated further, leading to a confirmed detection (DoF, 2015). Other systems involve education or training of members of the public, who may then actively search for marine species, including pests (Cribb et al., 2009). As citizen science relies on volunteers with varying levels of expertise, species which are difficult to visually identify are less suitable for these programs (Bridgwood and McDonald, 2010). However, several stakeholders pointed out that many people spend considerable time in the marine environment, as fishers, divers, beachcombers or otherwise, and so they can provide very wide coverage on some pest issues.

Public reporting can lead to new pest detections, as shown by the January 2015 detection of Asian paddle crab by a fisherman in Western Australia, who caught the crab and reported it to FISHWATCH, Western Australia's marine incident reporting hotline (DoF, 2015). Facilitating reports from the public is a common approach throughout Australia. In all jurisdictions, marine pests may be reported to the relevant government department, usually Fisheries. Commonly, a biosecurity or pest reporting hotline is provided to the public, as a dedicated line or as part of a general reporting line. For example, Tasmania provides an invasive species reporting phone line, where marine pests may be reported along with other pests (DPIPWE, 2014). In Western Australia, the FISHWATCH reporting line includes aquatic pests and diseases as well as illegal

fishing reports (DoF, 2012). The department then decides which reports to follow up on and how to do so. Materials such as posters and fact sheets are often produced to encourage the public to be alert for sightings of a particular species (Bridgwood and McDonald, 2010, Cribb et al., 2009)

In South Australia and Victoria, divers trained as part of Reef Watch programs conduct organised surveys for a variety of species including pests, as well as being able to search for pests on their recreational dives (Conservation Council SA, 2015, Reef Watch Victoria, 2013). A more in-depth program is the Nelson Bay Nudibranch Census, where a detailed survey of nudibranch species present in the area is conducted by interested divers, who have received identification training (R. Willan [Museum and Art Gallery of the Northern Territory] 2015 pers. comm., 13 January). Most programs are not exclusively focussed on pests, but do include observations of non-native species. For all citizen science programs, appropriate resourcing and support is required to maintain the engagement of the volunteers.

Stakeholders widely acknowledged that citizen science programs cannot be the only pest detection system used; rather they provide an additional pest detection method. It is commonly noted that public reports of pests do result in a large volume of false positives. A subsample of 75 public reports of the pest *Styela clava* in New Zealand yielded 56 per cent false positives (McFadden et al., 2007). Resources are needed to investigate reports and decide which are in need of further investigation. However, almost all stakeholders highly valued citizen science programs despite the acknowledged weaknesses. One stakeholder suggested that citizen science has a 'track record' of providing early pest detections. Identification issues may be mitigated, such as in Reef Life Survey, where the diver identifications can be verified by para-taxonomists, or fully trained taxonomists, if necessary (R. Willan [Museum and Art Gallery of the Northern Territory] 2015 pers. comm., 14 January). It is worth acknowledging that the volunteers involved in citizen science programs are not all unskilled or inexperienced. One stakeholder pointed out that many first detections have been made by marine science professionals making a chance observation and providing a report. Finally, even relying exclusively on expert biologists does not eliminate the risk of false positives (Kanary et al., 2010).

Emerging technologies

DNA-based technologies

DNA technologies have great potential for marine pest monitoring, however before they can be integrated into a National Monitoring Strategy, some issues would need to be resolved (Bott et al., 2010).

- Generally, specificity testing and refinement of the techniques would be needed before implementation, and continued as they are used to ensure that false positives are minimised.
- A framework for sample collection would be needed for each sample type, because while sensitivity for detection of DNA in a sample given it is present can be high, the probability of the DNA being present is governed by the sorts of sampling considerations discussed in the section on 'Required survey sensitivity'.
- A DNA purification and isolation technique which is effective on a variety of sample types would need to be developed. Ideally, the method would be effective in removing contaminants which may inhibit the DNA amplification process.
- In the longer term, it may be necessary to consider the capacity of laboratory facilities near ports to prepare samples quickly, or even to perform the analysis on site.

- Protocols for action following a positive DNA detection would need to be established, particularly if the detection is to result in regulatory or management action, such as the implementation of an emergency response. Positive DNA results may need to be followed by physical detection and identification of the pest (Bott et al., 2010), for example, as a positive DNA detection may have come from larvae that had not established.

No DNA technique will remove the need for taxonomists, as voucher specimens are needed, and reference DNA sequences must be based on correctly identified specimens (Lindeque et al., 2013).

Assays

SARDI is developing a series of qPCR assays, which detect the presence of a species' DNA in a sample. An assay relies on two primers and a probe, which are designed to be specific to a particular sequence in a species' DNA (Bott et al., 2010). That sequence can then be amplified using a polymerase chain reaction (PCR) in order to show the presence of a species. Ten assays are currently in development. Each assay can only detect the species it is designed for.

The sensitivity of the assays is very high for clean DNA samples, with the quantity of DNA required for a true positive result measured in femtograms. However, in practise, environmental samples contain a variety of contaminants which can interfere with the DNA extraction, purification and amplification process, and result in a false negative result (Bott et al., 2010).

Testing for specificity has been undertaken, and will continue. By applying the assays to samples from ports across a range of locations, the assays can be tested on a wider range of DNA from non-target species (Bott and Giblot-Ducray, 2011) to ensure they are not falsely detecting native species.

Next-generation sequencing

Next-generation sequencing is another DNA method under development worldwide, which is not yet widely applied in the detection of marine pests (Pochon et al., 2013). This method involves sequencing all DNA in a particular sample, for example, a scraping of biofilm from a settlement plate. The full DNA sequences of all the species present in the sample are then compared with a reference database (NCBI BLAST; <http://blast.ncbi.nlm.nih.gov/Blast.cgi>), and all species, or as many as possible, present in the sample are identified.

Because longer DNA sequences are analysed in next-generation sequencing than the assays, the potential for false positives is reduced (Pochon et al., 2013). False negatives remain a possibility, depending on the abundance of the species in the sample, and the reliability of the components required to amplify the DNA. The system tested by Pochon et al. (2013) was very sensitive to species present in low abundances, and additional research on the amplification process continues.

Next-generation sequencing relies on the availability of a comprehensive library of genomes so that the sequences in the sample may be referenced. Building on this library is a relevant consideration in the future of resourcing this field of research.

Currently, the cost of these techniques is prohibitive. Cheaper equipment and wider use may in future make next-generation sequencing more suitable for widespread application in marine detections (Pochon et al., 2013).

Remote-operated vehicles (ROVs)

Remote-operated vehicles (ROVs) are sometimes used as an alternative to diver visuals, in areas where a dive team may be too expensive because of safety requirements, or where divers are unable to enter the water because of risks such as crocodiles or port activity. Safety is the major advantage that ROVs have over divers.

While there is an initial cost outlay in purchasing a ROV, they are regarded as more cost-effective than divers in many situations (Floerl and Coutts, 2011). Different types of vehicle have different capabilities and costs, which must be considered. Some stakeholders interviewed have experience using ROVs and find that they are a useful and cost-effective alternative to divers.

The performance of ROVs in comparison to divers requires further testing, and may vary under different conditions. For example, a diver observing a transect is able to use peripheral vision and react if they suspect a species may be present, while a ROV cannot, and only provides a stream of video. However, peripheral vision may not be as important when observing different habitats, such as pylons. Many vehicles do not have the capacity to collect samples for further taxonomic analysis, and so diver follow up to collect these samples may still be required in some cases (Floerl and Coutts, 2011). Camera operators are still required to concentrate for long periods, but they may be less affected by physical fatigue than divers and are not subjected to discomfort from water temperature, perhaps reducing the impact of these factors on the data (Kanary et al., 2010).

ROV use does not eliminate the need for trained experts in marine pest monitoring. Skilled observers are required to watch the video feed and make judgements on any organisms that need further investigation. Divers may still be required to collect samples in some situations. However, their advantages on cost and safety may mean that ROVs can be used more extensively in marine pest monitoring.

3 Stakeholder consultation

There are numerous stakeholders engaged with the NMS. These stakeholders range from those with policy, operational, or scientific roles in state and territory agencies, to those in Commonwealth agencies, museum taxonomists, private consultants, industry bodies, such as port authorities and shipping organisations, and those who played a role in the development of the NMS. To engage feedback from stakeholders on the NMS, ABARES held 30 semi-structured face to face interviews or teleconferences with between one and four interviewees. These discussions took between 45 minutes and 2 hours, depending on the depth of discussion and number of topics relevant to that stakeholder. The discussions focussed on high level issues, such as major impediments to adoption of the NMS, through to more targeted issues such as experience with and use of MDET. It must be noted that not all stakeholders were able to comment on all issues. The following provides a summary of clear issues emerging from stakeholder consultation. Additional references to stakeholder feedback appear in sections 2 and 4 where appropriate. A more detailed summary of stakeholder consultation covering all issues discussed is presented in Appendix A.

It was clear from stakeholder feedback that a few simple modifications to the existing NMS would not be sufficient to ensure all monitoring required by the current NMS is performed. Rather, many stakeholders described a need to return to the foundations of the system, to develop clear objectives owned by all stakeholders, and to establish a system that can meet those objectives. Key issues for most stakeholders were:

- 1) there is a requirement for clear objectives and purpose to underpin the NMS
- 2) cost is a major impediment to implementation of the current monitoring strategy.

Other important issues which emerged from discussions were:

- 3) there is a lack of clarity on beneficiaries and responsibilities
- 4) a sustainable funding system is required to maintain the skills base required for effective marine pest monitoring.

Clear objectives to underpin a National Monitoring Strategy are required

Many stakeholders felt that the need for a National Monitoring Strategy must first be clearly established and articulated. Whilst many stakeholders felt that monitoring is important, the lack of clarity of the purpose of the NMS was seen as a disincentive to fund or carry out the monitoring. Many felt that current monitoring methodology is designed to support a domestic ballast water system, and the location selection, frequency of monitoring and statistical rigour required suit this objective. However, the domestic ballast water system is not an objective of the monitoring strategy, nor has such a system been implemented. This has contributed to uncertainty about the overall purpose of the NMS. Other stakeholders, while not explicitly questioning the purpose of the NMS, felt that early warning is a required objective of a national strategy; however stakeholders were almost unanimous in the view that the NMS cannot meet this objective in its current form, and some jurisdictions have adopted their own early warning monitoring systems as a consequence.

The impact of unclear objectives is amplified because the marine biosecurity sector typically does not have the same profile as other biosecurity sectors, such as animal health. Most marine pest incursions do not have the level of visible impact that, for example, a major animal disease event would have, with the 1999 incursion of black-striped mussel being an exceptional case rather than the norm. It can be difficult to justify funding monitoring for this sector without a clear purpose and outcomes from that monitoring. Linked to this is the practical reality that marine pest eradications, or eradication attempts, are costly and rarely successful.

Several stakeholders noted that different systems should be designed to meet different objectives and that this principle should underpin any National Monitoring Strategy.

Stakeholders who were less familiar with the NMS were sometimes unclear of how the assumptions inherent in the survey design affected how the data can be applied. For example, it was sometimes assumed that if a pest were not detected in the first monitoring of a location, and was detected in subsequent monitoring two years later, that the pest must have arrived in the intervening two years. In fact, with a design survey sensitivity of 0.8, the pest may have been present at the first monitoring occasion, but not detected, and the interpretation that it arrived in a clear two year window is incorrect.

Stakeholder feedback on the features of a monitoring system such as location prioritisation, target species, monitoring frequency and survey design were closely linked to stakeholders' views on the objectives of the monitoring system. For example, different monitoring objectives may alter the priorities when selecting locations; monitoring to detect pests at an early stage of invasion may focus on the areas at highest risk of introductions, while monitoring to prevent impacts on assets may focus on ecologically valuable or economically important areas where impacts felt will be greatest. Target species selection would likewise be affected, with stakeholders suggesting the need for defined selection criteria for target species lists that support specific monitoring objectives, for example, monitoring for a smaller list of known high impact pests for a domestic ballast water system. More detailed discussion of these factors may be found in Appendix A.

Cost is a major impediment

According to many stakeholders, the cost of completing a survey according to the monitoring guidelines is a key reason monitoring is not conducted. This cost, linked with the lack of clear purpose and benefit to completing monitoring, prevents the NMS from being fully implemented. However, the high cost of implementing NMS monitoring in its current form may not be justifiable even with clear objectives. Stakeholders presented many ideas on reducing costs including tighter spatial focussing of survey effort and the adoption of lower cost methods such as settlement arrays and the use of assays; these are detailed further in Appendix A.

Lack of clarity on beneficiaries and responsibilities

There is a perception that there is no clear leadership of the NMS, and that those involved with the NMS do not feel ownership of it or its objectives. This is partly driven by the fact that a national domestic ballast water management system has not been implemented despite considerable planning effort some years ago. The unclear objectives as described above also play a role in this perception. Some stakeholders felt that more tightly defined objectives of any system would make it clearer who risk creators and beneficiaries are, and that this would help identify how best to apportion responsibility for the various components required to make a National Monitoring Strategy function successfully.

A sustainable funding system is required to maintain the skills base required for effective marine pest monitoring

Any national system for marine pest monitoring relies on resources other than simply the funding to carry out the monitoring itself. Stakeholders nominated many important areas of capacity, including taxonomic ability (both highly skilled taxonomists and parataxonomists, as well as basic identification skills from observers), field skills, survey design skills, an informed research environment, and extensive reference collections in museums. Many stakeholders suggested that this capacity is already low, and declining, particularly that of taxonomic ability. Stability in funding could prevent the acceleration of loss of this capacity. Several stakeholders indicated that a more coordinated funding strategy is needed between monitoring and research, for example, where monitoring experience informs research needs, which in turn feeds back into improved monitoring.

4 Possible changes to a monitoring framework

Any monitoring system must have clearly defined objectives that will then determine the nature of the monitoring required to satisfy those objectives (section 2). This point was raised by numerous stakeholders as a serious limitation of the current NMS. To its credit the current NMS attempted to articulate objectives, but unfortunately (i) they were not defined tightly enough, and (ii) only one ‘system’ was developed to satisfy a range of objectives. This has led to a broad range of views among stakeholders about why monitoring is conducted and whether it is valuable or not. Here we present examples of more tightly defined objectives, as well as the factors to consider when designing different systems to satisfy each one. These include monitoring to:

- 1) Detect marine pest incursions as soon as possible to:
 - improve the likelihood of successful eradication
 - improve the likelihood of preventing spread to other domestic ports
 - allow time to prepare to deal with impacts of a new pest.
- 2) Support a domestic ballast water management system aimed at reducing the risk of port-port spread within Australia.
- 3) Monitor changes to a marine environment including the presence of IMS
- 4) Determine how well our prevention measures are working.
- 5) Measure the biodiversity outcomes of new port developments or significant changes in port activity.

It should be noted that the recommendations for different types of monitoring systems outlined in this section have not been discussed as a part of stakeholder consultations, though they support stakeholder feedback.

Monitoring to detect pests as soon as possible

It is well recognised in terrestrial systems that the chances of eradicating a pest improve the earlier it is detected after its initial establishment (Pluess et al., 2012a, Pluess et al., 2012b). A similar situation is likely to apply in marine systems (Hopkins et al., 2011, Bax et al., 2002). However, finding marine pests early enough is challenging, because eradicable populations are almost certainly very small populations which are hard to detect (Summerson et al., 2015). McFadden et al. (2007) noted in New Zealand that a high probability of detecting the pest *Styela clava* implied that the population was already well established, and ‘almost impossible’ to eradicate. There are other potential advantages to an early warning system though, such as improving the likelihood of slowing spread to other domestic ports and allowing time to prepare to deal with impacts. These different objectives would change how early a pest must be detected and hence frame the question on what characteristics an early warning system would need to have and whether the expense of these characteristics can be justified.

Various ‘early warning’ systems that fall outside the current NMS are being used by jurisdictions. These tend to include:

- more frequent monitoring than the two years suggested in the current NMS;

- higher spatial targeting to areas within the port where pest incursions are most likely to occur;
- smaller target species lists; and
- additional techniques such as the use of settlement plates.

These characteristics have been chosen to maximise the chances of early detection, often given a finite budget, rather than to target a specific design sensitivity, although new approaches such as stochastic scenario trees (Martin et al., 2007), modified for marine surveillance, are being developed to conduct a post-implementation estimate of survey sensitivity (G Inglis [National Institute of Water and Atmospheric Research] 2015, pers. comm., 26 February).

In New Zealand, the 'early warning' system is based on a combination of targeted surveillance, including trapping and visual surveys for a range primary and secondary target species, carried out every six months (Inglis et al., 2006b), and general surveillance reporting (public reporting) to broaden the geographic coverage of surveillance. Ports selected for targeted surveillance were based on the most likely ports for introduction, with further targeting within each port based on likely points of introduction, local water movement patterns and availability of suitable habitat. These surveys are carried out much more cheaply than the surveys designed under Australia's current NMS; 11 harbours including 32 ports and marinas are each actively monitored every 6 months for a cost of about NZ\$1.6 million a year for field surveillance activities. The total cost of targeted surveillance, that is field surveillance activities and diagnostics (performed by the Marine Invasive Taxonomic Service (MITS), is approximately NZ\$2 million a year (B Gould [New Zealand Ministry of Primary Industries] 2014, pers. comm., 29 October).

Australian jurisdictions also have early warning systems. For example, in the Northern Territory and Western Australia settlement plates are deployed at targeted locations and inspected multiple times in a year (Northern Territory Department of Primary Industries and Fisheries, 2014). In Western Australia, shoreline surveys, crab traps and crab condos (Hewitt and McDonald, 2013) are also deployed, twice per year. Queensland has a 'mussel monitoring' program, also using settlement plates. Settlement plates are relatively cheap to use, which makes them attractive for surveillance purposes, but the relationship between pest density and detection on settlement plates has not yet been established (Floerl et al., 2012). Hence their role in 'early detection', relative to alternative techniques like visual surveys, requires further investigation (Floerl et al., 2012). Early detection systems limited to settlement arrays will necessarily be limited to the detection of fouling species.

Focussing on targeted locations and increasing the frequency of early detection surveillance is likely to improve the likelihood of early detection of an invasion relative to a system that does not do these things. There are new methods being developed based on portfolio theory to allocate surveillance resources to maximise returns, while making the allocation less susceptible to uncertainty about where pests will arrive, which could be explored (Yemshanov et al., 2014). However, we are a long way from understanding whether early warning systems are truly cost effective. To date there have been very few primary detections from formal early warning surveillance programs and there is no evidence yet of whether these systems increase the chances of finding marine pests at an earlier stage of invasion that makes a difference relative to having no system, in order to justify their expense. However, this understanding will likely only accrue from having systems in place and seeing how they perform. Post-implementation estimates of survey sensitivity should be a part of any early warning system, because they provide an estimate of how effective the system may be at detecting pests at low densities. The system currently being developed in New Zealand (above) is one possible way to achieve this.

Indirect benefits may also arise from the use of an early detection system. These include maintenance of capacity in the marine pest space, and in some cases extension of that capacity to the broader community. For example, in New Zealand, divers employed to help with formal surveys have made subsequent detections while undertaking other activities.

The latter is a form of citizen science, an area being developed to contribute additional resources beyond formal programs to initial, hopefully early, detections of marine pests. First detections of pests have been made outside of formal monitoring processes: a stakeholder gave the example of *Undaria pinnatifida*, which was first detected in Victoria by university researchers. Citizen science is a way of trying to address some of the logistical challenges of marine pest surveillance by increasing the effective effort devoted to searching for marine pests. A system to detect pests as early as possible would be characterised by high frequency of survey effort. Citizen science may be able to provide this in some areas and for some species. It will always be constrained by taxonomic challenges, because many marine species are difficult to identify, even for professionals. To partly alleviate this, some citizen science programs focus mainly on conspicuous pests, for example, the Western Australian program (Bridgwood and McDonald, 2010). Other programs such as Reef Life Survey, whilst not focussing on marine pests, have systems where divers are able to upload pictures of unusual species to parataxonomists who can confirm their identity. If a parataxonomist is uncertain, they divert to a trained taxonomist (R. Willan, [Museum and Art Gallery of the Northern Territory] 2015 pers. comm., 14 January). It should also be acknowledged that some citizen science effort is donated by those who, while often not taxonomists, are professionals in the field, such as commercial survey divers or marine researchers. While citizen science approaches appear attractive they also require resources to operate effectively, so this should be included in any consideration of the cost effectiveness of early warning systems.

Of course detections made by any early warning system will require follow-up delimiting surveillance, but the required surveillance will be specific to any particular incursion and should be designed at the time.

Target species

Early warning systems tend to be focused on set target species, generally those species considered as highest risk to that area. As with the current NMS, surveys also look for other species that appear to be either unknown, or displaying invasive characteristics. Having a target species list can focus a system, but there is always the challenge of deciding which species should be included. Target species lists are common in biosecurity in Australia, but they are easier to develop for some systems than others. For example, for animal diseases there is a relatively small number of high impact diseases that currently do not occur in Australia, which are targeted for surveillance. There is often an imperative to monitor for these diseases, as many are internationally listed diseases for which surveillance programs provide Australia with its favourable trade status for animals and animal products. There is also constant scanning for emerging issues (for example, emergence of a new strain of Avian Influenza), which can result in changes to the system. In the marine pest world it has been relatively easy for the list to become large and arguably unwieldy, because of considerable uncertainty about the impacts of marine pests and because Australia-wide lists tend to cover diverse habitats. Australia's size means that early warning for spread of pests within Australia (for example, from east to west or vice versa), could also be part of an early warning system. A more tightly constrained list with a process for easy updating would be preferred by many stakeholders, but it still requires a process to prioritise the species.

The criteria used in this prioritisation will depend on the purpose of the system. If the intent of the system is early warning to only allow eradication, then there is clearly no justification for including species for which eradication is not likely to be technically possible. However, such species may be justifiably included if containment or other management actions or development of methods to deal with their impact would benefit from early detection. If the objective of early detection is to protect assets such as aquaculture, the pests which most affect those assets would be considered. Given uncertainty about the impacts of many species, focussing at a minimum on those species with *clear and large* documented impacts overseas may be justified. Monitoring is more likely to be cost effective if the species are easy to identify, either visually, or with the future availability of DNA methods. In any case, consideration should be given to a list of species constrained to those that are able to be identified.

While a white listing approach may appear attractive if the objective of a system is to minimise changes in biodiversity, given the large proportion of Australia's marine life which is as yet undescribed, this approach is likely to be unwieldy and prohibitively expensive if adopted for monitoring. A white listing approach may be better applied in other areas of marine pest management, such as for vessel compliance inspections.

Target locations

Cost-effective early warning systems are more likely to occur in areas where early pest detection has a clear link to subsequent action/benefit. For example, early detection may be justified if:

- there is a highly valuable nearby asset that would benefit most if eradication or highly localised containment was achievable; or
- early detection would make it more likely to prevent spread to other ports in Australia.

The likelihood of arrival of new pests is also likely to be important for prioritisation. The current prioritisation method considers likelihood of arrival and connectedness between Australian ports, but a refinement of the method to more explicitly include benefits would be justified.

New port developments or significant changes to existing ports present new opportunities for pests to arrive and establish. This comes from the vessels involved in implementing these changes, which are often high risk vessel types for biofouling (barges or dredges, Kinloch et al., 2003), and the disturbance created which may increase the likelihood of marine pests establishing in an area (Tyrrell and Byers, 2007, Kotta et al., 2013). Given this, any new developments could be considered for early warning monitoring, at least around the time of and in the immediate years following development.

Summary and recommendations

The current NMS is not appropriate as an early warning system.

Effective early warning systems are likely to have more frequent monitoring, tighter targeting within each port, and a smaller target list, than required in the current NMS. They may also use other techniques, for example settlement arrays and DNA-based tools, such as assays.

However, clear articulation of the goals of any early warning system to be implemented is required, including the expected benefits from that system, as these determine the design. Further, development of any early warning system should explicitly consider the cost-effectiveness of that system, including any indirect benefits.

Monitoring to support a domestic ballast water management system aimed at reducing the risk of port-port spread within Australia

The aim of the Australian domestic ballast water management information system (ABWMIS) is to reduce the likelihood of pests being spread from one Australian port to another via ballast water, while minimising the costs incurred by ballast water exchange. The system focuses on pests already present in Australia that are thought to have potential for large impacts: *Asterias amurensis* - Northern Pacific Seastar; *Carcinus maenas* - European Green Crab; *Varicorbula gibba* - European Clam; *Musculista senhousia* - Asian Date or Bag Mussel; *Sabella spallanzani* - European Fan Worm; *Undaria pinnatifida* - Japanese Seaweed or Wakame; and *Crassostrea gigas* - Pacific Oyster, but the NMS was also set up to detect other potential ballast water pests that would, once they became established in an Australian port, also be added to ABWMIS.

Transits that would require ballast water exchange are defined as those where (Hayes et al., 2009, Hayes et al., 2008, Hayes et al., 2007):

- a pest is present in the donor port (If the port has not been surveyed recently, within 3 years under the rules of the current NMS, it is assumed that the pest is present if the temperature is suitable); and
- larvae of the pest that could be taken up in ballast water are present in the water column in the month of departure from the donor port assuming the donor port has an existing population of the pest: and
- the pest survives in the ballast water during transit (Currently the probability of survival is considered to be 1 for all transits as a result of relatively short journey lengths within Australia and a lack of information on species-specific survival in ballast tanks): and
- the pest arrives in the recipient port where surveys have indicated that it is not present and the temperature is suitable (If the port has not been surveyed, then it is assumed that the pest is not present).

Comprehensive application of this system would rely on port surveys to determine the likelihood of pest presence, but risk-averse assumptions (above) would allow the system to operate without surveys.

There are significant problems with the current NMS supporting this type of domestic ballast water system, beyond the obvious one that very few surveys have actually been conducted since the original baseline surveys. If a survey is conducted strictly according to the current NMS, and does not detect a pest, then the interpretation is not that 'the pest is not present', but that there is an 80 per cent chance the pest is not present at a density at or above the target density that arose from the application of MDET. As shown in section 2 on Required survey sensitivity, this density arises from the target population size provided in MDET, combined with the area of the sub-location chosen by the designer, combined with the underlying assumption of a random distribution of the pest within the sub-location.

Some have argued that a domestic ballast water system that relies on port surveys is not practical, because of the challenges of carrying out meaningful port surveys, and because they rely on targeted species when risk may also occur from species that are present that are not on the target list (S Barry [CSIRO] 2014, pers. comm., 11 December). They have proposed a system that requires exchange based on some geographical separation of ports. Whether this would be more appropriate comes down to whether this would be more cost effective and/or practical for dealing with risk (including risk posed by known target species), relative to a targeted approach.

If a targeted approach is to be adopted, then a more appropriate approach may be to focus on a standard for detectability of the target species in the area where ballast water uptake occurs. Ports below the standard would be considered safe for uptake and vessels leaving those ports would not have to exchange before arrival in any other Australian ports. A standards-based approach is similar to that being explored in the USA, where standards apply to the ballast water being discharged (Albert et al., 2013), but in this case the standard would be applied to the water where uptake occurs. Ballast water uptake areas are likely to be much smaller than the entire port area, and if combined with DNA-based detection of species this has the potential to produce a much cheaper monitoring system compared with the current NMS. It also directly targets the risk (which comes from the uptake of pests in the water that could be transferred to other ports), and has a much greater chance of generating consistency between ports, because the standard would be based on some concentration of pests in the water. While an objective of the current NMS is to generate consistency between ports, in reality this does not occur because there is too much scope to modify the surveys, for example by choosing the area of a sub-location (see section 2 - Required survey sensitivity).

If this type of system were adopted, work would need to be done to:

- determine what the standard should be for the target pests, including standardised sampling (when and how much) and processing of samples
- identify where ballast water uptake occurs within ports

Recommendation

A standards based monitoring system focussed on areas of ballast water uptake should be considered if a domestic ballast water management system is to focus on targeted marine pest species.

Monitoring to record changes to the marine environment, including the presence of IMS

There are many drivers of change to the marine environment, including the establishment of invasive marine species. Intensive monitoring would be required to document changes, so it would be more tractable to focus on a smaller set of locations around Australia (than the 18 currently in the NMS), to achieve this. This type of monitoring would give some insights into changes occurring, but clearly attributing these changes to various management approaches would be difficult. A long-term intensive monitoring system might be able to indicate things like: the establishment of new IMS is rare; or establishments tend to be from species that are more likely to be associated with ballast water (or biofouling); but it would be difficult to attribute changes in establishment rates to any particular measure because of the complexity of the system and the difficulty of establishing case/control type studies in natural systems. This intensive monitoring approach falls more in the domain of research, and would also have the advantage of maintaining capacity in the marine pest area. It would also be addressing broader issues that just IMS.

Recommendation

Consider developing a detailed monitoring program at a small number (for example, around six) of Australian ports to underpin an understanding of changes to marine environments in Australia, including changes in invasive marine species.

Monitoring to determine how well our prevention measures are working

One of the 'broader objectives for the data' described in the current NMS is '*[to] inform the risk assessment of vectors to inform National System prevention measures (pre-border controls)*' (DAFF, 2010b). This objective is related to the desire from industry and others to understand how well preventative measures are working. Prevention measures in marine biosecurity are complex compared with sectors such as plant health, where biosecurity and quarantine for international arrivals are the responsibility of the Australian Government. While some prevention measures are the responsibility of the federal government, jurisdictions also implement some prevention measures, such as Victoria's domestic ballast water regulations, or international yacht inspections in the Northern Territory. If monitoring were to be used to measure the effectiveness of, or to inform, prevention measures, the measures in question would need to be clearly identified.

There are two main risks for the transport of invasive marine species into (and around) Australia: in ballast water and as biofouling on vessel hulls (Summerson et al., 2015). In Australia, current preventative measures rely on international ships exchanging their ballast water before they arrive at Australian ports. In some locations inspections are also carried out for biofouling, for example for international yachts arriving in Darwin. Australia is now exploring a new system to manage the risk of biofouling species being introduced to Australia by commercial vessels. Many stakeholders were mindful that any management of biofouling risk should be considered in the work that is occurring under the International Convention on the Control of Harmful Anti-fouling Systems on Ships (IMO, 2011).

There is considerable uncertainty about many aspects of marine pest biosecurity (Summerson et al., 2015), including the effectiveness of measures to prevent incursions, and studies to better understand this appear attractive. However, monitoring designed to fully address this question will be challenging. As indicated in section 2, separating timing of incursions from just missing a species that was actually present at an earlier time, is difficult, making it challenging to identify when a particular establishment occurred and hence assigning it to the failure of any particular management practice. Detailed monitoring over many ports is unlikely to be achievable for addressing this question.

If there is a desire to attribute changes in risk to specific management practices, then monitoring systems that focus more on risk agents may be more appropriate. For example, a monitoring system focussing on the state of vessels arriving in Australia before and after proposed new biofouling rules are introduced would allow some inference about whether the rules resulted in a change to the proportion of vessels fouled, or to the nature of fouling on those vessels. Inference from this type of monitoring would still be compromised by the fact that any changes could also be as a result of other drivers (for example, changing international practices), but it is not obvious how 'experimental controls' could be employed to allow clear attribution to the changes in rules if they are implemented Australia-wide. A focus on monitoring vessels also does not address the problem that we do not have a good understanding of the relationship between the proportion of arriving vessels fouled with IMS and establishment rates of IMS. However, in the long term a vessel monitoring program combined with detailed port monitoring at a small number of locations may at least provide some understanding about this relationship using the type of analysis conducted by Heersink et al. (2015) for example.

Recommendations

Consider developing vessel monitoring systems to provide some understanding of whether management practices aimed at preventing introductions of IMS are affecting the proportion of vessels carrying IMS.

Consider linking results from vessel monitoring with results from long-term intensive monitoring at a smaller number of ports (see section above - Monitoring to record changes to the marine environment, including the presence of IMS) to increase the understanding about arrival of vessels that may contain IMS and establishment of IMS.

Monitoring to measure the biodiversity outcomes of port developments

As discussed above, new port developments or significant changes to existing ports present new opportunities for pests to arrive and establish. If a more detailed understanding of the marine pest implications from these is required, before (baseline) and after (post-development) monitoring may be considered to assess the outcomes of these types of changes and could potentially be broadened to not only focus on marine pest implications, but broader biodiversity consequences of any development.

This type of monitoring program would likely draw on many of the principles in the current NMS, for example setting a target survey sensitivity, but should also consider more clearly defining the required spatial extent and target pest densities required. If pre- and post-development monitoring is conducted at exactly the same points within the area, this should increase the ability of the system to detect any change. In order to help attribute any observed changes to the development, pre- and post- monitoring at nearby un-manipulated areas should occur also (Underwood, 1994).

Recommendation

Consider before–after monitoring for new port developments or if there are significant changes to existing ports.

Appendix A: Stakeholder Consultation

Introduction

A wide variety of stakeholders are involved in the National Monitoring Strategy (NMS). Consultation was held with many of these stakeholders including policy, operational and scientific officers of state and territory agencies (including New Zealand Ministry for Primary Industries and NIWA), industry, including port authorities and shipping organisations, taxonomists, private consultants, and those who played a role in the development of the system. The list of stakeholders consulted was based on advice from Department of Agriculture officers, ABARES contacts in marine pest surveillance and further recommendations from stakeholders.

Consultation was held primarily to engage feedback on views of the current monitoring strategy. The discussions focussed on high level issues, such as major impediments to adoption of the national strategy and improvements which could be made, through to more targeted issues such as experience with and use of MDET, or the selection of target species. A total of 30 semi-structured face-face interviews or teleconferences were held with two ABARES staff and between one and four interviewees per agency. Only one organisation or jurisdiction was interviewed at a time. Discussions took between 45 minutes and 2 hours, depending on the depth of discussion and number of topics relevant to that stakeholder.

Prior to meetings or teleconferences, ABARES provided the stakeholders with a summary of issues of interest to the marine pest monitoring review. Stakeholders were advised that it was not necessary to cover all issues in the document, particularly if an issue was not relevant to their work or knowledge. It must be noted that not all stakeholders were able to comment on all issues.

Here we present a detailed summary of the consultations. A shorter summary is provided in section 3 of the report and key points of feedback appear throughout the report where appropriate.

Current monitoring

Consultations indicated that whilst monitoring in accordance with the national strategy requirements has only been conducted in a few locations, monitoring for marine pests is performed outside of the current NMS. Monitoring is conducted by state and territory governments, private industry, National Resource Monitoring groups, universities and community groups. The key points on the current state of marine pest monitoring in Australia are:

- monitoring according to the national strategy requirements has only been undertaken in a few locations
- monitoring by jurisdictions is generally targeted at early warning or responding to an incursion
- additional monitoring by the private sector occurs in some jurisdictions because of legislative requirements or specific agreements with government.

National Strategy monitoring undertaken in few locations

Monitoring according to the National Monitoring Strategy guidelines (the guidelines) and manual (the manual) in the National Monitoring Network (NMN) locations has been conducted

in the Northern Territory, Western Australia and South Australia, with little monitoring conducted on the east coast of Australia and in Tasmania. Several locations which are not identified as priority locations in the NMN have also been monitored according to the manual and guidelines, such as Skardon River in Queensland, and several locations in Western Australia. In all but one jurisdiction, stakeholders indicated it is unlikely that future monitoring will be undertaken by jurisdictions in accordance with the NMS.

Monitoring by jurisdictions is generally targeted to threat-specific follow ups and is highly targeted both to species and location

Consultations indicated that monitoring by jurisdictions is primarily threat-specific. This monitoring is largely as a follow up to a report of a marine pest species, for example, from the public or staff (citizen science is discussed further below). The design of the follow-up delimitation surveys is not in accordance with the NMS design, rather these surveys are species-specific and focus on areas of highest risk of invasion.

Monitoring is also undertaken to detect population changes of established marine pests. Similarly, if a pest has been predicted to spread, monitoring may be conducted to test whether this prediction is true. Again, in both of these cases, monitoring is highly targeted to a particular species and to sub-locations thought to be at highest risk of invasion.

Several NMN locations in Western Australia are monitored with an additional system called Ninja, in years when monitoring according to the NMS is not performed. This system again is more tightly targeted to areas of highest risk than the NMS, more like the system in New Zealand where the primary objective is early warning.

Monitoring by the private sector

In some jurisdictions, such as Western Australia and the Northern Territory, monitoring for marine pests is tied into port development applications. In Western Australia, legislation requires companies developing a new port to carry out monitoring in accordance with the NMS requirements. It is also understood that in some jurisdictions, such as in South Australia, aquaculture establishments conduct environmental monitoring. However the focus of this monitoring is not on marine pests, and it is unclear the extent to which marine pest monitoring is captured.

Some private sector consultants who perform marine pest monitoring on behalf of governments or other organisations have based their survey design on the NMS methods. In some cases, for well-resourced companies, the cost of monitoring was said to be of less concern, compared with having, and meeting, a national standard, which they see as providing extra credibility to their work.

Monitoring for early-warning

In jurisdictions where national strategy monitoring occurs, as well as in jurisdictions where it has not occurred, additional early warning systems may be in place. Western Australia and the Northern Territory have early detection monitoring in several locations. Typically, this involves passive surveillance methods and includes arrays with settlement plates and/or rope mops, which are checked relatively frequently (between 1 and 6 months, depending on the jurisdiction, location and program). It is acknowledged that these arrays cannot detect all species, and thus this monitoring is targeted to fouling species which have been identified as high risk to that location, such as the Asian green mussel. Other early detection monitoring methods include shoreline walks and the deployment of crab traps and crab condos several times per year.

Objectives

Stakeholders were asked whether they felt the NMS, if fully implemented at the 18 locations every two years, in accordance with the guidelines and manual, could meet both the intended specific and broader objectives of the NMS. Feedback was often that the answer depends on the interpretation of the objective, as many of the objectives were perceived as too broadly worded. Some were almost unanimously regarded as impossible for the monitoring strategy to meet, while others received mixed feedback, depending on the stakeholders' perspective.

Specific objectives

- ***to detect new incursions of established target species at a given location i.e. species already established elsewhere in Australia but not recorded at that location.***
- ***to detect target species not previously recorded in Australia that are known to be pests elsewhere.***

The feedback on these two objectives was mixed, both because of varied opinion and because of the general wording of the objectives. If the objectives are interpreted as asking about whether the methods described in the manual are suitable for detecting the target species, then the general conclusion is that they are, and therefore they should detect a range extension or an incursion of a pest in Australia.

On the first objective, if the question is whether the NMS will detect range expansions between the 18 monitored locations, then feedback was generally that this will be achieved. However, if the question is whether *any* range expansion would be detected, stakeholders generally felt that the NMS would not be capable of this objective, as only a selection of locations are monitored.

The interpretation of 'new incursions' is also relevant, as while stakeholders thought that an expansion of pest range would be detected, it would only be 'new' in that it would have arrived in the last two or more years, and not 'new' in the sense of an early detection. The second objective, which does not specify 'new incursions', was regarded as being able to detect a species not previously known in Australia, though once again, with monitoring conducted every two years (and with a design sensitivity of 0.8), it may not be an 'early detection'.

Some stakeholders also pointed out that meeting these objectives relies on the assumption that the species are both detectable and identifiable, which may not be true, particularly for species larval stages.

- ***to detect introduced species that appear to have clear impacts or invasive characteristics.***

Feedback on whether the NMS can meet this objective was varied. The guidelines acknowledge that it is impossible to predict all species which may become invasive in Australian waters, stating '... a secondary benefit to monitoring may be detection of species that are new and display invasive characteristics'. The guidelines (p21) provides a list of observations that might indicate the presence of an unknown invasive species.

Some stakeholders were confident that those conducting the survey would be able to identify unusual species with invasive characteristics, alongside the target species. A common reason for this is that a new species showing invasive characteristics or impacts should be obvious, for example, as it would form a monoculture in one area, or cause a noticeable change in the area.

It was also thought by some stakeholders that those observers who had more field experience, and who had had multiple visits to the survey site, would be more able to notice unusual new species, than those that didn't. In New Zealand, teams who monitor for marine pests are designed to have several members who have observed the same sites several times. This ensures the teams are familiar with the environment and can notice new or unusual features, such as those that may be caused by a new pest.

Conversely, some stakeholders felt that if inexperienced people were conducting the survey, then it is unlikely this objective would realistically be achieved. Though the observers may be attempting to search for non-target species, there is concern from some stakeholders that many people will not be able to distinguish exotic species from natives. Some stakeholders also suggested that even experienced divers are only able to search effectively for a limited number of species at a time, and so cannot be certain to detect every species. Multiple stakeholders expressed concern that the target list results in 'blinkers', where surveyors focus on target species and not other species.

Broader objectives for the data:

- ***inform the risk assessment of vectors to inform National System prevention measures (pre-border controls)***

The meaning and intent of this objective was unclear to many stakeholders. Generally, stakeholders were uncertain of how the type of data gathered by the NMS could inform vector risk assessments, except in the broadest of terms, by providing information on which locations contain which pests. Vessel detections, which the NMS does not include, were highlighted as the most informative data for vector risk assessment.

- ***provide earliest detection possible to trigger and inform emergency response arrangements in the event of an incursion***

Many stakeholders expressed surprise that early detection is an explicit objective of the NMS. There was consensus that a system of monitoring every two years is not sufficient to provide earliest possible detection, particularly if the objective of early detection is for eradication.

Several hold the view that an invasion which is of sufficient size to be detectable will be too large to be eradicable in most cases. One stakeholder commented that it may not be realistic to expect that pests can be detected at an eradicable stage: *'If you can detect it, you can't eradicate it, and if you can eradicate it, you can't detect it'*.

While the black-striped mussel outbreak in Cullen Bay Marina was successfully eradicated, many stakeholders were of the view that this was an exceptional case, which is unlikely to represent a normal detection and eradication event.

- ***inform decision making for the ongoing management and control of established marine pest populations, including informing risk assessments***
- ***inform broader policy decisions on marine pest management***

Feedback on these two objectives was mixed, possibly because monitoring in many of the NMN locations has not occurred, thus the discussion of how the data may be used is often hypothetical. The objectives are also very broad, so while it may be possible to interpret the

objectives in many ways to fit the data, many stakeholders noted that in practical terms these objectives do not effectively drive monitoring activity.

For example, the baseline survey data was used in the development of management plans for five pest species. In this way, the data was useful, yet several stakeholders point out that none of these management plans have been implemented and so have had no effect.

There was some feedback that the monitoring data would need to be accompanied with extra information, such as knowledge of the biology and characteristics of the pest species in question, before it could be truly useful.

The Commonwealth utilises data from the NMS for many policy applications. For example, it is used to maintain ballast water risk tables for the Australian Ballast Water Management Information System, though as yet, the tables are not applied to a national domestic ballast water system. The data is also used to inform the Monitoring Design Approval Panel, who may take into consideration the findings at one location when looking at a planned survey at another location. General purposes such as informing biosecurity measures and tracking which pests are present in Australia are also relevant, as is this knowledge for international discussions. The use of NMS data, for example for policy decisions and in an international context, was not widely understood by stakeholders.

Other comments on objectives

Stakeholders were asked whether there were other objectives not identified in the guidelines or manual, which they would like to see as part of a National Monitoring Strategy. The strongest message received on this question was that whatever the objectives are, there must be agreement from all jurisdictions and stakeholders, the system must be fit to meet the objectives, and the application of data from the system must be clear and relevant. The most common complaint about the objectives of the current system was that the objectives themselves, and how the system could possibly meet them, is unclear.

It was noted by many stakeholders who have had a history with the NMS was that the objective of the monitoring strategy supporting a domestic ballast water system was missing. If the objective of supporting a domestic ballast water system was included, it was emphasised that this would need to be truly national, that is, monitoring implemented in all jurisdictions, or it would be ineffective.

Several industry stakeholders commented that, since prevention is preferable to eradication, it would be ideal if an objective of the National Monitoring Strategy were to identify failures in the prevention system. A detection of a pest through the monitoring strategy should be able to be used to address the risk of further introductions via that vector or pathway. While this is broadly included in the current objectives, stakeholders were unsure of the ability of the NMS to inform vector risk assessments and hence prevention measures.

Several stakeholders emphasised that whatever the objectives, there will not be one set of methods and survey design which can meet all of them. If there were multiple objectives, such as early detection and informing a domestic ballast water system, the necessary monitoring designs to meet those objectives would be considerably different and should be designed in that way. Some stakeholders cautioned that a system which attempts to meet too broad a range of objectives may not be able to achieve any of them.

Locations

The strongest view from stakeholders was that location selection should be guided by the objectives of the monitoring strategy. Factors which were not considered in the original port prioritisation were discussed, such as asset value, recreational fishing vessels and aquaculture. The main elements of the discussion of location were:

- Location selection should be guided by the objectives of the monitoring strategy.
- The principles behind the selection of the current 18 locations are regarded as sound for informing a domestic ballast water system, but other factors may need to be considered if the system is to meet other objectives.
- Location selection needs to be reassessed as a result of changes in location activity and shipping patterns.
- Asset prioritisation could be considered in the selection of monitoring locations.
- Flexibility for jurisdictions to alter monitoring locations may be desirable.

Location selection guided by objectives of the monitoring strategy

Several jurisdictions focussed on monitoring to support a domestic ballast water system. These stakeholders felt that if supporting a domestic ballast water system was an objective, then the prioritised locations made sense. However, many of these stakeholders were of the view that once a location was deemed 'high risk', continued monitoring in that location was unnecessary unless there were to be a reassessment of that status. In this way, under the domestic ballast water system, monitoring was to provide evidence that a location was 'low risk'. This links to views by the majority of jurisdictions, who indicated they would most likely select other locations in their state to monitor, often on the basis that they already knew some NMS locations had substantial pest infestations, while monitoring at other locations would provide new information.

For the purposes of an early warning system, few stakeholders felt that ports were not the right locations to monitor. One stakeholder noted that far more detections had been made by citizens, outside of the monitoring program, and outside of the port areas. However, some other stakeholders noted that ports are the appropriate locations to monitor as they are the most likely arrival point of pests, and, because they are typically disturbed habitats, they are also the most likely areas for pests to establish. Another stakeholder suggested that there needs to be a risk-ranking for locations for early detection, based on frequency of vessel traffic, habitat availability for pests and likely spread.

In the consideration of location selection, other points raised during consultation include:

- Continuity in monitoring locations for monitoring over time.
- Taking a strategic view of assets across the country.
- Recreational boats, including international yacht arrivals and aquaculture risks need to be accounted for.
- Remove current locations and only monitor new developments, for example, new ports or changes in location activities (new development).
- Ensure all port developments are required to monitor for marine pests before development, during and after.

Reassessment of locations as a result of changes in location activity and shipping patterns

For informing a domestic ballast water system, the locations would need to be updated to reflect changed shipping patterns and activity. Some stakeholders believe that the highest risk locations in their area of expertise remain unchanged, whereas others suggest that changes in vessel type, volume and port of origin, since the design of the system mean that the location selection should be reviewed. For example, some stakeholders suggested that Hobart may have changed in risk profile as the amount of international shipping arrivals has decreased substantially. Jurisdictions with high levels of mining activity have seen the development and expansion of many ports in recent years, and these should be included in any risk assessment.

In a location selection system based on the risk of pest introduction, some stakeholders felt it may also be worth considering the activity at the location. Activity at a location, such as construction or dredging, may increase the pest risk by disturbing the area and increasing certain types of traffic, such as slow moving barges. There was comment from industry that specific types of monitoring being fixed to port project development stages provides certainty for those wishing to complete any activity in a port, and allows for better planning of the cost and timing of this monitoring. A similar suggestion was that monitoring could be linked to specific risk stages of a project. Generally, stakeholders thought it reasonable that a baseline survey could be completed before major development or activity.

There is a perception that the development of a domestic ballast water system was a priority at the time that the NMS was designed, and that this influenced the selection of locations. It is understood that some emphasis was placed on locations where a large volume of ballast water exchange occurs. Opinion is divided over whether location selection would change if biofouling were more heavily weighted in a location's risk profile. Some stakeholders suggest that the inclusion of shipping volume as a risk factor is a sufficient proxy for biofouling risk. Others were concerned that while not all vessels carry ballast water, all vessels can carry biofouling, and therefore that biofouling risk may not be fully accounted for if some vessel traffic was not included in the analysis, such as recreational fishing vessels. Other risk factors that stakeholders suggested may not be fully accounted for are aquaculture and international yacht traffic. Whilst international yacht arrivals were accounted for in the location selection, it is understood at the time of development, data on international yacht arrivals was incomplete. Locations with heavy international yacht traffic such as Thursday Island are not captured as priority locations under the current system.

Asset prioritisation

Asset prioritisation was also suggested by some stakeholders as worth considering when prioritising locations. The initial location selection did not consider asset value and prioritisation, but several stakeholders mentioned that this could be relevant in several contexts. This may include assessing the value of environmental or economic assets (for example, aquaculture and tourism) across Australia, and the potential impacts of invasive marine pests at these locations.

Flexibility

Flexibility for a jurisdiction to change which locations it is required to monitor in accordance with the national system may also be desirable. While a formalised ranking system was not generally criticised by stakeholders, more than one commented that it would be good if jurisdictions could make a justified change to their NMN locations. Reasons for location

modification may include lack of likely pest habitat in a selected location, or close proximity and connectivity to another location which is monitored under the national system.

Target list

The majority of stakeholders were of the view that the target species list requires review. Stakeholders noted a number of concerns with the current monitoring list, namely:

- the target species list must align with the purposes of the monitoring strategy
- mechanisms for adding and removing species from the list are needed
- some species on the list are difficult to identify
- set list of species does not capture 'unknowns'.

Target species list to align with the purposes of the monitoring strategy

Many stakeholders expressed that the target species list needs to be aligned to the purpose of the monitoring strategy. Several stakeholders conveyed that one list could not sufficiently be used for all purposes. If the purpose of the monitoring strategy is to support a domestic ballast water system, some stakeholders felt that the species list is too large and should be limited to a small subset of the pests of greatest concern. One suggestion was to limit the target list to only the five species deemed to be the greatest threats, and rely on other types of surveillance for detections of other species. If the purpose of the system was for early-warning, several stakeholders suggested not to have a list fixed in time, but rather ensure continued literature scanning is performed to assess emerging pests and identify particular threats.

Listing criteria

Several stakeholders felt that the criteria for selecting species on the current monitoring list are unclear. For example, there are some species on the list, such as toxic dinoflagellates, which are difficult to identify and cannot be controlled. Other stakeholders pointed out that as marine eradications are rarely successful, any monitoring with the aim of enabling eradication should target species for which a control option exists. Several stakeholders commented that if a smaller target list is desirable, listing criteria must be applied more strictly than they have been in the past.

It was mentioned by several stakeholders that there should be a regular review process to add or remove species from the list, with defined criteria. It was also mentioned by several stakeholders that a mechanism is needed to add species to the list, for example, if there is a new incursion of a previously unknown or untargeted species. In determining criteria for pests, stakeholders felt that the potential impact of species should be considered, and those with the highest impact should be monitored for. The probability of a species arriving, being detected, and causing impact was mentioned as factors to consider when determining a list. Several stakeholders noted that species should not be on the list if they could not be identified (see section on species difficult to identify, p 41).

Some stakeholders felt that additional criteria could be used to further narrow the target list at a particular monitoring location. Currently, MDET can be used to select species based on assumed salinity and temperature tolerances, but one suggestion received was that this process is not adequate, possibly because of out of date or insufficient data on these tolerances. The suggestion was that local marine experts should also be consulted when narrowing a target list, as their experience in the area provides valuable information. Several stakeholders noted that vector information could be incorporated into species selection, and monitoring targeted to species

most likely to be present on incoming vectors. In the absence of high resolution vector information, this may to some extent rely on local expertise. Similarly, another stakeholder suggested that jurisdictions should have the ability to determine their own priority list and be adaptable to changing circumstances.

A view that was expressed by some stakeholders was that if we know a species is already in a location, it is unlikely to disappear, and so continuous monitoring to confirm its presence is wasted effort. This links to the earlier comment that, under a domestic ballast water risk system, once a location is rated as high risk there is little point to continued monitoring, unless there is an expected change in location status.

Species difficult to identify

Several stakeholders noted the difficulty in distinguishing between native and introduced taxa (particularly given that much of the Australian marine fauna is not yet described). The inability to identify several target species, particularly at the larval stage, may be an obstacle to recording complete data from National Strategy monitoring. It was noted that the inability to identify species on the list could cause large impacts in the case of suspect detections, particularly if there is consideration of stopping vessel movements. For these reasons, it was suggested that if there was a revision of the list, or design of new lists, that taxonomists should be involved to provide advice on whether or not the species are able to be clearly identified. The majority of stakeholders noted that the lack of, and continuing decline in, taxonomic expertise in Australia, is of key concern. In addition to professional taxonomic expertise, with any monitoring system, field staff and others involved with sorting and preparing samples need appropriate training and experience, or monitoring is compromised.

Unknown species

Another concern from some stakeholders was that having a set target species list does not allow for 'unknowns', the potential future pests to be detected. The species which next arrives and causes an impact is unpredictable, and may be a species that has no serious invasive history elsewhere in the world. Whilst an objective of the monitoring strategy is to detect introduced species that appear to have clear impacts or invasive characteristics, a concern amongst these stakeholders was that a target list gives rise to a focus on a set species without looking for other evidence of invasion.

An alternative to a target list mentioned by few stakeholders is a 'whitelist' approach. Under this type of system, acceptable species are placed on a whitelist, and any other species are assumed to be suspicious or harmful. This type of approach may help with the problem of 'blinkers', but may be confusing to implement in some contexts. It may be that approaches without a list are better suited to prevention measures.

Methodology

The most appropriate sampling methods and monitoring design depend on the objectives and goals of the monitoring strategy. The current methodology and monitoring design was deemed too costly by the majority of stakeholders, with the majority of jurisdictions advising that they were unlikely to conduct future monitoring in accordance with the national system. The majority of stakeholders felt lower cost targeted surveys would need to be explored. Key issues brought up by stakeholders include:

- monitoring design and methods must be designed to meet the objectives of the system

- some modifications could improve the sampling methods, but generally they are fit for purpose
- more cost effective sampling methods and survey design are desirable
- new methods may include assays and next generation sequencing, but these methods and the protocols required are not yet fully developed
- monitoring staff must be sufficiently skilled and experienced
- the monitoring manual needs updating.

Monitoring design and methods to meet objectives of the system

Stakeholders felt that if early detection is an objective of the system, it is clear that the current monitoring strategy is not suitable as early detection would require more frequent monitoring than every two years. As the current system is deemed too costly at every two years, more cost effective methods or designs would need to be employed than those in the current system. If a domestic ballast water system is the objective of a monitoring strategy, then in general, stakeholders felt that there needs to be a degree of statistical rigour, particularly if monitoring were to support regulations or controls. However, for early detection, this rigour may not need to be as strict, as frequency and coverage were considered most important. Some stakeholders suggested that even the current level of rigour is excessive, but others feel that it gives credibility to the system.

Some modifications to sampling methods, but generally fit for purpose

In general, there were no comments against the ability of the current methods being able to detect species, however some methods were noted as not being effective in particular circumstances. In practice, stakeholders modified these to suit conditions. For example, in some areas of Australia, divers are not able to be used because of OH & S concerns. This is particularly the case where crocodiles are present in the water, as well as in mining ports where divers are unable to enter the water. In these circumstances, stakeholders used remote-operated vehicles as an alternative to divers. Some examples of other modifications to sampling methodology noted by stakeholders include changes to the shoreline surveys, replacing beam trawls with an epibenthic dredge, and altering the timing at which epifaunal scrapings are conducted. These modifications are typically based on staff experience and research of the literature.

Several stakeholders noted that sample processing was an issue. While not needing to be trained taxonomists, staff need to be skilled in order to search through samples effectively, and process samples for taxonomic identification. In the experience of some stakeholders, this was not always the case. There was concern from these stakeholders that surveys could be compromised because of staff capacity.

There were several additional methods that stakeholders noted could be applied in the monitoring strategy. In several jurisdictions, early warning monitoring for targeted species occurs. In Western Australia, settlement plates are used in conjunction with shoreline surveys, 'crab condos' and traps, as an early warning system. The Northern Territory also uses settlement arrays. It was mentioned by some stakeholders that these methods are significantly less expensive than monitoring to the NMS standard. This could allow them to be used for an early warning system, where the frequency of surveys is important.

New technologies

Stakeholders often mentioned DNA based methods, such as PCR assays, are potentially suitable for low-cost targeted monitoring. However, these assays are not at the stage where they can be reliably incorporated into a monitoring strategy. As for most sampling methods, to ensure that they work efficiently, samples need to be collected and stored correctly, and DNA extraction methods need to be performed correctly.

It is understood that molecular techniques could in future be a useful way to streamline surveys and help to reduce costs. However, stakeholders who promoted DNA methods often felt that these could not replace the need for taxonomists to identify voucher specimens to confirm positives. Rather, they felt that the targeted assays could be used for monitoring of locations for the presence of a set target list of species, in a way that might support a domestic ballast water system. There was general consensus that when using DNA methods, there would need to be agreed protocols in the case of positive detections. For example, where a positive result is detected using assays, stakeholders stated that follow-up physical surveys are needed to confirm the species presence, whether living individuals are present and where they are located, because an assay can only give evidence of the presence or absence of a species, and not whether it is alive or dead, or its physical location.

SARDI are in the process of testing 10 species-specific assays. These assays may, in future, represent an additional method for species detection. For larval samples where an assay is used, work is in progress to relate the strength of a DNA signal to the population of the species in question, but as yet, an assay cannot give information about population size.

An alternative DNA technology is next-generation sequencing. This method involves sequencing all DNA in a particular sample, for example, a scraping of biofilm from a settlement plate. The full DNA sequences of all the species present in the sample are then compared with a reference database (NCBI BLAST; <http://blast.ncbi.nlm.nih.gov/Blast.cgi>), and all species, or as many as possible, present in the sample are identified. Next-generation sequencing is not widely applied in marine pest monitoring, partly because of the cost, which is considered prohibitive. However, as with all technologies, it can be expected that costs will decrease in future. Some stakeholders suggested that while next-generation sequencing could not be considered as an immediate improvement to the NMS, it may be in the future.

Monitoring manual to be updated

It was noted by several stakeholders that the monitoring manual was out-of-date. Some of the sample processing techniques do not meet current legislative requirements, processing techniques are not current, and the taxonomic contact list requires updating. A stakeholder commented that in some ways the manual is overly-prescriptive, yet does not contain enough detail to allow it to be followed completely as a standard operating procedure. It was suggested that a decision should be made whether the manual's purpose is to provide standard operating procedures, in which case it needs more detail, or to provide guidance, in which case it needs to be simplified.

MDET

Just over half of all stakeholders consulted could provide comment on MDET, and only four stakeholders had used MDET to design a survey. The principles behind MDET were often thought of as sound, particularly the aim of ensuring statistical rigour in a survey and standardising monitoring across locations. Stakeholders felt that this rigour and consistency across locations was enhanced by each monitoring design requiring approval by the Monitoring

Design Assessment Panel (MDAP). However, the interface of MDET was generally regarded as intimidating, confusing or clunky. It was regarded as useful to have a standardised starting point for survey design, though several stakeholders felt that more flexibility could be added to the survey design, if rigour could be maintained. Stakeholders felt:

- some assumptions are unrealistic
- the principles behind MDET and the consistency it provides are positive qualities, though stakeholders would like more flexibility
- the useability, interface and transparency of MDET are not satisfactory.

Assumptions

MDET selects which species should be monitored for at a particular location based on temperature and salinity data. Several stakeholders commented that the selections the MDET automatically makes are likely incorrect. This may be because of out of date, or, most likely, lack of species information, which is an issue that cannot be entirely solved. Some stakeholders verified the list of target species with specialists in their jurisdiction, and in this way added or removed species from the list, with justification. A stakeholder suggested that to allow for further prioritising within the target list, vector information could be added to this step to focus on which species are more likely to arrive in that particular location.

Another stakeholder noted several problems with the MDET assumptions, such as that it only assumes that sampling /encounter rate is imperfect, whilst sample processing is assumed to be perfect; the reality is that field staff may lose species in the sorting of samples, and it may not be possible to taxonomically identify species. Several stakeholders also noted that the costs MDET provides are not realistic.

Principles

A key principle behind MDET is a sensitivity of 0.8, or an 80 per cent probability of detecting a specified population of the species, given its presence. We discussed this principle with stakeholders, and found that the requirement for standardised sensitivity level largely depends on the purpose of the system. A monitoring strategy which produced data upon which regulatory decisions depend would require a degree of standardisation and be comparable between locations. In this case, to support a domestic ballast water system, a set sensitivity may be required. However, if the objective of monitoring is the early detection of new incursions, monitoring with a wider coverage of locations, higher frequency and the ability to target areas of high risk may be a greater priority than direct comparability of data between locations.

Because the sensitivity requirement is also based on an assumed population of the target pest, small survey areas can translate to a relatively high density and greater ability to detect the pest. In larger areas, the density based on that assumed population is much lower.

Views on the principle of standardising surveys using MDET tended to vary with how much understanding the stakeholder had of the statistics behind it. Those who had used MDET but did not have statistical expertise trusted that the calculations were correct, and concluded that while the theoretical aspect must be correct, the practical implementation of such a survey design was not sufficiently considered. Some other stakeholders with more in depth knowledge of MDET were concerned that this confidence would lead to 'false rigour', where survey designers believe that their survey is more statistically powerful than it really is. For example, they might have good confidence in the sensitivity calculated by MDET, because they are unaware of the

assumption behind the sensitivity calculation, that the species are distributed randomly, instead of the more likely scenario of a patchy distribution.

Some stakeholders commented that the principle behind having a set level of survey rigour is desirable, and would be beneficial to the quality and comparability of the data. In some locations, the 0.8 sensitivity is easy to achieve, while in others, the sensitivity must be lowered because the sample numbers become impossible to achieve. In many cases, the sample numbers were not just so large that they made the project expensive, but would actually be impossible to implement (for example, 600 benthic trawls).

One person who had used MDET commented that it is possible to reduce the size of sub-locations in MDET, as a way of targeting high risk areas while using the NMS, and also reducing the sample numbers. This approach seems to be legitimate and within the principles of the national strategy, though it must also be justified to the MDAP. One stakeholder expressed concern that the ability to adjust surveys in this way means that different surveys are not as comparable as many believe them to be.

When monitoring is performed outside the NMS, most stakeholders select the highest risk locations for monitoring, rather than spreading effort over large areas as the national strategy suggests. Stratification is possible within the NMS, but not to the extent that targeted surveillance efforts often achieve. For example, in one case of monitoring completed outside the NMS, the locations sampled most intensively were directly associated with the vectors expected to translocate marine pests; the pilings the ships berthed next to, and the sediment directly underneath (this approach was also suggested by other stakeholders who had not completed monitoring). In other cases, the targeting was less intensive, but still relied on those with experience of the area and species to select the most likely areas for establishment of marine pests.

Several stakeholders would like to see MDET be made to be more flexible, whilst still maintaining rigour. For example, these stakeholders felt there was no point in monitoring one of every habitat type, if the pest was not likely to be there. Some stakeholders suggested the design should be a more targeted system, which will therefore be more cost effective. These stakeholders suggested targeting sampling to where the pests are likely to be, for example hard substrate where biofouling organisms live and areas where ballast discharge occurs.

Useability

Few stakeholders had used MDET to design a survey. Some users commented that once they had learned to use the system, it was tolerable, but that the guidance material provided was not sufficient. It seems that rather than being able to rely on guidance material, those who use MDET rely on the experience of others, and personal communications, to learn its use. Though most stakeholders felt that it was too complicated for designing a survey, it is understood that MDET was originally designed in Excel as it is a program that all users could be expected to have access to and be proficient in, rather than more complex statistical programs.

However, many who had used the template commented that it does not necessarily need to be in Excel, particularly if this affects transparency. Some who had used MDET commented that they would prefer to be able to see the 'back end', or the formulas behind MDET's calculations. To others, this was not an issue. Because MDET may be used by a variety of people, it was suggested that there could be the option of accessing the detailed equations behind the outputs, while putting this on the front of the interface may not be necessary as not everyone will need to see it.

Citizen science

Citizen science is widely used throughout Australia, and has resulted in some detections of invasive marine species. Arrangements vary between jurisdictions, and may be in place at community, local government, NRM region and state/territory level. Stakeholders were generally in favour of citizen science as a support for marine pest monitoring, with several cautious that it should not be a replacement for monitoring programs. In general, citizen science was thought of as a complement to formal marine pest monitoring arrangements. The key points on citizen science raised by stakeholders were that:

- citizen science is widely used and includes passive surveillance and active surveys by members of the public
- citizen science could be used as a tool for early detection
- resourcing and support for those conducting citizen science is vital.

Use of citizen science throughout Australia

There were many examples of citizen science programs provided during consultation. These range from truly passive surveillance, where chance observations can be reported to state and territory agencies and investigated, to active citizen science programs, where members of the public are trained and coordinated to conduct a survey. Some of these programs involved the distribution of communication materials such as brochures, stickers and posters at targeted areas such as marinas, slipways, or recreational fishing areas. Other activities included talking to vessel owners, providing live specimens in tanks for display, and giving talks at various community meetings and schools. In Western Australia, an example was provided of apps that have been developed to assist the public in identifying pests: 'Fishwatch' and 'Pestwatch'. In South Australia, support has been provided to Reefwatch divers on multiple occasions, who conduct underwater surveys as well as being capable of observing pests as part of their recreational dives. This support included providing an identification workshop and training programs on pests of concern. A similar program is Reef Life Survey, where divers may be assisted in their identifications by para-taxonomists, who are in turn supported by fully trained taxonomists if needed. Citizen science can also provide very intensive survey effort, as demonstrated by the Nelson Bay Nudibranch Census. The census involves interested divers who are provided with identification training, and collects very detailed data on nudibranch presence, including invasive species.

Citizen science as a valuable tool

A common theme from stakeholders was that citizen science has an important role in marine pest biosecurity, particularly for the objective of early detection of new incursions. One stakeholder described citizen science as having a 'track record' of early detections, both for pest incursions and for detections on vessels. Reasons given for its success include the personal engagement of those conducting the surveillance, the frequency with which they can make observations, and their familiarity with a particular environment or area. Citizen science is thought of as a low cost method for early detection. Many noted that citizen science provided many more eyes over a large area. A stakeholder noted that citizen science could raise the profile of marine pests.

Many stakeholders noted that not all pest species are suitable for inclusion in a passive surveillance system. Macroinvertebrates such as crabs are more likely to be suitable, while some

native marine species are difficult even for trained taxonomists to identify. There was also a concern from a few stakeholders that too much emphasis may be placed on citizen science, and that it should be used to complement monitoring, not replace monitoring.

Resourcing and support

While citizen science was raised as a useful tool for early detection, stakeholders noted that it requires a knowledgeable and informed community to be effective. Stakeholders raised the need to consider the available support for those who are being relied upon to conduct surveillance. Some stakeholders emphasised that strong support for those reporting detections results in better participation. This has been experienced in areas where citizen science has been used, with a stakeholder noting that face to face engagement has been much more effective than simply distributing materials. An informed community also means one which knows who to report a suspicious organism to. In small communities, this may arise from effective engagement by the relevant authorities. To cover a larger area, more organised systems such as pest reporting hotlines may be of use.

There is also the consideration that those conducting citizen science are providing a benefit to the government and that this should be recognised, by allowing the public to see the outcomes of passive surveillance through reporting or data sharing. Participation may be encouraged if citizen scientists can see tangible outcomes from their work. One stakeholder mentioned that citizen science for marine pests could be linked to the Atlas of Living Australia, which is one way of making data visible.

A stakeholder noted that for citizen science to be successful there needs to be a framework around its role in monitoring generally, and continued investment in training and support. There was general agreement from those who had been involved in citizen science programs that they do not work if support is not continued.

Role of Industry

Stakeholders felt:

- there is a role for industry in marine pest monitoring
- industry prioritises prevention, and monitoring which can inform prevention measures.

The shipping industry is recognised as a risk creator for marine pests. There is a strong preference for prevention measures from industry, as these tend to be more cost effective than dealing with a pest after it has invaded. With this in mind, having any National Monitoring Strategy that is capable of informing prevention measures could be appealing to the shipping industry.

Privately owned and managed ports have an interest in the monitoring strategy as most of the monitoring sub-locations are within their jurisdiction. This is particularly important if a domestic ballast water system results in ports having a risk rating, with the potential to impact the image or operations of a port.

Both ports and shipping representatives highlighted that clarity and consistency is a vital consideration for them in any monitoring design. Generally, having more national agreement on monitoring objectives could help with this. Other suggestions include the linking of monitoring to stages of port activity, as mentioned above. A general concern from these stakeholders was that monitoring costs and requirements may be unclear, or cause surprises to activities such as a port expansion or dredging, and so cause uncertainty in their business activities.

Private organisations who conduct marine pest monitoring frequently noted that having a nationally endorsed target list, methods and manual is extremely helpful to them in their business. It can help them achieve confidence and consistency in their work. While the aim of the NMS is not to provide this assistance, it is worth noting this endorsement of a nationally consistent system could in the future result in more comparable and useable data being collected from across a variety of organisations.

The aquaculture industry undertakes some pest monitoring for its own purposes, though this is generally not integrated with jurisdictions' marine pest monitoring. Some jurisdictions noted that connections with aquaculture may improve over time. Recent events such as an outbreak of Abalone Virus could highlight the importance of biosecurity to the aquaculture sector and encourage integration with other monitoring. One stakeholder suggested that aquaculture may be a risk creator for marine pest incursions. Aquaculture could also be considered under an asset protection approach for selecting monitoring locations, as described above.

Impediments to implementing the NMS

Since the NMS was implemented, few locations have been monitored in accordance with the guidelines and manual. The points in this section reflect both impediments identified by jurisdictions, as well as perceived impediments by other stakeholders. The main impediments raised by stakeholders were:

- cost
- lack of clarity around objectives and purpose
- lack of resources, particularly taxonomic capability
- low profile of marine pests and marine issues generally
- uncertainty around monitoring responsibility between risk creators and beneficiaries.

Cost and objectives

According to the majority of stakeholders, the cost of completing a survey according to the monitoring guidelines was the dominant reason monitoring was not conducted. This cost, linked with the lack of clarity around objectives and purposes, prevents the national system from being fully implemented.

Monitoring a location may cost between \$150 000 and \$500 000, depending on its size, depth, risks such as port activity or dangerous animals and availability of expertise. This is a significant outlay in comparison to the cost of supporting passive surveillance or citizen science, or having frequent checks of settlement arrays. There was some discussion of cost-sharing to assist with this, but as the objectives of monitoring will alter who the risk-creators and beneficiaries are, this would depend first upon re-clarifying the objectives of the strategy.

This is not to say that simply lowering the cost of the system would guarantee its implementation. For some stakeholders, the issue of cost interacts with the lack of clarity around objectives. It may be that even a low cost system would not be implemented, because the objectives and the ability of the system to meet the objectives are not sufficiently clear to many stakeholders in their current form.

Historical issues may also discourage jurisdictions or others from monitoring according to the national system. The domestic ballast water system which influenced the design of the NMS has not been implemented, and so there may be discouragement about any revision of the system if there were not a clear indication that the data will be supporting a concrete outcome.

Additionally, several stakeholders felt that one of the main reasons for the high cost of the system is the rigour required to support this domestic ballast water system. Because that rigour is not currently being used in a ballast water system, they feel that investing significant funding into the NMS would not be worthwhile.

This is particularly relevant when cost is considered, as one of the reasons for the high cost of the system is the statistical rigour required to support a regulatory system.

Low profile of the marine space

A number of stakeholders noted that there are no visible impacts of marine pests, which links to comments by others that there is a lack of profile of marine issues by governments. The marine biosecurity sector typically does not have the same profile as other biosecurity sectors such as animal health. There is a wide variety of reasons for this, but one likely factor is that the impacts of marine issues are generally invisible to the public, which in turn leads to little political urgency. An exception was seen with the black-striped mussel incident in Darwin. Some stakeholders perceived that the comparably low profile of marine biosecurity can make funding hard to secure. Linked to this is the practical reality that marine pest eradications, or eradication attempts, are costly and are rarely successful.

Another issue raised was responsibilities and beneficiaries. The question of who is responsible for implementing and funding monitoring, and who benefits from monitoring occurring, commonly arises. The low profile of marine issues makes it more difficult to pinpoint the beneficiaries of monitoring. For instance, industry bodies contributed significant funding to conducting the initial baseline surveys, on the expectation that a domestic ballast water system would be implemented based on this data, and that they could receive a benefit such as a low risk rating for a port or an exemption from domestic ballast water exchange. Given that no concrete product came out of those surveys, stakeholders suggested that those same bodies would be reluctant to agree to fund another monitoring strategy without very strong reassurance that the system will be followed through to implementation.

Resourcing and taxonomic capability

A number of jurisdictions noted the lack of resourcing in their organisations as an impediment to conducting the monitoring in accordance with the NMS. Several of these jurisdictions stated required expertise is declining. Another obstacle to the NMS, and indeed to all marine biosecurity issues, is the lack of taxonomic expertise in Australia. Very few marine taxonomists are available, and a lack of funding means that training of new taxonomists is difficult.

It is possible that the profile issues discussed above contribute to the unstable funding environment for taxonomy more generally. Taxonomists consulted were concerned that too few people were available for identifications in this field.

Taxonomists are not the only skill area which is lacking. Changes in organisations and funding mean that many organisations have a high staff turnover rate. Some stakeholders felt that this contributed to the lack of capacity, as new staff are likely to have less experience with marine monitoring.

Potential improvements to the monitoring strategy

We sought input from stakeholders on how they thought the NMS could be improved, in order to encourage stronger participation, better meet its objectives, or otherwise be made more effective. National consistency was very desirable for many stakeholders, including industry. While a system may not be able to meet all objectives of all interest groups, there is broad support for some form of National Monitoring Strategy for marine pests. Many stakeholders felt that for monitoring to be undertaken, in a nationally consistent manner, more cost-effective ways of monitoring must be explored.

Many improvements that could be made were put forward.

Revisiting the objectives

Many stakeholders felt that the objectives and purpose of monitoring needs to be re-visited. Once there are goals that have been set, and agreed to by all stakeholders, then a monitoring strategy (or systems) could be designed to meet these goals. Several stakeholders noted that different systems should be designed to meet different objectives, or else the system may not be fit for purpose. For example, separate systems for early detection and domestic ballast water system may be needed, though the systems could be coordinated.

The objectives of the system will help define the risk creators and beneficiaries. Some stakeholders felt that clarifying where responsibility for planning, funding and implementing marine pest monitoring lies would help create engagement with a monitoring strategy, and therefore a better chance that it would be fully implemented.

Achieving early detection

It was noted by several stakeholders that if the monitoring strategy were to meet the objective of early detection (though the goal of eradication is contentious), more frequent monitoring is needed. By extension, costs would need to be lower, as cost is currently preventing even two-yearly monitoring from being carried out. High-frequency, low-cost methods could include citizen science, passive surveillance, and simple methods such as shoreline walks or settlement plate arrays. DNA methods could have a role in future, as discussed below. It was also noted that an early detection system would not have the same requirement for statistical comparability that the current NMS has, though a degree of rigour is desirable.

The location selection for early warning would need to be determined by the objective of this monitoring. Some alternatives to deciding on monitoring location selection were put forward by stakeholders, such as asset prioritisation and points of first entry. For example, if the objective of early warning is to prevent impacts on high-value assets, such as environment, tourism (for example, Great Barrier Reef) and economic assets (for example, aquaculture), then a strategic view of assets across the country could be undertaken and early warning prioritised on these areas. If the early warning system is designed to be in areas where pests are most likely to first establish, to have the greatest chance of initiating management actions to prevent them spreading, then ports may be the most appropriate areas to target.

Informing domestic ballast water regulations

If the monitoring strategy were to meet an objective of informing a national domestic ballast water system, stakeholders noted that in this case the comparability between locations and the statistical rigour would still be required. However, a common theme was that stakeholders

would like monitoring to be more tightly targeted, in terms of both monitoring sub-location and target species. Many stakeholders felt that a target list of 55 species was too large for a domestic ballast water system, and should be limited to a small subset of pest species of greatest concern, with taxonomists being formally involved in species selection process. Similarly, many stakeholders felt that rather than searching an entire port or bay for a pest, the riskiest areas within the port for example, berths for international ships, areas where ballast water exchange occurs, or ideal habitats for a targeted pest, should be the focus of monitoring. Where monitoring occurs outside of the NMS, it seems targeted monitoring is a common approach. We understand that in a few cases, this could be formally determined, using vessel traffic and other data, but in many cases this relies on the expertise of those designing the survey.

Incorporating low cost and new methods

The potential of molecular methods, such as assays, was suggested as suitable for supporting a domestic ballast water system or early warning for some species. Several stakeholders noted that using assays, plankton trawls could be used several times per year to detect a set number of species at relatively low cost. In this manner, monitoring could occur at greater frequencies than it currently does. Most stakeholders who were in favour of assays agreed that clear protocols for a positive pest detection would be required, particularly if a positive detection had regulatory or management implications such as changing the risk rating of a location in a domestic ballast water system. Several stakeholders felt that a positive DNA detection should be followed by physical surveys. They highlighted that assays could not replace the need for taxonomists during the process, as they are required to identify voucher specimens.

Many of the low-cost methods suggested for early warning will not be able to detect all the species on the target list. Rope mops and settlement plates are often used to target to select types of species, such as mussels and barnacles. Citizen science, too, may only be useful for detecting certain species, as stakeholder acknowledged that species targeted by these methods need to be recognisable and identifiable. Taxonomists were in strong agreement that taxonomic expertise should be more closely and formally involved in both target species selection and the monitoring process, particularly when the target list is being selected, in order to prevent the targeting of unidentifiable or taxonomically controversial species. Citizen science may be a valuable tool, but many noted that this involves a knowledgeable and informed community. In this manner, for citizen science to be successful there needs to be a framework around its role in monitoring generally, and continued investment in training and support. There was general agreement from those who had been involved in citizen science programs that they do not work if appropriate support is not available.

Involvement of taxonomists

Taxonomists were in strong agreement that taxonomic expertise should be more closely and formally involved in both target species selection and the monitoring process, particularly when the target list is being selected. The taxonomists' role in sample identification is also important, and one stakeholder commented that museum taxonomists should be contacted early to identify specimens which have implications for management actions. There is uncertainty in this area from those who need to rely on advice from taxonomists, also; another stakeholder noted that it would be better if there were clear procedures around where to send samples for identification, which could fit with a more formalised procedure around taxonomists' involvement.

Coordinated funding strategy

In line with suggestions that objectives must be clear and owned by all involved, some stakeholders highlighted that a funding strategy is needed. An ideal funding strategy was described by one stakeholder as being one where monitoring, research and training all have a long term future. In this situation, monitoring outcomes would feed into research subjects, and research could in turn feed into an improved monitoring strategy.

Communication

Some stakeholders commented that communication of monitoring results is a weakness. The NIMPIS system is regarded as out of date, though it should provide current information on pest detections at NMN locations, and detections of pests outside of the NMS. Jurisdictions are able to share information on pest detections through the Marine Pests Sectoral Committee and some were content with this arrangement, but some still noted that this type of data sharing is not as good as it could be. Industry and the private sector who work on monitoring are generally excluded from this process and so are less able to access data sharing.

Glossary

ABWMIS	Australian Ballast Water Management Information System: The system developed to support domestic ballast water exchange decisions once implemented.
Ballast water	Water (including sediment that is or has been contained in water) held in tanks and cargo holds of ships to increase stability and manoeuvrability during transit.
Biofouling	The attachment of marine organisms to any part of a vessel, or any equipment attached to or on board the vessel, aquaculture equipment, mooring devices and the like.
CCIMPE	Consultative Committee on Introduced Marine Pest Emergencies.
CRIMP	Centre for Research on Introduced Marine Pests. Ran from mid 1990s to early 2000s.
Cryptogenic	A species whose geographic origins (i.e. whether they are native or non-indigenous) are uncertain.
Epifauna	Organisms that live on the surface of seabed.
False negative	A result that appears negative when it should not.
False positive	A result that appears positive when it is not.
Infauna	Organisms that live within the seabed.
IGAB	Intergovernmental Agreement on Biosecurity 2012.
IMS	Invasive marine species.
Incursion	The unauthorised entrance or movement of a suspected pest species into a region where it is not already established.
Introduction	The transport of an exotic marine species to a location within Australia's marine environment from a source beyond Australia's marine environment.
MDAP	Monitoring Design Assessment Panel.
MDET	Monitoring Design Excel Template: An excel based tool to help design surveys according to requirements of the National Monitoring Strategy.

MPSC	Marine Pests Sectoral Committee: comprised of representatives from the Australian governments (Commonwealth, state and territory) and marine scientists.
NEBRA	National Environmental Biosecurity Response Agreement.
NIMPCG	National Introduced Marine Pests Coordination Group: comprised of representatives from the Australian governments (Commonwealth, state and territory), industry, marine scientists and environmental organisations. Replaced by MPSC.
NMN	National Monitoring Network: Priority location for monitoring under the NMS. Currently 18 locations.
NMS	National Monitoring Strategy.
Parataxonomist	A person who provides assistance in the identification of organisms, but is less qualified than a taxonomist.
qPCR	Quantitative Polymerase Chain Reaction
ROV	Remote-operated vehicle
Sensitivity	The probability of detecting something given presence.
Specificity	The probability that a negative result comes from a truly negative sample; complimentary to the false positive rate.
Taxonomist	A person who specialises in the identification of organisms.
The guidelines	Australian marine pest monitoring guidelines
The manual	Australian marine pest monitoring manual

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