CEBRA Project 1608E: Methodology to guide responses to marine pest incursions under the National Environmental Biosecurity Response Agreement

Final Report

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ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
BCA	Benefit-Cost Analysis (the same as cost-benefit analysis)
CCIMPE	Consultative Committee on Introduced Marine Pests
DAWR	Department of Agriculture and Water Resources
NBIRP	National Biosecurity Incident Response Plan
NBMCC	National Biosecurity Management Consultative Committee
NBMG	National Biosecurity Management Group
NEBRA	National Environmental Biosecurity Response Agreement
NIMPIS	National Introduced Marine Pest Information System
OBPR	Office of Best Practice Regulation
Net present value	Net Present Value (NPV) is the sum of discounted net benefits (i.e. benefits minus costs), and shows whether a project generates more benefits than it incurs costs (Emerton and Howard, 2008).
Benefit-cost ratio	Benefit-Cost Ratio (BCR) is the ratio between discounted total benefits and costs, and shows the extent to which project benefits exceed costs (Emerton and Howard, 2008).
Counterfactual	The base case condition for calculating the costs of impacts, which translate to the benefits (avoided losses) side of the benefit-cost equation.

1. Executive Summary

The National Environmental Biosecurity Response Agreement (NEBRA) establishes the national cost-sharing arrangements between the Commonwealth, States and Territories for responding to significant pest and disease incursions, including in the marine context. When an incursion is of national significance, potentially eligible for cost sharing under NEBRA, and likely to be eradicable, the notifying party responsible for the original notification must supply additional information to assist with decision-making. A benefit-cost analysis (BCA) is one of these key pieces of information.

Development of the initial BCA must be undertaken relatively quickly and ideally by staff with experience in developing BCAs. A particularly difficult aspect of BCA development is identifying and valuing the 'non-market' impacts of the pest on marine environments. In the time-critical context of responding to a marine pest incursion it can be difficult to find (or reallocate) in-house staff with skills in developing BCAs in general, or for marine pest incursions in particular. Some jurisdictions outsource BCA development to consultants experienced in BCA. However, resources may not be available to outsource development of the BCA in all cases.

This report provides guidance to staff within jurisdictions – economists and non-economists – on preparing a BCA for a marine pest incursion. A set of notated guidelines takes staff through the steps required in a BCA and detailed advice is provided in a series of appendices. The guidelines are based on those provided by the Office of Best Practice Regulation, and are consistent with requirements of the NEBRA. They are also intended to improve consistency in BCA development. While only responses that aim at eradication are considered for cost-sharing under the NEBRA[1], the guidelines in this project would be equally applicable to BCA developed for other management options.

Key recommendations

1. **That the Key Requirements for BCA within the NEBRA be re-worked to provide clearer, step-by-step guidance. The guidelines prepared in this report, based on those of the Office of Best Practice Regulation, may provide such guidance**

   The primary purpose of this report is to provide guidance on developing a BCA for a marine pest incursion using established BCA methodology whilst maintaining consistency with the NEBRA's Key Requirements (NEBRA Schedule 4, Attachment 4A). The Key Requirements were found to be inadequate for providing guidance on developing a BCA for a number of reasons, which are elaborated on in Chapter 5.

2. **That jurisdictions be assisted with resourcing for BCA development**

   The potential impacts of marine pest incursions are challenging to understand and value. The time-critical context of a new incursion makes resourcing more

[1] While the NEBRA may fund "initial containment and control work" (Schedule 5, Sect 2.2) it will not fund containment or other management options that are not aimed at eradication.

difficult. Developing a BCA that adequately reflects the potential impacts of an incursion and the costs of eradication will require a team of staff with a range of skills, especially in economics, accounting, science and response-management. While the required skills set is already acknowledged in the National Framework for biosecurity BCA (Attachment 4a, 3e[2]), the intent of that statement should be operationalised.

We therefore recommend that:

a) A list be compiled of available DAWR/ABARES and jurisdictional staff and consultants who may be available to assist in the development of the BCA for submission to NEBRA. A draft list has been compiled in Appendix A (Providers of BCA expertise). This list could be developed further and maintained by CCIMPE.

b) Emergency funding be made available to assist in the development of a BCA.

c) Consider undertaking "retrospective" BCAs as an exercise to develop BCA expertise. Undertaking BCAs retrospectively is likely to provide valuable insights and knowledge that could be used to improve the conduct of future BCAs.

3. **That pre-emptive primary studies be undertaken on the non-market values of the marine environment**

The economics discipline provides a range of rigorous and credible methods for valuing the non-market impacts of marine pest incursions. Unfortunately, most of these methods involve primary data collection through surveys, and may take months and require significant resources to implement. The methods are therefore usually inappropriate for application in the time-critical response context of invasive marine species. Primary non-market valuation studies, undertaken 'pre-emptively', could provide a pool of data from which to make inferences about likely impacts of marine-pest incursions once an incursion is notified. Some information on non-market values in the marine environment has been recently completed (Mazur et al., 2017) and would be valuable to guide further studies as applicable.

[2] NEBRA Attachment 4A, Part 3 (e): "More commonly however, there will be significant uncertainties and unknowns with postulated relationships and impact values, and the BCA will need to employ techniques to handle risk, uncertainty and information gaps. Previous experience with this type of analysis will be important, as will the availability of suitably qualified personnel to conduct the investigation. A good biosecurity BCA requires both economic and scientific inputs."

2. Introduction

The National Environmental Biosecurity Response Agreement (NEBRA)[3] establishes the national cost-sharing arrangements between the Commonwealth, States and Territories for responding to nationally significant biosecurity incidents where there are predominantly public benefits, including in the marine context. The NEBRA contains a formal, ten-step decision structure, describing the process for the national approach to a cost-shared response (steps 6 to 10 are presented in Figure 1). Important parts of this process are the decision-making bodies and the information they use to make their decisions. Early in the response process a National Biosecurity Management Group (NBMG) is convened to consider whether the pest or disease is of national significance, should be subject to NEBRA cost sharing, and is likely to be eradicable. If these things are considered to be likely, the notifying party[4] responsible for the original notification must supply:

1) a risk assessment to consider whether an emergency response should be mounted. It may consider the potential economic, environmental and social amenity impacts, and will be used to develop emergency actions to be undertaken as part of the national biosecurity incident response plan.
2) a technical feasibility analysis that addresses 17 criteria.
3) a benefit-cost analysis (BCA) that considers whether the costs of a national biosecurity incident response would be outweighed by the benefits and, if so, to whom the benefits would accrue.
4) a draft national biosecurity incident response plan (NBIRP) which must consider 7 pre-defined activities/matters, including items 1 to 3 above, as well as specific actions that would be undertaken in a response.

These requirements are outlined in step 7 of Figure 1.

For marine pests, the notifying party supplies these four pieces of information to the Consultative Committee on Introduced Marine Pests (CCIMPE), a committee that is convened following the original notification of the pest. CCIMPE will be involved in developing the NBIRP with the affected jurisdictions. Under the NEBRA, CCIMPE must make a set of recommendations to the NBMG. If the NBIRP is approved and NBMG determines that a national biosecurity incident response is required, CCIMPE will provide advice to the affected jurisdiction implementing the NBIRP.

Development of the BCA under the NEBRA is guided by the National Framework for Biosecurity Benefit-Cost Analysis. The National Framework comprises six sets of ‘Key Requirements’, aimed at achieving a more increased transparency and accountability into national biosecurity decisions. The key requirements do not provide a specific template or detailed instructions for undertaking a BCA and as a result, there is flexibility in how the BCA is presented and structured, and in how non-

[3] The NEBRA was signed by the Commonwealth, state and territory governments in January 2012 and is reviewed every five years. Recommendations from the 2017 review may be accessed at http://www.agriculture.gov.au/SiteCollectionDocuments/nebra-five-year-review.pdf

[4] Section 6.3 (a) of the NEBRA states the chief biosecurity officer, chief veterinary officer, chief plant health manager or equivalent in the jurisdiction in which the suspected outbreak of the pest or disease occurs will comprise the notifying party.

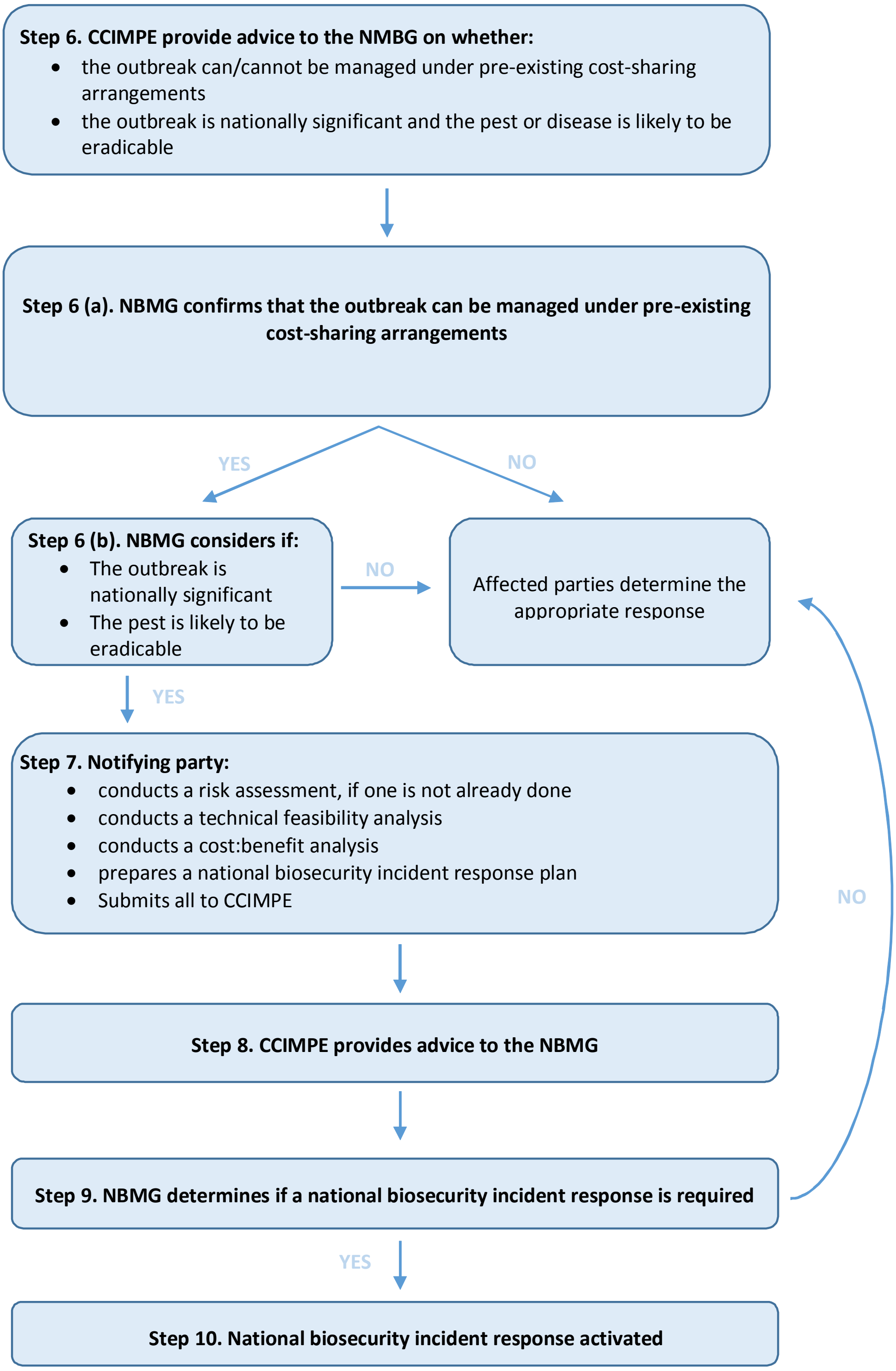

Figure 1. Steps 6 to 10 of the NEBRA process. (Source: NEBRA, Schedule 1).

market impacts are valued. Flexibility is essential due to the complexity of environmental incidents but a level of consistency is also a requirement to assist in decision making.

The jurisdiction affected by the marine pest is responsible for developing the initial BCA, a task which must be undertaken relatively quickly, and ideally by personnel with experience in developing BCAs for marine pest species. In the time-critical response context it can be difficult to find, or reallocate, in-house personnel with experience in developing BCAs, therefore in some jurisdictions outsourcing for BCA is normal practice. In some cases resources may not be available to out-source the BCA.

This report provides guidance to personnel within jurisdictions and companies contracted to perform BCA for marine pest incursions – economists and non-economists – on how to incorporate requirements of the NEBRA in the development of BCAs for marine pest incursions.

Objectives

The aim of this project is to deliver guidance on BCA methodology and advise on the future development of tools that would assist decision-makers to rapidly evaluate management responses to a marine pest incursion. Its specific objectives are:

- Categorise, quantify and value the range of potential impacts (avoided damages) of, and costs of responding to, marine pest incursions.
- Establish a consistent, transparent and generic approach for developing BCAs for marine pest incursions that reflects the criteria of the NEBRA National Framework for Biosecurity Benefit-Cost Analysis.

Methodology

Many existing resources give excellent guidance for undertaking BCAs in general but none were found that specifically deal with BCA in the marine biosecurity context. We have therefore modified existing BCA guidelines developed by the Office of Best Practice Regulation (2016) for the marine pest context. The guidelines developed in this project therefore meet the key requirement for consistency with Commonwealth BCA guidelines and are consistent with the NEBRA guidelines on BCA[5]. The guidelines are given in Chapter 4, which includes details on the information required

The guidelines were ‘road-tested’ using a hypothetical, but plausible, incursion. The case study analysis is presented as a supplement to this report.

[5] The NEBRA requirements on BCA may be found in NEBRA Schedule 4, Attachment 4A: A National Framework for Biosecurity Benefit:Cost Analysis. The framework includes the Key Requirements.

3. Benefit-cost analysis

Benefit-cost analysis (BCA) is the standard method of evaluating the cost-effectiveness of response options in the management of a marine pest incursion. It is a well-developed technique that is widely used in many other areas of human activity, such as the development of policy proposals in government (Office of Best Practice Regulation, 2016). Benefit-cost analysis can be thought of as an equation with response costs on one side and the losses that will be avoided if the incursion is not eradicated, which would therefore be the benefits, on the other. If the response costs are estimated to be less than the avoided losses then carrying out the response is economically the better option. The method consists of identifying and estimating the costs of carrying out the response plan and the costs forecast to be incurred from the impacts of the incursion if it is left unmanaged - the 'do nothing' counterfactual. These two sets of costs are then compared in terms of net present value and the alternative with the highest return would be selected. It is important to characterise the counterfactual accurately because the costs of management actions will be measured against it.

In the context of the NEBRA and a cost-sharing agreement, the response to an incursion is detailed in a national biosecurity response plan (NBIRP) and may comprise preliminary actions to contain the invasive species followed by an attempt to eradicate it (NEBRA Schedule 4, especially item 3). The NEBRA specifies that funds will not be made available for "ongoing management, containment and recovery", including "containment that is not leading to eradication" (NEBRA Clause 7.5). The NBIRP is required to detail a risk assessment, the national significance criteria, technical feasibility, benefit-cost analysis, the response actions to be undertaken, how proof of freedom will be determined, and the budget and review points. The BCA is therefore part of a much larger process and must therefore be integrated with the other elements of the NBIRP. NEBRA Schedule 1 comprises a flow chart laying out the approach to a national biosecurity incident response (Figure 1).

Since impacts of a particular pest will mostly accrue over time, a key part of a BCA is predicting the extent of each impact and the future time periods in which they are likely to occur. This may mean taking account of social, political and climatic uncertainty that could affect impacts in the future. A crucial element of estimating impact will therefore be predicting the spread of the pest. Guidance on natural and anthropogenically-assisted spread is provided in Appendix A.

Undertaking BCA in the time-critical response context has additional challenges – key information on spread and impact may be difficult to collate or may not exist, and it is challenging to value the non-market impacts of an incursion in the marine environment. In this situation it can be tempting to make decisions based on only the easily measurable impacts. A BCA provides a way to incorporate market and non-market impacts. Decisions based on a BCA where available information about a proposed change is organised in a systematic, objective and transparent manner, are likely to be better than those based on prejudice, instinct or intuition.

BCA and the NEBRA

Under the NEBRA a BCA is undertaken once the NBMG have agreed that the incursion is nationally significant, the pest is likely to be eradicable and the incursion cannot be managed under other cost-sharing arrangements (Figure 1). The BCA is an

integral part of the national biosecurity incident response plan that will be developed for the incursion (NEBRA Schedule 4, Clause 3) and is undertaken in conjunction with a risk assessment and a technical feasibility analysis. The six sets of Key Requirements in the National Framework (NEBRA Schedule 4, Attachment 4A) provide detailed requirements that must be addressed when developing a BCA.

Marine pest BCA

The NEBRA framework was tested on black-striped mussel (*Mytilopsis sallei*), using the Darwin incursion of 1999, eradicated at an estimated cost of $2.3M, as the basis of the investigation of 10 incursion scenarios spread across four case-study ports (Summerson et al. 2013). This case-study remains the only official testing of the framework on a (hypothetical) marine pest incursion. The aim of the project was to develop a prototype BCA rather than provide a critique of the recently introduced National Framework for BCA.

A number of conclusions were drawn from the black-striped mussel case study and these are salient in the context of the current project:

i. The BCA is likely to be most successful when compiled by a team with the appropriate expertise across all the issues the BCA covers.

ii. The BCA was based on an analysis of the relative costs of (attempted) eradication and containment to a port, rather than the cost of impacts per se. In most cases eradication was the preferred option but in some cases this depended on the probability of eradication and containment for a particular port.

iii. The rate and direction of spread, both through natural dispersion and human-assisted, is critical in determining the distribution of impacts. Spread rate is intrinsically difficult to determine, especially in the marine environment and will be further complicated by the effect of control measures.

iv. Uncertainty is likely to be a factor in many elements of a BCA, from determining the extent of an incursion to the extent of its spread after a period of time has elapsed and the impacts it creates. It is important that this uncertainty be communicated to decision makers.

4. Guidelines for benefit-cost analysis

The NEBRA sets out the steps to be undertaken in the event of an incursion of an invasive marine species. Schedule 1 comprises a flow chart outlining the approach to a national incident response. Step 7 in the flowchart includes conducting a technical feasibility analysis, details of which are in Schedule 4. The purpose of the technical feasibility analysis is to determine the feasibility of the response. Eradication is the only response that will be considered for cost-sharing under the NEBRA. The technical feasibility analysis will outline the actions that will form part of the chosen policy option, and these actions will be assessed as part of the BCA.

This chapter contains a set of guidelines for conducting a benefit-cost analysis (BCA) to determine whether it is worth investing in the proposed national biosecurity incident response plan (NBIRP). These guidelines are intended to provide practical assistance with completing the BCA by taking the reader through the steps involved in a logical sequence and explaining information requirements. This step-by-step guide follows, as far as possible, the Guidance Note on cost-benefit analysis published by the Office of Best Practice Regulator (Office of Best Practice Regulation, 2016), modified to make it suitable for a marine biosecurity BCA (Table 1).

The NEBRA includes a national framework for biosecurity benefit-cost analysis, which includes a set of key requirements (Schedule 4, Attachment 4A). The matching section of the NEBRA key requirements are indicated in each step. It should be noted, however, that the NEBRA key requirements for benefit-cost analysis do not cover all aspects of a standard BCA.

Table 1. Major steps in undertaking a benefit-cost analysis. (Source: OBPR 2016)

Step	Actions	NEBRA key requirements
1	Specify the option(s).	2.1. Statement of Context
2	Determine the costs of the response action.	Schedule 4, clause 5.2 (Relevant matters), especially sub-clause (c).
3	Identify impacts.	2.2. Identification of likely impacts of the threat and proposed response
4	Predict the impacts over time.	2.2. Identification of likely impacts of the threat and proposed response
5	Attach dollar values to impacts (benefits).	2.3. Quantification of impacts of the threat and proposed response
6	Discount and compare costs and benefits of alternatives.	2.3. Quantification of impacts of the threat and proposed response; Part (c) Explain and justify the choice of discount rate
7	Calculate the costs and benefits using net present value.	nil
8	Perform sensitivity analysis.	2.4. Risk and Uncertainty 2.6. Transparency and accountability; Part (b) a critique to test the significance of all known assumptions, biases, and omissions
9	Assess the BCA and reach a conclusion.	nil

Step 1. Specify the option(s).

Step	Actions	NEBRA key requirements
1	**Specify the option(s).**	**2.1 Statement of Context (incl. 2 (g))**
Notes • Confirm the national incident response plan • Identify the base case		

Step 1 of the BCA is to confirm the objective of the NBIRP and to define the base case option.

The purpose of confirming the objective of the NBIRP is to ensure that the team compiling the BCA fully understand all aspects of the response plan. The response plan contains the plan for eradicating the incursion together with the preliminary containment activities, if planned, and surveillance activities. In order to cost these accurately it is vital to understand exactly what actions are planned.

The chosen response option(s) will be compared to the base case – sometimes referred to in the BCA literature as the "counterfactual". This is the situation that would most likely exist if no response action is taken. It is important to characterise the base case accurately because the benefits and costs of management actions will be measured against it. The cost of doing nothing, the base case, is calculated by costing the impacts of the incursion over time as it develops and spreads (these are the costs that the management action is trying to avoid). The methods of calculating these costs are covered in Steps 3-5 and may include costing impacts on both market and non-market values.

Step 2. Determine the costs of the response action

Step	Actions	NEBRA key requirements
2	**Determine the costs of the response action (NBIRP).**	**Schedule 4, clause 5.2 (Relevant matters), especially sub-clause (c).**
Notes • Use an Excel spreadsheet to break down the response actions into their component parts and cost the time and materials required for each.		

The actions to be carried out in response to the incursion are limited to containment, but only where containment is a precursor to eradication, and eradication. Ongoing management of a marine pest incursion is specifically excluded from the NEBRA's cost-sharing arrangements (NEBRA Clause 7.5).

NEBRA Schedule 4, Clause 5.2 (Relevant matters) states that "the benefit: cost analysis should compare all the expected costs of an impact (the benefits of responding) with all the expected costs of responding" and that this should include "the costs and impacts of the response plan's actions, including the opportunity cost of any alternative uses of the funds required to implement the response plan (Sub-clause 5.2 (c))".

In order to estimate costs it will be necessary to identify the surfaces and areas that are infested with the organism and calculate the amount of material and the amount of effort (person/days) that will be needed to be applied to each surface type. This may mean, for example, calculating the length of plastic wrapping needed to wrap each pylon on a jetty to the height and depth of the tidal range plus the depth to which the organism has become established and, if a chemical treatment is proposed, the quantity and frequency of application for each pylon. In terms of effort, how long will this take to accomplish and how many people are needed to do it.

The process of costing the NBIRP is relatively a simple one. Every action must be reduced to the time it is estimated to take, the number of people required carry it out and the materials they will require. Each action is then costed for the number of people multiplied by the cost of their time plus the amount of material required multiplied by its cost. Table 2 outlines a simple example: wrapping the 10 pylons of a jetty with plastic sheeting and dosing each with a simple biocide (vinegar). Note that the costs listed are for demonstration purposes only.

Thus the staff costs for wrapping the 10 pylons of the jetty come to $11,000 ($10,000 for the divers and $1000 for the support boat coxswain), the materials cost $1000. The total cost is $12,000 for wrapping the pylons of one jetty and one dose of vinegar. The dosing should be repeated at regular and frequent intervals which would probably involve the boat with one additional crew. The divers may have to carry out repairs to the sheeting at weekly intervals for a month. These costs may have to be repeated for additional jetties or other items of infrastructure, depending on the incursion scenario.

These calculations can be done simply in an Excel spreadsheet by a competent accountant.

Table 2. Example of costing one element of a response action. (The costs are approximate and are given only as an example).

Action or material	**Amount required per pylon**	**Unit cost**	**Total cost per pylon**	**Total cost**
2 m width plastic sheeting	12m	$5/m	$60	$600
Tape to secure sheeting	7m	$2/m	$15	$140
Vinegar (1 dose)	5l	$5/l	$25	$250
Total cost			**$100**	**$1000**
People	**Number required**	**Cost per hour**	**Time req. per pylon**	**Cost per pylon**
Divers	2	$500	1 hour	$1000
Support boat coxswain	1	$100	1 hour	$100

Step 3. Identify the impacts and select measurement indicators.

Step	Actions	NEBRA key requirements
3	**Identify impacts**	**2.2 Identification of likely impacts of the threat and proposed response** **2.5 Consideration of equity**

Notes

- Identify all impacts
- Identify and categorise the likely impacts of the pest
- Consider how the impacts will be measured
- Identify the scale of the impact (e.g. regional, national, export-market level)
- It may not be necessary to estimate all possible impacts

It is important to identify all the potential impacts[6] thought to be likely from the incursion of a marine pest if it were left unmanaged, even though it may be difficult to subsequently value all of them. It is also important to consider how each may be measured.

Information about potential impacts can be found in existing resources such as the Rapid Response Manuals, National Introduced Marine Pest Information System (NIMPIS), scientific literature and from experts in the field. Overseas expertise may be required if the species is new to Australia and has not been assessed for potential impacts. Appendix A provides sources of information on locating sources of taxonomic expertise.

The full range of impacts should be identified and described. Impacts may be classified in a number of different ways. We recommend the following classification:

- Economic impacts (on business activity)
- Impacts on the environment
- Impacts on social amenity (people)
  - Impacts on human health
  - Impacts on infrastructure

If the invading organism is one that has been well-researched and impact information has been compiled in a database such as NIMPIS (http://data.daff.gov.au/marinepests/), it should be relatively easy to predict its impacts in and around the incursion site. If the species is new to Australia there may be information on an international invasive species database such as the IUCN Global Invasive Species Database (http://www.iucngisd.org/gisd/), Delivering Alien Invasive Species Inventories for Europe (DAISIE) (http://www.europe-aliens.org/) and the USGS Nonindigenous Aquatic Species (https://nas.er.usgs.gov/).

Indicative measurement indicators should also be selected for each impact. There are three possible categories:

[6] Impact is defined in the NEBRA as causing "significant negative consequences" (Clause 2.2).

- Monetised (dollar) values;
- Quantified but not monetised (e.g. number of species or ecological communities threatened by the pest);
- Qualitative, i.e. described but not quantified or monetised.

There are two types of monetised values:

i. Monetary values (market values), for example the costs to industry of managing biofouling.

ii. Non-monetary values (non-market values) that can be estimated in monetary terms through non-market valuations techniques (such as choice modelling) to determine willingness to pay for an environmental good.

Impacts on values that are already monetised are the easiest to calculate. The calculation of impacts on non-market values require expert input from an economist and can only be calculated from a purpose-designed or pre-existing study. More details are provided in Appendix E.

The NEBRA also requires details of the impacts on the “values affected under the relevant national significance criteria” and “the potential costs of mitigating those impacts in the absence of a national biosecurity incident response”. The determination of whether the incursion is nationally significant will have been made before the development of the NBIRP is started and the benefit-cost analysis is carried out. A number of difficulties in this regard were identified with the national significance criteria in the NEBRA review (KPMG, 2017). It seems likely that unless the incursion takes places in or near a marine reserve, the national significance criterion most applicable to an incursion by an invasive marine species is “extensive impacts”.

It may not always be necessary to calculate values for every impact if easily calculated figures on both the costs of the response and the impacts avoided give a result with a clear indication that there are positive benefits to mounting a response.

Step 4. Predict the impacts over time.

Step	Actions	NEBRA key requirements
4	**Predict the impacts over time.**	**2.2 Identification of likely impacts of the threat and proposed response**
Notes • Use available models to predict natural spread of the pest • Detail assumptions behind modelling • Highlight key uncertainties in spread predictions • Work to 30 – 50 year time frame		

As the incursion becomes established, it will spread naturally and there are also risks of organisms being spread by anthropogenic vectors, for example, ships, recreational craft and even on floating debris (Gilman, 2015). Predicting the spread of a marine organism should therefore be approached at two levels:

- natural dispersion from the site of the incursion; and
- anthropogenically-assisted dispersal.

Natural dispersion may be modelled using a hydrodynamic model, if one has been built for the incursion port and anthropogenic spread may be modelled using shipping data and whatever information can be gleaned on the movement of recreational craft (Appendix A).

Impacts are unlikely to be felt widely early in an incursion, but will increase over time if the incursion is unmanaged and the organism is allowed to spread. Richmond et al. (2010) mapped the maximum potential range of 29 actual or potentially invasive marine species based on their water temperature tolerances and provide the methodology for modelling maximum potential range for any other species (see also NEBRA Schedule 5, Attachment 5D).

The total period selected for the BCA needs to be long enough to capture all the potential costs and benefits, noting especially that the full impacts from an incursion may not be felt for 20 years or more. Because this exercise involves forecasting, exercise caution for time horizons that exceed 20 years (Office of Best Practice Regulation, 2016). Nevertheless it is recommended that for invasive marine species, a time period of 30-50 years be chosen (See the section on Time in benefit-cost analysis in Appendix D). Both the choice of time horizon and the assumptions behind spread modelling should be clearly justified. As far as is practical, the costs and benefits for all affected people residing in Australia should be considered (Office of Best Practice Regulation, 2016).

Step 5. Attach dollar values to impacts.

Step	Actions	NEBRA key requirements
5	**Attach dollar values to impacts (benefits[1]).**	**2.3 Quantification of impacts of the threat and proposed response**

Notes

- Place dollar values on the benefits of management action (=avoided losses)
- Place dollar values to the costs of management action
- List key uncertainties in the measurement process

Where a marine pest causes a direct or indirect impact on a business activity the value of impacts is readily calculable in dollar terms using market prices. At this stage these will be in nominal terms – not adjusted for inflation.

For environmental impacts, we suggest using the Total Economic Value framework (Figure 10) to i) categorise impacts listed in Step 7.3; and ii) choose the appropriate valuation technique. Many of the non-market valuation techniques are not simple to apply and in many cases the time and resources required for primary studies would not be available. Often the only appropriate course of action to value environmental impacts will be benefit transfer. Benefit transfer involves transferring existing estimates of non-market values to the present study that are considered broadly similar. If undertaking benefit-transfer appears to be an option, an economist with expertise in this process should assist with this task.

In some cases it may not be possible to monetise particular impacts – it may be possible to discuss impacts quantitatively but in non-monetary terms; or it may be that impacts may only be described in qualitative terms. All relevant information about impact should nevertheless be reported in the BCA. The challenge is to consider non-monetised impacts adequately.

It may not always be necessary to calculate values for every impact if easily calculated figures give a result with a clear indication that there are positive benefits to mounting a response. Nevertheless, it is recommended that all impacts be at least identified and described.

Appendix C provides full details on how the costs of impacts can be estimated, including impacts on non-market values.

Step 6. Discount future costs and benefits to obtain present values.

Step	Actions	NEBRA key requirements
6	**Discount and compare costs and benefits of alternatives.**	**2.3 Quantification of impacts of the threat and proposed response; Part (c) Explain and justify the choice of discount rate**

Notes

- Select an appropriate discount rate
- Calculate a discount factor for each year in the future and apply to net benefits

Because the value of a dollar today is different to the value of a dollar in the future, it is only appropriate to compare current and future costs and benefits after future values have been discounted. Appendix F explains the process of discounting in more detail and provides an example spreadsheet. In summary, the steps involved in discounting are as follows:

i. List the costs and benefits for each year of the management program;

ii. Calculate the net benefit for each year – this will be benefits minus costs for that year;

iii. Calculate the discount factor for each year using the formula $1/(1+r)^t$, where r is the discount rate (the Office of Best Practice Regulation recommends using $r = 0.07$) and t is time; and

iv. For a given year, multiply the discount factor by the net benefits to obtain the *discounted* net benefits for that year.

Step 7. Compare the costs and benefits using net present value

Step	Actions	NEBRA key requirements
7	**Calculate the costs and benefits using net present value.**	**(Schedule 4, Clause 5 (Relevant matters))**
Notes		

Costs and benefits of a particular management option should be compared using the net present value (NPV) rule. The NPV is the sum of the discounted net benefits (see Appendix F). It is important to note that NPVs are predicted (average) values. Sensitivity analysis of uncertain aspects of the BCA will be required to understand potential variation in NPV.

When NPV is positive, a proposal is considered to be economically efficient and the community as a whole would be better off from its implementation. When more than one policy is being considered to solve a particular problem, the policy resulting in the highest NPV should be chosen, contingent on the results of sensitivity analysis.

Step 8. Perform sensitivity analysis.

Step	Actions	NEBRA key requirements
8	**Perform sensitivity analysis.**	**2.4 Risk and Uncertainty** **2.6 Transparency and accountability**
Notes • Re-run BCA for worst and best case values of uncertain variables		

The BCA developed in the previous steps will be based on the most plausible values of costs and benefits, and will produce a value of NPV that is therefore thought to be most representative. There will be many parts of the BCA, however, where there is significant uncertainty. Sensitivity analysis is undertaken to demonstrate how changes in different variables will affect the overall costs and benefits of the proposed management action. It shows how sensitive predicted net benefits are to different values of uncertain variables, including the effect of different spread rates and to changes in assumptions. Importantly, it tests whether the uncertainties identified actually matter. It also identifies critical assumptions.

Sensitivity analysis needs to be undertaken systematically and presented clearly. A common approach is to undertake a w*orst/best case analysis.* In this method the BCA is re-run where uncertain variables take on:

i. the least favourable of a plausible range of values; and
ii. the most favourable of the plausible range of values.

If the worst case analysis gives a negative NPV, an additional investigation into critical values will be required using either partial sensitivity analysis or Monte Carlo simulation (see OBPR 2016) for more details.

Step 9. Reach a conclusion.

Step	Actions	NEBRA key requirements
9	**Assess the BCA and reach a conclusion.**	**nil**
Notes • The final step in the BCA is summarising results, reaching a conclusion and providing this advice to CCIMPE.		

When more than one option is under consideration, the option with the highest net present value (NPV) is usually the recommended option. In some cases, however, sensitivity analysis might suggest that the alternative with the largest NPV is not necessarily the best alternative under all circumstances. For example, the option with the lower expected NPV might also be less likely to impose significant costs on the community.

The summary of the BCA should include the following (OBPR 2016):

- the time profiles of costs, benefits and net benefits;
- Net present values;
- the discount rate used;
- information on the sensitivity analysis;
- a list of assumptions made; and
- how costs and benefits were estimated.

(This is not explicitly discussed in the NEBRA key requirements).

5. Conclusions and recommendations

1. The primary purpose of this report is to provide guidance on developing a BCA for a marine pest incursion using established BCA methodology whilst maintaining consistency with the NEBRA's Key Requirements (NEBRA Schedule 4, Attachment 4A). They Key Requirements were found to be inadequate for providing guidance on developing a BCA for the following reasons:

- The structure of the Key Requirements is confusing and does not reflect the logical structure of a benefit-cost analysis. For example, Clause 6.4 states that "NBMG to decide whether outbreak is of national significance and likely to be eradicable (step 7)" whereas this step is numbered as Step 6 in Schedule 1.
- There is no mention or guidance on costing the response (eradication attempt) which is an integral part of the BCA process. Rather, the focus is on identification and quantification of impacts (benefits).
- No guidance is given on comparing response costs with benefits (avoided losses from impacts) nor the appropriate way to prepare and present the conclusions and recommendations from the BCA.
- A number of the Key Requirements seem to be unimportant or irrelevant. For example:
  - Section 2.1 (c) asks "what is the goal of any proposed government involvement"? In the context of cost-sharing between governments, this seems to be irrelevant.
  - Section 2.1 (d) discusses "the scope of policy responses" when only (initial) containment and eradication are within the scope of cost-sharing.
- Some of the Key Requirements are inconsistent with other aspects of the NEBRA. For example:
  - Section 2.2 (e) "Identify the likely affect [sic] of the proposed response on mitigating each of the above impacts." First, the effect of the proposed response on mitigating [sic] impacts should be discussed in the section on developing a national biosecurity incident response plan and, second, cost-sharing under the NEBRA is only available for eradication, not for mitigation (Clause 7.5).
  - Section 3 (d) discusses "how the spread would be affected by alternative eradication and containment strategies". This seems to imply that containment is a valid option under the NEBRA; Clause 7.5 explicitly rules it out.
- A number of terms are not explained, for example, 'distributional incidence', 'distributional analysis' and 'environmental asset valuation'.

We therefore recommend that the Key Requirements for BCA within the NEBRA be re-worked to provide clear, step-by-step guidance. The guidelines prepared in this report, based on those of the Office of Best Practice Regulation, may provide such guidance.

2. The potential impacts of marine pest incursions are challenging to understand and value. The time-critical context of a new incursion makes resourcing more difficult. Developing a BCA that adequately reflects the potential impacts of an incursion and the costs of eradication will require a team of staff with a range of skills, especially in economics, accounting, science and response-management. While the required skills set is already acknowledged in the National Framework for biosecurity BCA (Attachment 4a, 3e[7]), the intent of that statement should be operationalised.

In order to do this we suggest the following:

- A list of available DAWR/ABARES and jurisdictional staff and consultants who would be readily available to assist in the development of the BCA for submission to NEBRA. Such a list could be developed and maintained by CCIMPE.
- Emergency funding to assist in the development of a BCA.

3. The economics discipline provides a range of rigorous and credible methods for valuing the non-market impacts of marine pest incursions. Unfortunately, most of these methods involve primary data collection through surveys, and may take months and require significant resources to implement. The methods are therefore usually inappropriate for application in the time-critical response context of invasive marine species. Primary non-market valuation studies, undertaken 'pre-emptively', could provide a pool of data from which to make inferences about likely impacts of marine-pest incursions once an incursion is notified. Some information on non-market values in the marine environment has been recently completed and would be valuable to guide further studies as applicable. Mazur et al. (2017) carried out a choice modelling study that included questions about Australians' willingness to pay for:

a) protection of a number of native species, and

b) protection of a length of coastline and adjacent waters.

It is recommended that this study be repeated in five years' time to determine if attitudes have changed.

As described above, we recommend a number of other primary "pre-emptive" studies be carried out, to obtain:

- Social, cultural and iconic values of a variety of locations around Australia, including the Great Barrier Reef[8], Ningaloo and smaller marine reserves;
- Community perceptions of coastal and marine assets, including the amenity values of beaches and ocean views
- Visitation rates over time, and uses of, selected beaches, marine parks and other coastal assets.

[7] NEBRA Attachment 4A, Part 3 (e): "More commonly however, there will be significant uncertainties and unknowns with postulated relationships and impact values, and the BCA will need to employ techniques to handle risk, uncertainty and information gaps. Previous experience with this type of analysis will be important, as will the availability of suitably qualified personnel to conduct the investigation. A good biosecurity BCA requires both economic and scientific inputs."

[8] Whilst we acknowledge that that a significant body of work has been developed on the Great Barrier Reef, these values may not be readily transferable to marine biosecurity.

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Appendix A. Information sources to help with developing a BCA

While developing a BCA information will be required on a number of issues such as the biology of the organism making the incursion, the environmental and human assets that could be at risk from the incursion and conditions that would enable the organism to spread. In this section a range of information sources have been compiled to assist with this task.

Rapid Response Manuals

Rapid Response Manuals were developed under the Emergency Marine Pest Plan (http://www.agriculture.gov.au/pests-diseases-weeds/marine-pests/empplan) for five high priority invasive marine species

- Northern Pacific seastar (*Asterias amurensis*)
- European shore crab (*Carcinus maenas*)
- Black-striped mussel (*Mytilopsis sallei*) and Asian green mussel (*Perna viridis*)
- Japanese seaweed (wakame) (*Undaria pinnatifida*)

In addition, there is a generic manual for use with other species. This would be useful in the event of an incursion by a species for which a specific RRM has not been prepared. Nevertheless, there may be useful information in a species-specific manual if the incursion species is related to or similar to one of those species for which a manual has been prepared.

The Biosecurity Incident Management System describes the generic policy and procedures for managing a response to a marine pest emergency within Australian waters. The Rapid Response Manual describes the steps required in responding to an incursion. Each manual includes a section on **Stages in an emergency response to a marine pest of national significance.** Management of a marine pest emergency of national significance has four phases of activation:

1. Investigation Phase
2. Alert Phase
3. Operations Phase
4. Stand down Phase

The first two phases, while detailed separately in the Rapid Response Manuals, may be run concurrently as outlined in the Biosecurity Incident Management System. Progression from one stage to the next depends on the nature of the emergency and available information (Department of Agriculture and Water Resources, 2015)

National Control Plans

National Control Plans have been developed for six invasive marine species that are already established in Australia: *Asterias amurensis*, *Carcinus maenas*, *Arcuatula* (formerly *Musculista*) *senhousia*, *Sabella spallanzanii*, *Undaria pinnatifida* and *Varicorbula gibba*.

Australian Priority Marine Pest List

The Australian Priority Marine Pests List (APMPL) will comprise a list of priority marine pests that have been assessed as being of national significance and meet a number of agreed criteria, such as feasibility of control. The compilation of the list included expert assessment of a wide range of species that may be useful information in the event of an incursion, even if the species is not included in the final priority list.

Information about the APMPL can be found on the DAWR website.

Key information sources – Environment

Local knowledge

Operators of slipways are often familiar with vessels and their owners and the local fauna and flora as they have to remove them from vessel hulls. They are likely to notice an unfamiliar species on vessel hulls so would be a valuable source of early warning that a new species was in the locality.

Managers of marinas and yacht clubs are often familiar with patterns of movement of recreational vessels so may be able to advise on popular destinations for vessels from their marina or yacht club and therefore possible directions of spread. Many recreational fishers use the same fishing spots and may observe new arrivals or changes in shoreline fauna.

There are several volunteer coastguard/marine rescue organisations in Australia: Australian Volunteer Coastguard (QLD, VIC, NT & SA), Marine Rescue (NSW, QLD), Royal Volunteer Coastal Patrol (SA), Volunteer Marine Rescue (WA) and Volunteer Marine Rescue (TAS), a different organisation. Each of these organisations has members with considerable experience of the coastline in their local area.

Hydrographic charts

Hydrographic charts (e.g. Figure 2) contain much useful information such as water depth, substrate type, infrastructure that could be impacted by an incursion and access points (e.g. boat ramps) for launching small vessels for an incursion response. The Royal Australian Navy (RAN) Hydrographic Service produces raster images of all Australian hydrographic charts in GeoTIFF format (http://www.hydro.gov.au/prodserv/digital/ausGeoTIFF/geotiff.htm). This format allows their use in geographical information systems (GIS) (see below) as well as viewing on a computer screen.

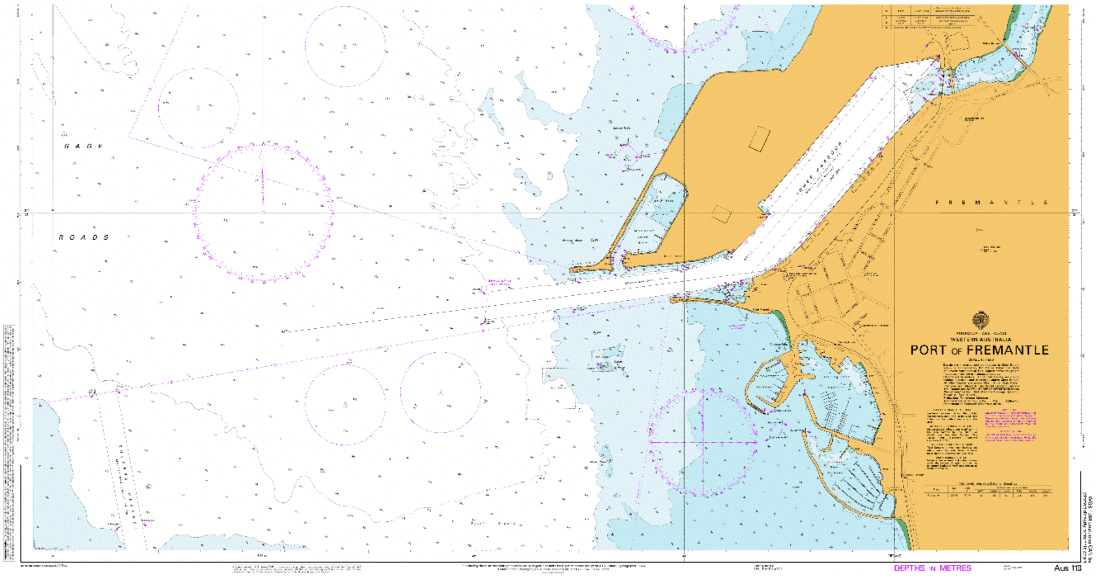

Figure 2. RAN Hydrographic chart AUS 113 of the port of Fremantle.

Bathymetric (depth) data

Water depth is a constraining factor for many invasive species. For offshore areas Geoscience Australia has developed a bathymetric digital elevation model where depth data is accessible. Geoscience Australia has also acquired high resolution bathymetric data in a small number of localities, e.g. the port of Darwin (Figure 3). For inshore areas hydrographic charts are better, though the depth data is not accessible digitally.

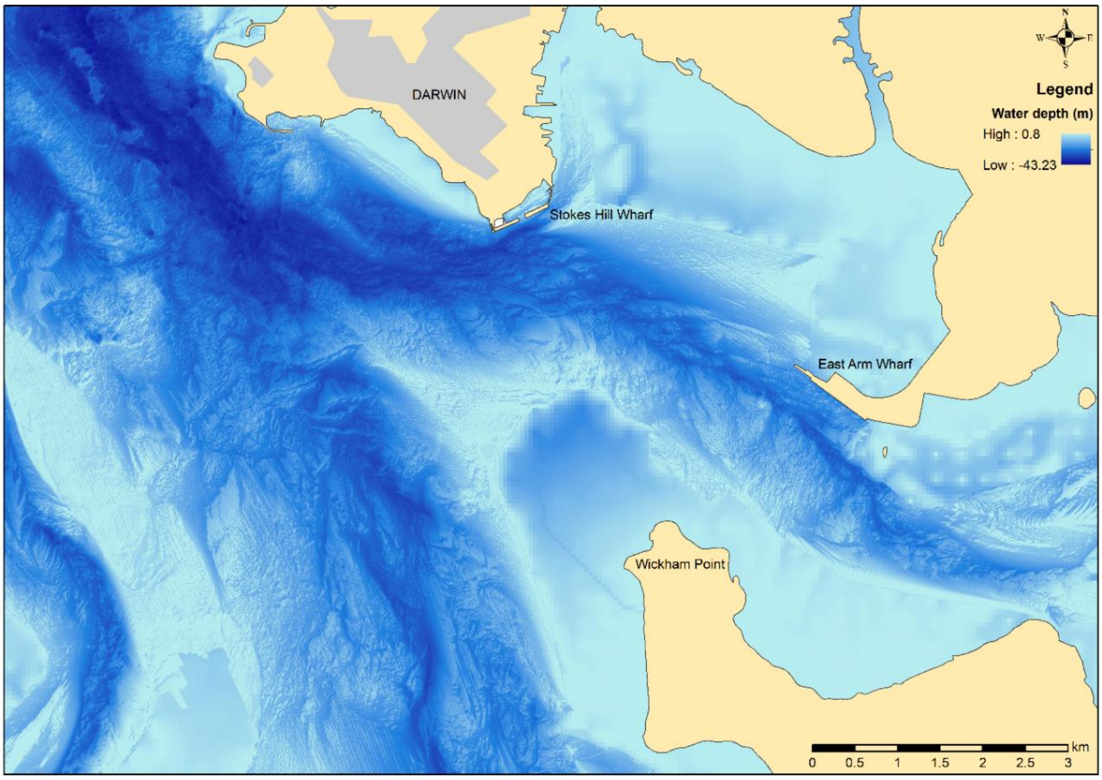

Figure 3. High resolution bathymetry of Darwin Harbour. Source: Geoscience Australia.

Google Earth and Google Maps

The satellite imagery and aerial photography on Google Earth, Google Maps and similar systems can be invaluable to identifying natural features, infrastructure and other information in any location. Figure 4 is a high resolution satellite/aerial photography image of King Bay within the Port of Dampier. Within this image can be seen, from left to right, what appears to be a landing barge on a ramp, a small wharf, a slipway (inclined upper right to lower left), tidal mud flats and mangroves along the shore. All this could be useful information for assessing vulnerabilities to invasion and facilities for accessing the shoreline in the event of an incursion. Many of these software packages incorporate simple tools which enable measuring distance, etc.

Figure 4. High resolution Google Maps image of King Bay in the port of Dampier. A landing barge with its loading ramp down on an access ramp is on the left of the image; a slipway is in the upper centre of the image. Mudflats and mangroves are clearly visible on the right of the image. Source: GoogleMaps

Habitat suitability data

Habitat suitability data is unlikely to be available for large scale areas and will need to be derived from other data including bathymetry, substrate, shoreline type and an index of degree of exposure. OzCoasts (http://www.ozcoasts.gov.au/index.jsp) is a portal to data on estuaries and coastal waterways. Figure 5 is an example of the data available through the OzCoasts portal. While these data are not a direct indication of habitat suitability for any individual species, a measure of suitability can be broadly derived.

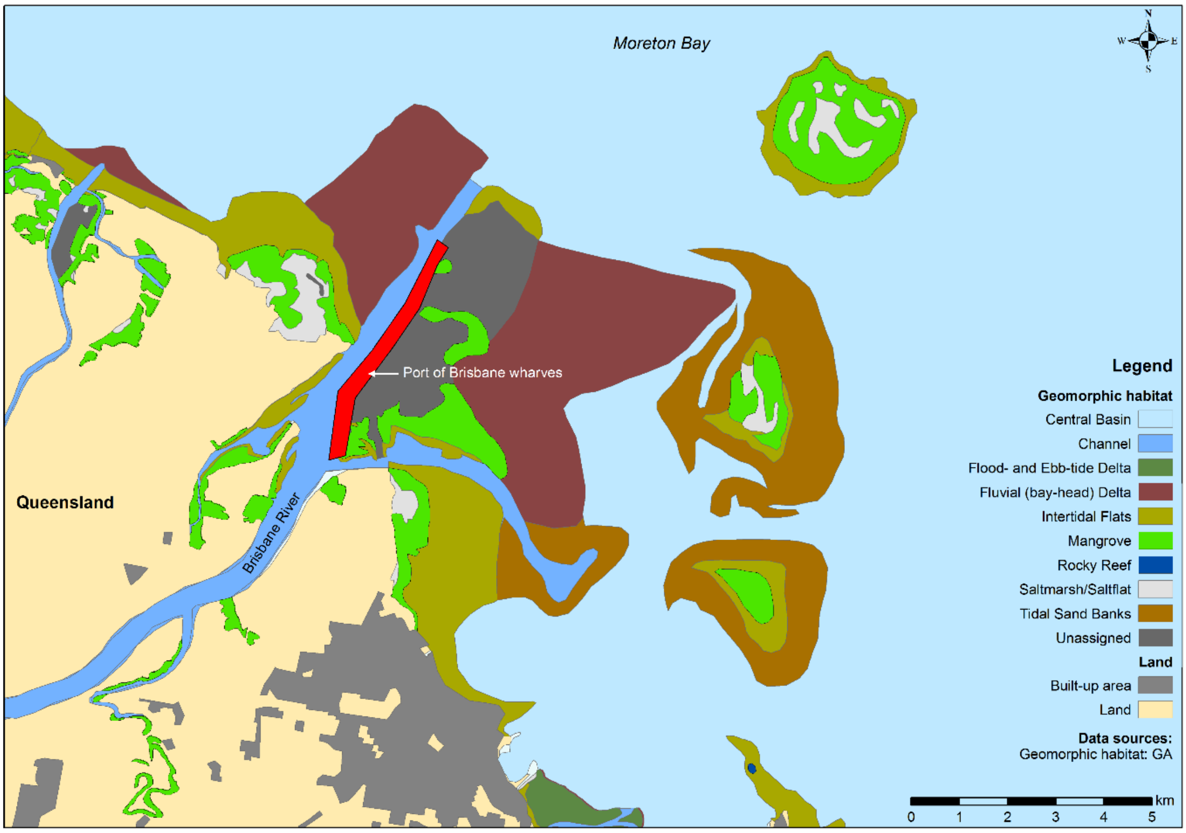

Figure 5. Example of habitat data available through the OzCoasts portal. The area of the Port of Brisbane wharves, which is indicated in red, is not part of the habitat data but is included for context.

Jurisdiction and jurisdictional boundaries

The jurisdiction of Australia's maritime domain is divided between the Commonwealth, states and Northern Territory. The division of jurisdiction moves progressively away from the coast and is formally measured from the Territorial Sea Baseline (TSB). The TSB is generally the low water line along the coast but where the coastline is deeply indented by a bay or estuary a straight baseline cuts across between the headlands on either side. Straight baselines are also used where there is a cluster of offshore islands. State, or coastal, waters are those out to a distance of three nautical miles (5.56 km) from the TSB plus any waters on the inshore side of the TSB, which are known as 'internal waters' (Figure 6).

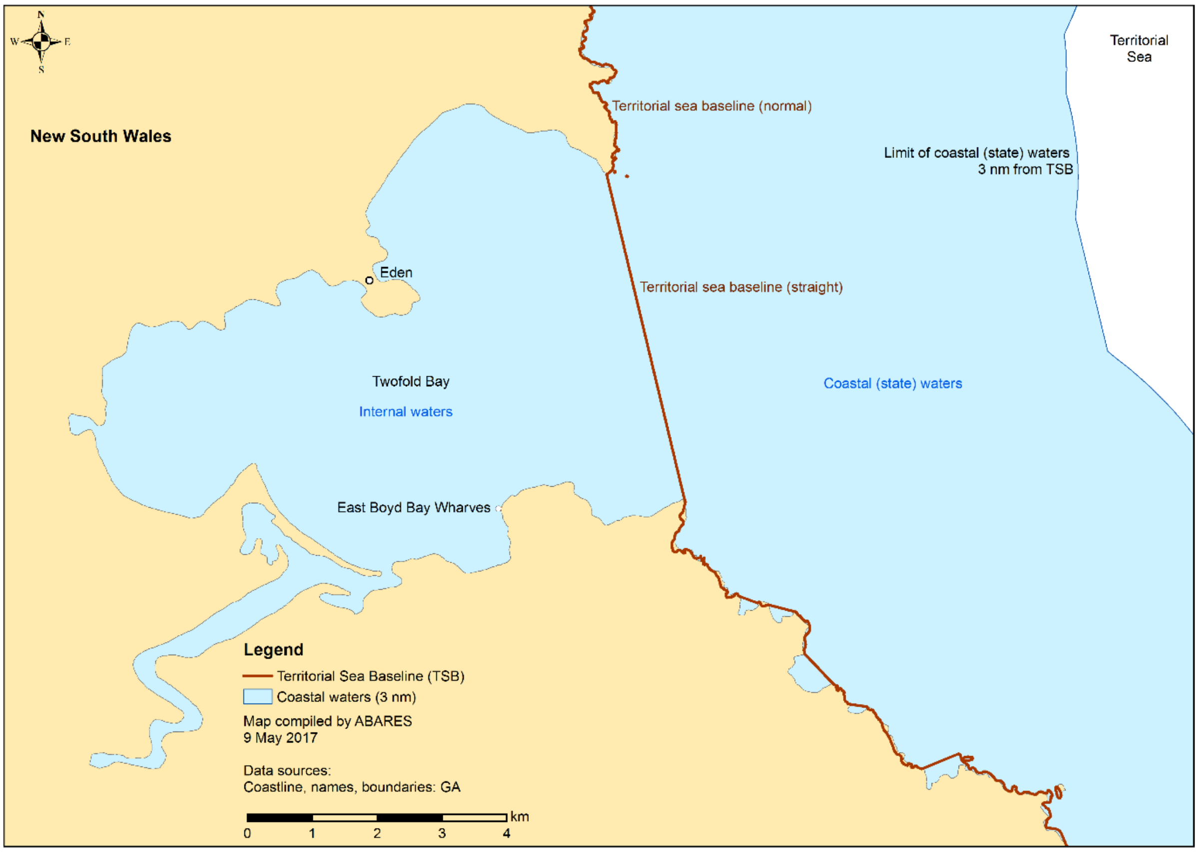

Figure 6. Territorial sea baseline, coastal and internal waters.

Note: The territorial sea extends for 12 nautical miles from the TSB and includes coastal waters. The Commonwealth retains some jurisdiction over state waters including navigation and defence.

Waters out to 12 nautical miles from the TSB are termed the Territorial Sea. In Australia, waters beyond the three nautical mile limit out to the limit of the Exclusive Economic Zone and extended continental shelf are under Commonwealth jurisdiction. The Commonwealth also retains jurisdiction over shipwrecks that are 75 years old or older up to the low water mark under the Historic Shipwrecks Act (1976).

The vast majority of incursions by invasive marine species are likely to impact the coastline and the relatively shallow coastal waters and are therefore most likely to be within the jurisdiction of a state.

Key information – business activity

1. Aquaculture

The management of aquaculture is the responsibility of state governments and the Northern Territory as aquaculture is almost invariably conducted within three nautical miles (5.56 km) of the coastline (http://www.agriculture.gov.au/fisheries/aquaculture).

Market prices

Sources of useful information for understanding the impact of a marine pest on aquaculture include:

- *Australian fisheries and aquaculture statistics*, produced annually by DAWR/ABARES
- The Fisheries Research and Development Corporation
- Aquaculture industry associations
- State Government Departments, for example the Queensland Government provides a website containing information on all aspects of starting up an aquaculture operation

Vessel information

In the event of an incursion by an invasive marine species, vessel hulls may become colonised by the invading species, especially recreational vessels, which may be static for lengthy periods. These vessels will need to be taken out of the water for inspection and cleaning, which will require contacting the vessel owners. Every state except the Northern Territory requires recreational vessels above a certain size to be registered. Table 3 lists the agencies that are currently responsible for vessel registration in Australian jurisdictions. Note that these agencies may change name or that responsibility may be transferred to another agency.

Table 3. Vessel registry agencies in Australian jurisdictions.

State	Registering agency
QLD	Department of Transport & Main Roads
NSW	Roads and Maritime Services
VIC	VicRoads
TAS	Marine and Safety Tasmania
SA	Department of Planning, Transport & Infrastructure
WA	Department of Transport
Commonwealth	Australian Maritime Safety Authority (AMSA)

Vessel traffic data

The Department maintains more or less up-to-date data on shipping movements from Lloyds Maritime Intelligence Unit. This provides data on historic shipping movements from which patterns of activity can be derived. In general terms shipping tends to follow the same routes with increasing levels of traffic.

The Department has recently instituted the Maritime Arrivals Reporting System (MARS) which will allow easy interrogation of vessel arrivals and movements for authorised users of the system.

For current shipping movements, each port authority maintains a daily running sheet of vessel arrivals, departures, movements within the port and forecast arrivals. See, for example, the

"Today's Movements" sheet in Fremantle: https://www3.fremantleports.com.au/VTMIS/dashb.ashx?db=fmp.public&btn=TodaysMovements

Movements of recreational vessels are much more difficult to trace. Marinas and yacht clubs may have data on movements in and out of their marinas and by their members. Coastal volunteer radio stations such as Tasmanian Maritime Radio (http://tasmaritime.com.au/) and those operated by Marine Rescue NSW (http://www.rms.nsw.gov.au/documents/maritime/safety-rules/publications/vol-marine-radio.pdf) maintain logs of movements of those vessels that register with them.

All commercial vessels[9] are required by the IMO Convention for the Safety of Life at Sea (SOLAS) to carry Automatic Identification System (AIS) transponders which automatically provide information about a ship, including its location, to other ships and to coastal authorities. Some recreational vessels have also installed AIS transponders. The data from these systems are now being made available on the Internet by a number of service providers, e.g. Marinetraffic.com, who provide a number of services related to AIS, including providing a free online instantaneous map of shipping traffic worldwide.

Key information sources – marine biology

Species identification

Taxonomic expertise is critical to correctly identifying a marine organism suspected of being an invasive alien species. The Australian Marine Invertebrate Taxonomists (AMIT) was established in 2002 to provide a network of expert marine invertebrate taxonomists able to identify marine invertebrate species. Many of these taxonomists are employed in the state, or Northern Territory, natural history museum. Other sources of taxonomic expertise are universities, CSIRO and other Commonwealth research institutes such as the Australian Institute of Marine Sciences (AIMS).

Species life history

Information on a species life history is essential to understanding its potential impacts, habitat, reproduction and likely spread. The Department of Agriculture and Water Resources maintains the National Introduced Marine Pest Information System (NIMPIS) (http://data.daff.gov.au/marinepests/) which contains information over 240 marine species.

Key information sources – Human Systems

Infrastructure

Infrastructure can be vulnerable to invasive marine species in different ways. Fouling of surfaces can result in restrictions of water flow within piping, including water inlets and outlets, storm water drains and sewerage. Fouling can also result in jamming of moving parts such as dock gates and ship hoists, and navigation buoys sinking under the weight of fouling. Table 4 lists representative types of infrastructure and the type of agency that is likely to be responsible. Note

[9] The IMO SOLAS Convention requires AIS to be fitted on all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size (IMO 2017).

that the same type of agency may not be responsible for each type of infrastructure in every jurisdiction in Australia.

Table 4. Infrastructure responsibility.

Infrastructure type	**Likely responsible agency**
Boat ramps	Local council
Jetties, wharves, breakwaters, dolphins	Port authority
Slipways − Public − Private	 − Local council − Port authority / private owner
Mooring buoys	Marine and Safety agency (e.g. MAST)
Navigation buoys and markers − Coastal and offshore − Inshore − Within port limits	 − AMSA − State marine and safety agency − Port authority
Pontoons, steps and ladders	Port authority
Infrastructure within a marina	Marina owner (public or private)
Stormwater outfalls	Local council
Waste water and sewage outfalls	Water & sewerage supply company

Distribution and spread models

There are several types of species distribution models: correlative, process-based and mechanistic (Robinson et al., 2011). Many of these models aim to determine the areas or ecological niches that species are likely to inhabit and are done by a variety of means including climate and habitat matching (Guisan et al., 2013). They can also be developed and used to predict where invasive species may become established.

Spread models

There are many different types of models for predicting the spread of invasive species. Most of these models have been developed for terrestrial invasive species.

In the marine environment there are two types of spread: natural dispersion and anthropogenic dispersal.

Natural dispersion

The predominant mechanism of natural dispersion in the marine environment is the pelagic larval phase most marine animals go through during their development. Marine plants have a

similar dispersion mechanism, as gametophytes, but many also can reproduce vegetatively through plant fragments. Marine animals can generally be divided into two groups: sessile and motile. Sessile animals, like mussels, e.g. *Perna viridis* and European fan worm (*Sabella spallanzanii*) remain fixed to the substrate. Motile animals, like crabs and the northern Pacific sea star (*Asterias amurensis*) are able to move independently. The Chinese mitten crab (*Eriocheir sinensis*) has been found to migrate over very large distances; Ojaveer et al. (2007) suggest that it may migrate as much as 1500 km across the Baltic Sea.

Natural dispersion of animals, during their pelagic larval phase, and plants as gametophytes (and also plant fragments) can be modelled using a hydrodynamic model, which simulates water movement. Hydrodynamic models are described in more detail below.

In the absence of a hydrodynamic model, useful factors for helping to determine the rate and direction of spread are ocean currents and coastal winds. Ocean current data can be obtained from the Australian Ocean Data Network (AODN) (https://portal.aodn.org.au/search) and coastal wind data from the Bureau of Meteorology (BOM). The following link is to monthly climate statistics for Cairns, as an example:
http://www.bom.gov.au/climate/averages/tables/cw_031011.shtml.

The 9am and 3pm wind speed vs direction plots ("wind roses") provide a graphical representation of wind direction and speed. Figure 7 shows 9 am and 3 pm wind roses for Cairns in January. From these it is quite clear that the prevailing wind is from the south and south-east which will tend to push the surface waters northwards - and any larvae entrained in the surface waters.

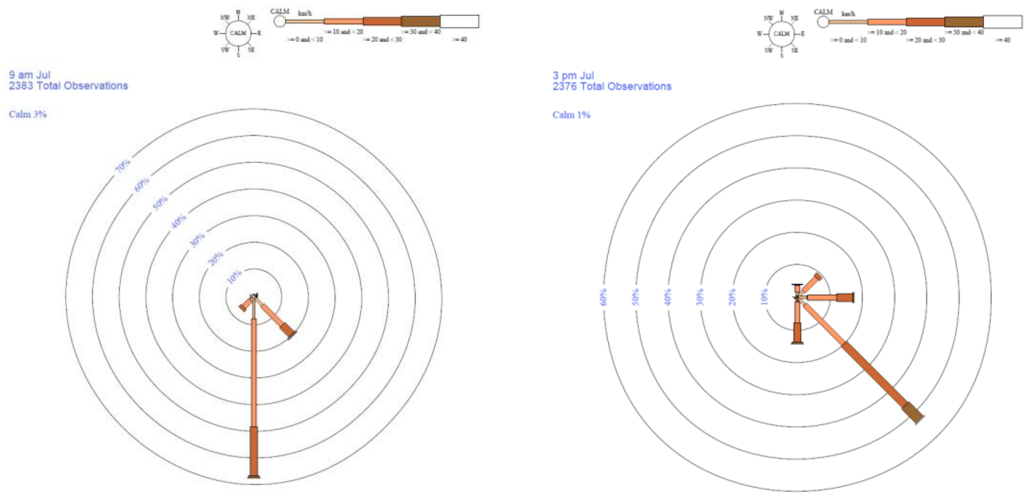

Figure 7. 9 am and 3 pm wind roses for Cairns in January.

Source: Bureau of Meteorology.

Anthropogenic dispersal

Anthropogenic dispersal involves a number of stages:

Entrainment > Translocation > Settlement > Reproduction > Establishment

The principal vectors are commercial and recreational vessels and the principal pathways are ballast water, which is predominantly used in commercial shipping, and biofouling. There have

been many assessments of the risks of translocation of invasive marine species in ballast water (e.g. Hayes, 1998, Carlton, 1985) and biofouling (e.g. Hewitt et al., 2011) with varying assessments of the relative risks associated with each.

No models have been built to simulate anthropogenic dispersal but patterns of movement by large vessels (generally over 500 tonnes DWT) can be discerned by analysing shipping traffic data from Lloyds List Maritime Intelligence or other data sources on shipping. Patterns of movement of recreational vessels are much more difficult to discern as there are no datasets on their movement.

Hydrodynamic models

Hydrodynamic models are computerised models of complex marine environments. Assembling the data for input into the model and writing the computer programs that drive the models are time-consuming and therefore invariably expensive. Their value lies in being able to simulate the outcomes of a particular action or event in the marine environment. For example, if an invasive marine species is found to have colonised an area of infrastructure in a port, a particle tracking algorithm in a hydrodynamic model can simulate the dispersion of larvae by tides, winds and currents over the period it takes for them to develop and determine where they are likely to settle. This would be useful to determine whether the larvae are likely to be able to settle in suitable habitat and for focussing eradication efforts. The integration of hydrodynamic models with statistical models to determine the probability of these events is in its infancy. Nevertheless, hydrodynamic models can provide useful insights into the movement of larvae from the site of the incursion. Table 5 lists the hydrodynamic models that are known to have been developed for locations around Australia. It is likely to be incomplete.

Table 5. A list of the hydrodynamic models that have been developed for locations around Australia.

Where	Who	When	Model	OS
Port Curtis (Gladstone)	CSIRO	2002	MECO	UNIX
Fitzroy Estuary	CSIRO	2005	SHOC	LINUX
Moreton Bay	CSIRO	2010	SHOC	LINUX
Port Phillip Bay	CSIRO	1992-96	MECO	UNIX
Spencer Gulf	CSIRO	2008	SHOC	LINUX
North West Shelf	CSIRO	2007	SHOC	LINUX
Derwent Estuary	CSIRO	2008	SHOC	LINUX
Huon Estuary	CSIRO	2001	MECO	UNIX
Huon/D'Entrecasteaux	CSIRO	2008	SHOC	LINUX
Gippsland Lakes	CSIRO	2001	MECO	UNIX
Port Curtis (Gladstone)	RPS APASA	2010	Delft3D-FLOW	
Sydney Harbour	U Sydney	2013		
Bunbury	Wave Solutions	2013	CMS	
Dampier	RPS APASA	2009	HYDROMAP	
Port Hedland	Cardno	2010	Delft3D-FLOW	
Weipa	GHD	2009		

MECO = Model of Estuaries and Coastal Oceans. SHOC = Sparse Hydrodynamic Ocean Code.
Note: This list may not be complete.

Hydrodynamic models are complex and require expert input to load data and "drive" the models. Expert interpretation is also required. In order to maximise the value of hydrodynamic models it is recommended that links be established with the owners of these models to perhaps run some simulations that would be useful in planning for incursion responses and to develop relationships that could be drawn upon in the event of an incursion. It is unlikely to be feasible to acquire, e.g. by purchase, a hydrodynamic model and the data that underpin it and expect to be able to run it without extensive training and developing the understanding on how it works.

Species maximum potential range

An important question is whether an incursion by an alien invasive species will survive and develop a population at the site of the incursion. All marine species have a temperature tolerance range and, to a lesser extent, a salinity tolerance range. Australia has a latitudinal range of nearly 35 degrees, from 9° 13' S (Boigu Island in Torres Strait) to 43° 38' S (South East Cape in Tasmania), excluding Macquarie Island (54° 46' S), a distance of over 3,800 km. Such a distance encompasses both tropical and temperate waters. Although invasive species are by their very nature adaptable and have wide ranges of tolerances, not many invertebrate species are able to survive across both tropical and temperate ecosystems.

ABARES has developed a temperature tolerance modelling system for a range of species, currently 30 species, based on the best available information on temperature tolerance (Richmond et al., 2010). Figure 8 shows the modelled maximum potential range of *Perna viridis* (Asian green mussel), which is a tropical species.

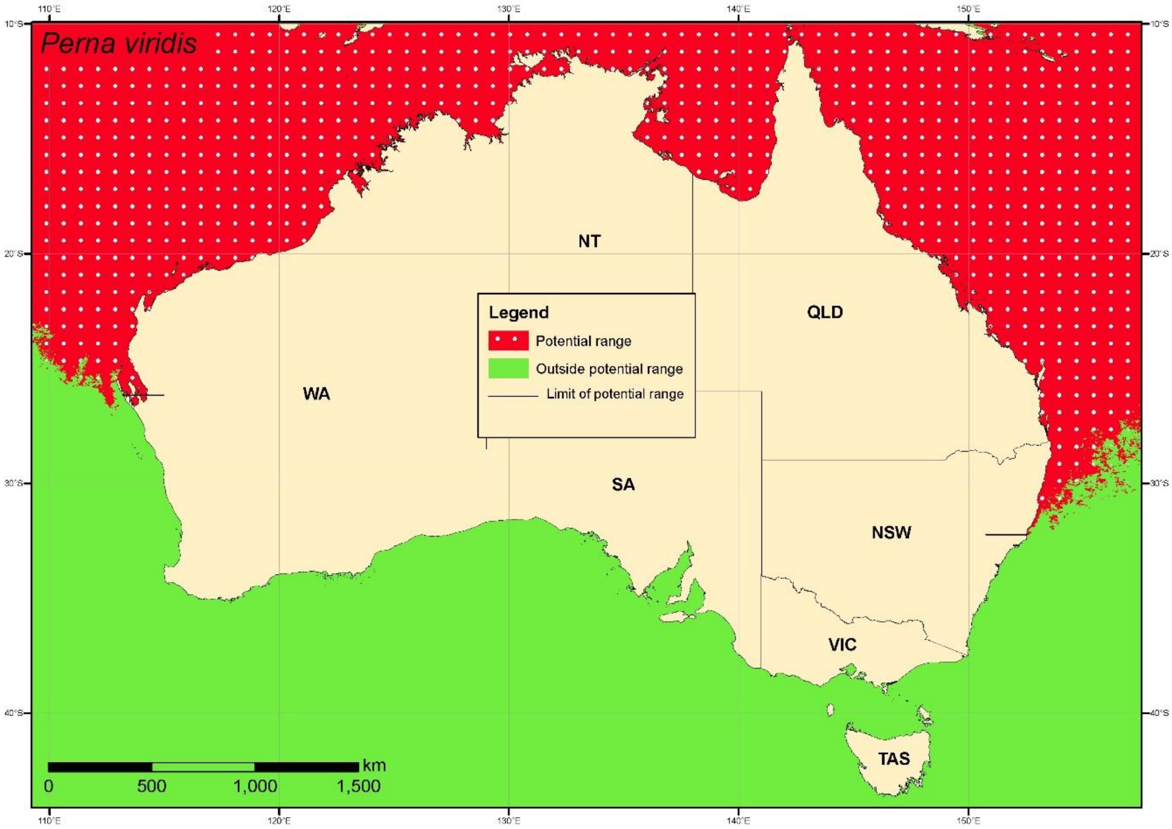

Figure 8. Modelled maximum potential range of *Perna viridis* (Asian green mussel).
Source: Richmond et al., 2010.

High value marine assets

High value marine assets are urban, port and industrial infrastructure, recreational assets and environmental assets that are at risk from damage or disruption by invasive marine species. The risks to infrastructure are from becoming fouled or clogged by invasive marine species. Fouling occurs when organisms settle on or in the infrastructure and restrict its operation. Examples of fouling species are mussels, barnacles and bryozoans. Invasive marine species that may clog infrastructure are free-living species like the comb jelly *Mnemiopsis leidyi* that could be sucked into water intakes. Direct & indirect impacts are listed below.

Human

Urban infrastructure

- Storm water drains
- Sewage outfalls
- Desalination plant water intakes and outlets
- Movable infrastructure such as swing bridges

Port infrastructure

- Dry dock gates, ship hoists and slipways
- Dry dock water inlets and outlets
- Resident vessels, e.g. tugs, lines boats, pilot boats
- Fouling pontoons, barges, ladders, steps, hawsers, buoys, etc.
- Tide gauges

Industrial infrastructure

- Water inlets and outlets, e.g. cooling water and/or process water

Recreational assets

- Marina and yacht club infrastructure, e.g. pontoons
- Moored vessels
- Boat ramps and slipways
- Sea water swimming pools
- Beaches

Heritage sites

- Shipwrecks

Environmental

- Marine protected areas
- Ramsar sites

There are many types of marine protected areas, including marine reserves, marine parks and purpose-specific protected areas such as dugong protection areas. Information and data on marine protected areas is maintained by the Department of the Environment and Energy in the Collaborative Protected Area Database (CAPAD), mapped in Figure 9. Figure 9 also includes important wetlands, including wetlands protected under the Ramsar Convention on Wetlands of International Importance, especially as waterfowl habitat that are adjacent to the coast.

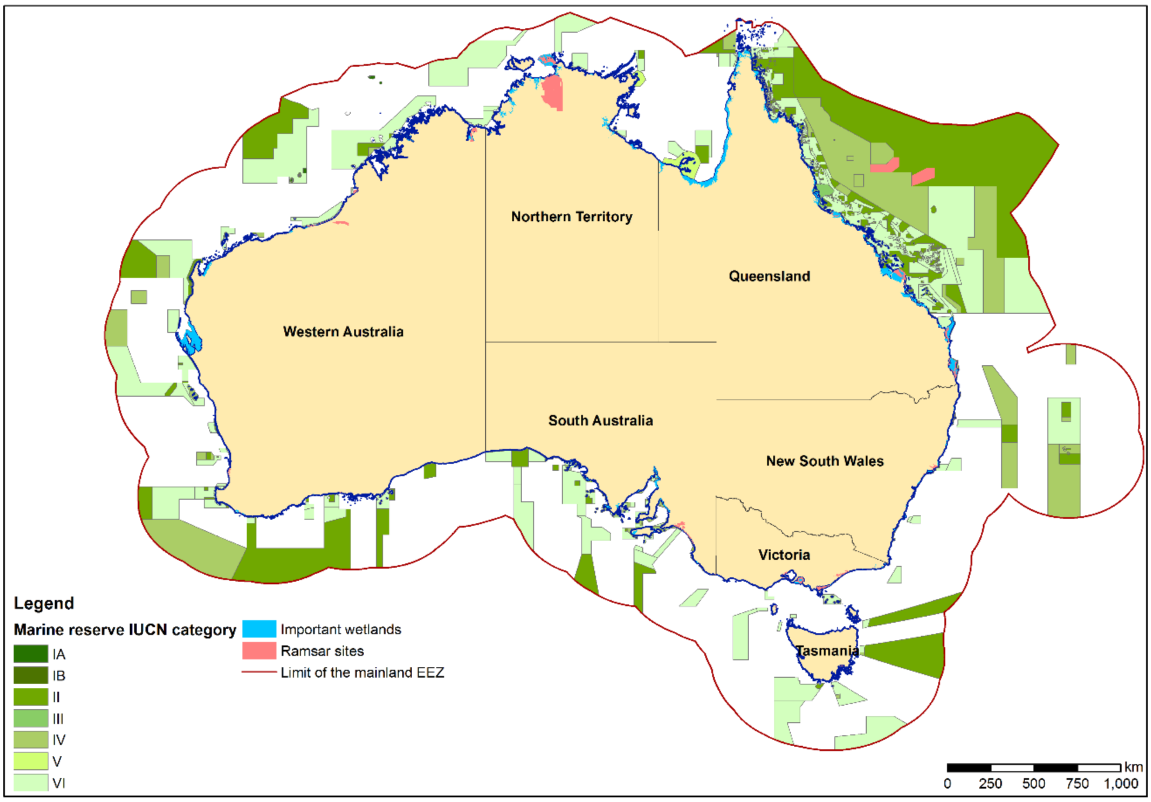

Figure 9. Marine reserves, both state and Commonwealth, and important wetlands adjacent to the coast. (Data source: CAPAD 2016, Department of the Environment and Energy).

Data integration

Large volumes of disparate data need to be integrated in order to make sense of it all. Geographical information systems (GIS) were designed with this problem in mind. With the exception of Figure 8, all the maps in this section were made using a GIS.

Key information sources – BCA

Providers of BCA expertise

Developing a BCA that adequately reflects the potential impacts of an incursion and the costs of eradication will require a team of staff with a range of skills, especially in economics, accounting, science and response-management. The following organisations may be able to assist in the development of a BCA (this list is not exhaustive):

- ACIL Allen Consulting: http://www.acilallen.com.au/
- Agribusiness and Economics Research Unit, Lincoln University, NZ: http://www.lincoln.ac.nz/Research/Research-Centres/Agribusiness-and-Economics-Research-Unit/About-Us/

- Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)[10] within DAWR: http://www.agriculture.gov.au/abares/
- BDA Group: http://www.bdagroup.net/
- Centre for International Economics: http://www.thecie.com.au/
- CSIRO: https://www.csiro.au/en/Research/BF
- Deloitte Access Economics: https://www2.deloitte.com/au/en/pages/finance/topics/deloitte-access-economics.html?icid=top_deloitte-access-economics
- Frontier Economics: http://www.frontier-economics.com.au/
- Marsden Jacob Associates: http://www.marsdenjacob.com.au/

Non market valuation

Many of the resources describing principles of BCA will also contain information on non-market valuation (NMV). Additional sources of information about NMV principles and practices include:

- Bennett, J. (2011). *The International Handbook on Non-Market Environmental Valuation*, Edward Elgar Publishing, Cheltenham.
- Baker, R. and Ruting, B. (2014). *Environmental Policy Analysis: A Guide to Non-Market Valuation*. Staff Working Paper, Productivity Commission: http://www.pc.gov.au/research/supporting/non-market-valuation
- Johnston, R.J., Rolfe, J., Rosenberger, R.S. and Brouwer, R. (2015). *Introduction to Benefit Transfer Methods*, Springer, Dordrecht. doi: https://doi.org/10.1007/978-94-017-9930-0
- Bergstrom, J.C. and Randall. A. (2010). *Resource economics: an economic approach to natural resource and environmental policy*, 3rd Edition.

Primary studies for use in benefit transfer

Unfortunately many primary studies remain unpublished, and there is only one known searchable database (EVRI). Published studies may be found within the following:

- *Australasian Journal of Environmental Management*: https://www.tandfonline.com/loi/tjem20
- *Australasian Journal of Agricultural and Resource Economics:* https://onlinelibrary.wiley.com/journal/14678489
- *Ecological Economics*: https://www.journals.elsevier.com/ecological-economics/
- EVRI (Environmental Valuation Reference Inventory): http://www.evri.ca/)
- *Journal of Marine Resource Economics*: https://www.journals.uchicago.edu/journals/mre/about

[10] ABARES has tested the National Framework for Biosecurity Benefit Cost Analysis on six hypothetical and actual pest or disease incursions including *Mytilopsis sallei* (black-striped mussel).

- *Journal of Environmental Economics and Policy:* https://www.tandfonline.com/loi/teep20
- *ABARES* publications http://www.agriculture.gov.au/abares/publications/

Recent publications include: Mazur, K., Bath, A., Curtotti, R. & Summerson, R. (2017). An assessment of the non-market value of reducing the risk of marine pest incursions in Australia's waters. Canberra: ABARES

- Ocean & Coastal Management: https://www.journals.elsevier.com/ocean-and-coastal-management

Appendix B. Attaching dollar values to costs

Do nothing

Doing nothing or adopting a wait and see approach are potentially high risk options. Most marine organisms reproduce by broadcast spawning which can potentially result in large numbers of larvae being rapidly dispersed. The more generations that are produced the less chance there will be of eradicating them. While it may not be possible to eradicate an incursion of highly mobile organisms such as crabs, control measures may be helpful to reduce the population and its impacts.

Doing nothing is also the basis of the counterfactual or the base case situation where impacts from the invasive species are allowed to develop unhindered. It is the calculation of these impacts that form the benefits side of the benefit-cost analysis equation and are the losses it is hoped to avoid by eradicating the pest. The time period over which the impacts are calculated is discussed in the 'Time in cost-benefit analysis' section in Appendix F.

Eradication

In order to estimate costs it will be necessary to identify the surfaces and areas that are infested with the organism and calculate the amount of material and the amount of effort (person/days) that will be needed to be applied to each surface type. This may mean, for example, calculating the length of plastic wrapping needed to wrap each pylon on a jetty to the height and depth of the tidal range plus the depth to which the organism has become established and, if a chemical treatment is proposed, the quantity and frequency of application for each pylon. In terms of effort, how long with this take to accomplish and how many people are needed to do it.

Calculation of the costs is made relatively easy by breaking the operation down into discrete tasks (Table 6). An Excel spreadsheet will help with this task. An important caveat, however, is that unless the teams carrying out the eradication have had experience with undertaking the treatment tasks, or similar tasks, previously, it is highly likely that they will take much longer to carry out than anticipated. It is recommended, therefore, that trials be carried out to determine the amount of materials required, the time each task is likely to take and optimal conditions in which to do them. For example, it is likely to be much easier to wrap plastic sheeting around a pylon at slack water at the end of an ebb tide than in a fast running ebb or flood tide.

Table 6. Example of a cost calculation, in this case the costs of using a steam heater to clear a small patch of an exposed invasive organism, such as a mussel.

Technique	Area (m^2)	Unit cost ($)	No. units	Fuel cost per hour	No. hours	No. operators	Operator cost per hour ($)	Total operator cost	Total Cost
Hot water/steam	25	500	1	$25	2	1	200	400	$950

In addition to the costs of eradication, additional costs may include:

- Quarantine/closures to prevent unintentional spread

- Further surveys to monitor and to confirm eradication
- Monitoring/surveillance

It is unlikely that every component will be completely successful at the first attempt; it will therefore be necessary to allow for multiple eradication attempts. If it is anticipated that eradication is likely to be continued for more than one year it will be necessary to discount the second and subsequent years' costs. Appendix F provides guidance on discounting.

Containment

Funding for containment is not available under the NEBRA except where it is initial containment in preparation for eradication (NEBRA Clause 7.5).

While containment (Wittenberg and Cock, 2001) may be possible in terrestrial systems where movement of livestock, vehicles and other potential vectors can be relatively easily controlled, containment of spread by natural dispersion will be unlikely in the marine environment except in exceptional circumstances. The black-striped mussel incursion in Darwin in 1999 (Bax et al., 2001) is an example of a containable incursion in that it occurred in a marina that was able to be isolated with a lock gate. Unless an incursion happened in a similarly isolatable environment the chances of being able to contain natural spread will be slim. Spread by anthropogenic vectors may be able to be contained by managing the main pathways by which organisms can be entrained and translocated. If translocation by ballast water is considered a risk, for example if larvae are likely to be in the water column, ballast water management, either treatment or exchange, can be mandated. If translocation as biofouling is considered to be a high risk, there are a number of management options that can be considered including slipping and cleaning recreational vessels, in-water cleaning for larger vessels (but noting the in-water cleaning guidelines (DAFF and DSEWPaC, 2013) and restrictions on the time allowed in port for high risk vessels.

Containment costs

Containment costs will most likely be restricted to the management of translocation by human agency and may include the following:

- Vessel surveys to determine whether they have been infested with the invasive species and therefore have a higher risk.
- In-water cleaning of vessels.
- Ballast water treatment or exchange to prevent larvae being translocated to new areas.
- Management of vessel movements from the infested port or location.

Appendix C. Categories of impacts.

The NEBRA requires that an incursion by an invasive marine species (in this context) meets at least one of a set of national significance criteria before a national response, including cost-sharing, can be invoked (NEBRA Clause 5.1 (b) (iii), Clause 6.4). In the event of an incursion, the determination of whether the incursion is nationally significant will have taken place before the BCA is commenced (NEBRA Schedule 1, Step 6). Table 7 summarises potential impacts that may fall under the national significance criteria, examples of actual or potential impacts and how measurement of impacts may be undertaken.

Table 7. Categories of impacts (adapted from NEBRA Schedule 3. National Significance Criteria.)

Impact	Example	Measurement
Environment		
Projected impacts on nationally important species, ecologically valuable species, nationally important places, ecologically valuable places or extensive impacts on; the physical environment, Australian biodiversity, the structure of ecological communities, ecosystem functions, environmental amenity or ecosystem services		
Impacts on nationally important species		
Lead to the extinction or significant decline of a nationally protected or endangered species or community	Predation by northern Pacific seastar (*Asterias amurensis*) on spotted handfish (*Brachionichthys hirsutus*) spawning substrates or eggs in Tasmania is thought to be one of the factors contributing to its decline (Edgar et al., 2017).	Number of species and/or communities affected; qualitative description. Non-market values.
Impacts on ecologically valuable species		
Significant negative consequences on ecologically valuable marine species	The northern Pacific seastar (*Asterias amurensis*) and European shore crab (*Carcinus maenas*) are both opportunistic predators and have been implicated in the declines of native species such as (spotted handfish (*Brachionichthys hirsutus*) and a venerid clam (*Katelysia scalarina*) respectively. (Edgar et al., 2017, Walton et al., 2002)	Number of species affected; qualitative description. Non-market values.
Impacts on nationally important places		
Significant negative consequences on a nationally important place (i.e. relevant to the national identity)	This criterion may be restricted to an IMS becoming established in the Great Barrier Reef (GBR) or possibly Ningaloo. There are a number of species whose maximum potential ranges may include parts of the GBR and Ningaloo (Richmond et al., 2010). It is possible, that one or more could become established in a disturbed environment such as a port, and subsequently spread.	Extent of the place affected; qualitative description. Non-market values.

Impacts on ecologically valuable places		
Significant negative consequences on an ecologically valuable place	Marine reserves or coastal Ramsar sites are considered as ecologically valuable places (Campbell and Hewitt, 2013). Marine reserves are usually sited in areas with healthy ecosystems; disturbed environments, such as within port areas, are thought to improve invasion success by invasive marine species. The spatial separation of marine reserves from disturbed environments is likely to be an important factor in assessing whether an invasive marine species will reach the reserve. Despite the expectation that invasive marine species would be less likely to invade marine reserves, this has not been the case in the Mediterranean Sea (Otero et al., 2013). It is highly likely that species like the northern Pacific seastar (*Asterias amurensis*) and European shore crab (*Carcinus maenas*), which are both fecund and mobile, are present in Tasmanian coastal marine reserves but this has not been documented.	Extent of the place affected; qualitative description. Non-market values.
Extensive impacts		
Severe or extensive impacts on the physical environment, biodiversity, ecological structure or function, or ecosystem services	Once an alien marine species has shown invasive traits and has been detected, research into three factors should provide information about the likelihood of severe and extensive impacts: 1. Knowledge and experience with the species, or a close relative, from overseas 2. Physiological research into specimens that will show its potential fecundity 3. The traits it has demonstrated during the early stages of its incursion in Australia Note that it may take some time for the species to become established and develop extensive impacts. It is possible that northern Pacific seastar (*Asterias amurensis*) was first introduced into Tasmania in the late 1970s (Goggin, 1998). The first specimens of the northern Pacific seastar from the River Derwent were found in 1986 (Turner, 1998); the first specimen in Port Phillip Bay was found in 1995 (Garnham, 1998).	Extent of the place affected; qualitative description. Non-market values.
Impacts on People		
Projected impacts leading to the inconvenience of people and society or impacts on human infrastructure		
Impacts on human infrastructure		
Impacts on infrastructure used by a significant proportion of people	A number of fouling species could cause serious negative consequences. A number of species of mussel have been implicated in risks to fouling cooling water intakes in industrial plants, including power stations (Rajagopal et al., 2005).	Monetary value
Impacts on social amenity		
Impacts on amenity of resources used by a significant proportion of people over an extensive area	The period die-offs ("death assemblages") of *Mya arenaria* and the associated bad smell has been a problem for the tourism industry on the Black Sea coast of Romania (Leppäkoski, 1991). Its forecast maximum range is however restricted to Victoria, Tasmania and south-eastern South Australia.	Monetary value

Cultural impacts		
Impacts on cultural assets valued by or the practices or customs of a significant segment of the community.	No documentary evidence has been found for invasive marine species having an impact on cultural values in Australia. Possible impacts may include interference with indigenous practices and on shipwrecks.	Descriptive.
Business Activity		
Substantial increases in business costs or a substantial loss of production or business opportunities for an extended period		
Likely to affect domestic trade (incl. movement of commodities) or national biosecurity standards	The response to the incursion might affect domestic trade, if, for example, vessels travelling between the infected port and other ports were required to exchange/treat their ballast water or be inspected for biofouling. During the incursion of *Mytilopsis sallei* (black-striped mussel) in Darwin in 1999, 420 vessels were identified as being potentially fouled with *M. sallei* (Ferguson, 2000).	Monetary value
Likely to cause revenue losses for major primary production sectors (e.g. recreational or commercial fisheries, incl. aquaculture) over and above current consequences or costs due to native or established introduced species?	A fouling species like *Mytilopsis sallei* could cause revenue losses in the pearling oyster fishery (Ferguson, 2000), similarly a colonial tunicate species, for example *Didemnum* sp. or an alga, for example *Undaria pinnatifida*, could cause revenue losses in the tuna, salmonid and shellfish aquaculture through decreased production and/or increased production costs (Switzer et al., 2011, Fitridge et al., 2012).	Monetary value
Human Health		
Impacts on public health may be used to support the full impact assessment of a pest but do not form part of an assessment of national significance		
Likely to have serious national public health ramifications	Blooms of toxic dinoflagellates have the potential to cause impacts on human health in a variety of ways, most notably by paralytic shellfish poisoning (PSP) (Hallegraeff, 1992). It is not certain whether the organisms that cause PSP are alien to Australia as many have a worldwide distribution. Harmful blooms of toxic dinoflagellates are usually restricted in extent and are therefore unlikely to meet national significance criteria (Hallegraeff et al., 1988). No macroscopic invasive marine species have been documented to present a national public health risk.	Monetary value

Appendix D. Identify impacts and select measurement indicators

The NEBRA BCA Key Requirements are specific about how potential impacts should be evaluated in the BCA (NEBRA Schedule 4, Attachment 4A, Section 2.2). Impacts should be described and/or quantified as follows:

- Type of impact (qualitative or quantitative; market and non-market)
- Scale of impact, both spatially and to businesses and environment.
- Affected entities (individuals, industry, the environment, etc)
- Likely effect of the response measure on mitigating the impacts.

The intent of the response, i.e. the eradication attempt, will be to prevent any of these impacts occurring. If the eradication attempt is unsuccessful, however, a decision will have to be made whether to continue eradication attempts or move to a different strategy, such as containment or control. Note that containment and control are out of scope of the NEBRA (Clause 7.5).

The Key Requirements also state that all known potential impacts should be listed. It is important to identify all the potential impacts thought to be likely from the incursion of a marine pest, even though it may be difficult to subsequently value all of them. It is also important to consider how each may be measured.

It may not always be necessary to calculate values for every impact if easily calculated figures give a result with a clear indication that there are positive benefits to mounting a response. Nevertheless, it is recommended that all impacts be at least identified and described.

Identify impacts

When a marine pest invades a new range, a number of negative impacts might occur if it were left unmanaged. For example, an aquaculture operation may face stock losses due to predation, part of a coastline previously used for swimming may become unusable, or a marine ecosystem may be smothered by an invasive algae. The likely negative impacts from the presence of the marine pest are the losses that the selected management action (e.g. eradication) is attempting to avoid (the *benefits* of management action).

Impacts can be categorised in many different ways. For the purpose of incorporating impacts into a benefit-cost analysis we suggest a broad division of impacts into:

- the environment;
- business activity;
- people
  - impacts on infrastructure
  - impacts on social amenity
  - cultural impacts
  - human health

This results in a categorisation of impacts that can be broadly assigned monetary values according to particular methods, i.e. market or non-market values (Appendix E). Categories of impact that fall under the national significance criteria are shown in Table 7 together with examples of impacts and methods of measuring impacts.

It is to be expected that obtaining a definitive identification of an invading species may take some time, especially if it is not on a list of anticipated invasive marine species. Obtaining information about the life history of the species and its potential impacts could take considerably longer. Lack of information should not cause a delay in a response to an incursion, especially if the organism is displaying signs of invasiveness. If no information is found about the impact of the invading species, the first step should be to research the impacts of related species.

Measurement indicators

Indicative measurement indicators should be selected for each impact. Ideally, all impacts would be amenable to calculation or estimation in dollar terms, but in reality this will not be the case. Time and resource constraints, the nature of the impact, and uncertainties around timing of impacts are all reasons why 'monetisation' may not be feasible. All likely impacts should still be listed in the BCA, with the analyst selecting the likely way in which magnitude of the impact will be discussed. There are three possible ways of doing this. Impacts may be:

- monetised (given dollar values);
- quantified but not monetised (e.g. measured in terms of number of species or ecological communities likely to be threatened by the pest);
- qualitative, but not quantified or monetised

Time in benefit-cost analysis

There is no hard and fast rule over what time period impacts should be calculated. The key issue is that of spread: how far is the organism likely to spread and how long will it take to reach that point? This is the basis of the counterfactual, which with the cost of the impacts across this range, is the total estimated cost of doing nothing. The question is: over what period of time that should that be done? Richmond et al. (2010) mapped the maximum potential range of 30 invasive and potentially invasive marine species for cost-sharing purposes in the NEBRA. These maps, and the methodology to create maps for other species, can be used to estimate the maximum range that these species will spread. No estimation of how long it might take for a species to reach the limits of its range nor fully saturate it was attempted, however. These ranges should therefore be taken as the outer limit and it should not be assumed that invasive species will reach them within any given time frame.

It is unlikely to be possible to predict with any certainty how long it will take for an invasive species to spread to the full extent of its predicted maximum range. It is therefore recommended that a time horizon of 30 – 50 years be chosen and that an estimate is made of how far the species will spread over that time, including spread by natural dispersion and anthropogenically-assisted. Any anthropogenically-assisted range extension may, of course, be followed by natural dispersion from that point.

A marine pest incursion may take many years to develop sufficient numbers for its numbers and/or impacts to become visible. It is thought that *Asterias amurensis* (northern Pacific seastar) may have been resident in the Derwent Estuary in southern Tasmania for a decade or more before it was identified as an invasive alien species in 1992 (Turner, 1998). As with most marine species its distribution is difficult to determine but it is estimated to occupy about 1% of its maximum potential range. *Mytilopsis sallei* (black-striped mussel) had been resident in Cullen Bay Marina, Darwin, in 1999 for less than six months when it was detected at very high densities (Bax et al., 2002) and although its temperature tolerances suggest that it

could become established anywhere around the coast of Australia the incursion was eradicated before it could spread.

Some species may move very rapidly. *Mytilopsis sallei* is a sessile invertebrate but its distribution extends from Mumbai in India to Tokyo in Japan, including Singapore, Hong Kong and Taiwan, which it has achieved in about 50 years. Invasive lionfish species (*Pterois volitans* and *Pterois miles*) are thought to have been introduced into the coastal waters of Florida via the aquarium trade and were identified as invasive in the early 2000s (Hixon et al., 2016). Their current distribution extends from Cape Hatteras in North Carolina to Brazil (including most of the Caribbean Sea and parts of the Gulf of Mexico), a distance of approximately 6,000 km following offshore coastlines (Hixon et al., 2016). Lionfish are free-swimming fish. The difference between the two is that lionfish have extended their range by natural dispersion whereas *M. sallei* has spread entirely by anthropogenic assistance.

Summerson et al. (2013) analysed the costs of eradication versus containment of hypothetical incursions of *Mytilopsis sallei* (black-striped mussel) over three time periods: 10, 20 and 30 years. Leigh (1998) calculated benefits for an 11 year control program for ruffe (a freshwater fish introduced into the North American Great Lakes) over a 50 year time period. Coutts & Sinner (2004) in their benefit-cost analysis of management options for *Didemnum vexillum* (carpet sea squirt) in Queen Charlotte Sound selected a time horizon of five years and assumed that spread would not extend beyond Queen Charlotte Sound. Their benefit-cost analysis was based on these assumptions/expectations. This had the benefit of reducing the scope of potential impacts which made their calculations much shorter and easier. On the other hand, *D. vexillum* is unlikely to be restricted to Queen Charlotte Sound in the long term.

As discussed above, the application of a discount rate will reduce the value of impacts in the distant future considerably and this may provide a pragmatic cut-off for the time over which to estimate impacts. The time period over which this will happen will depend on the initial valuation of impacts and the discount rate. For example, if impacts of $1M are estimated and assuming a 7% discount rate, after 34 years the value will have been reduced to 10% of the original value. The consequence of discounting on one hand and developing impacts over time on the other may mean that the value of the impacts will be discounted just at the time when they are making themselves felt.

Predicting impacts over time

Impacts will change over time if an unmanaged pest spreads in area and/or density. It is the impacts from this spread that the management action is seeking to avoid. Modelling pest spread over time and space is therefore a key part of a BCA.

As discussed above (Time in benefit-cost analysis section), the rate a non-native species spreads is dependent on a wide range of factors and is therefore highly variable. Predicting the spread of a marine organism should also be approached at two levels:

- natural dispersion from the site of the incursion; and
- anthropogenically-assisted dispersal.

Natural dispersion can be best predicted using a hydrodynamic model to model the dispersion of larvae, in the case of marine animals and sporophytes and plant fragments in the case of marine plants (algae). A hydrodynamic model is a sophisticated computer model and would be best used in collaboration with an expert who understands how it was built and how it functions. Hydrodynamic models are described in more detail in Appendix A.

Anthropogenically-assisted dispersal requires understanding the patterns of movement of anthropogenic vectors (shipping, fishing vessels, recreational craft, aquaculture etc.) and developing models of risk based on the risk factors inherent in these vectors. Risk factors include the movement of ballast water between ports in Australia and risks of biofouling, though other pathways should not be discounted. Modelling anthropogenic dispersal of invasive marine species is not currently well developed; there are, however, good quality data on the movement of commercial shipping from Lloyds, MARS and others, based on historic shipping movements. Movement of recreational vessels is less well understood as it tends to be more random.

A geographical information system (GIS) such as ArcGIS (https://www.esri.com/arcgis/) is an invaluable tool to map the incursion, the location of vulnerable urban, industrial and environmental assets and estimate the rate and direction of spread. These and other data will be built into a hydrodynamic model, if one is available for the locality of the incursion.

If the incursion site is within or near a port or if it is estimated that natural dispersion will enable the organism to reach a port, there are risks that ships in the port will become infested with the organism, either as biofouling or in ballast water taken up in the port. Although there are measures that can be carried out to mitigate these risks, such as minimising time spent in port, insisting that the antifouling coatings on vessels are kept in date and mandating ballast water treatment or exchange after leaving the port, none of these measures are likely to be one hundred per cent effective. If a ship becomes infested and transports the pest to a new location all the response costs may have to be repeated at the new location. It is likely that the infestation of Port Phillip Bay by *Asterias amurensis* (northern Pacific sea star) was the result of a secondary incursion from the site of the original incursion in south-east Tasmania (Parry and Cohen, 2001).

Aspects of the spread models will be uncertain, and these should be noted, and subject to a sensitivity analysis as part of the BCA.

Appendix E. Attaching dollar values to impacts

Once impacts have been listed (Chapter 4) the next step is to 'monetise' the impacts – attach a dollar value to them. These values should be viewed as the amount that the affected parties are willing to pay in order to avoid the impacts from the invasive-species incursion.

In many cases, dollar values of impacts can be estimated by observing behaviour – for example the value people place on a good or service can be observed from the amount they actually pay for it, and how much is purchased. In many cases, however, particularly where impacts occur on the environment, monetising impacts can be difficult – environmental goods and services typically are not traded in markets. Furthermore, the timing and extent of impacts will be uncertain. Various methods are available to monetise impacts on the environment of invasive species. Even when monetising impacts is difficult, a BCA should present the best estimates of expected costs and benefits, along with a description of the major uncertainties and how they were taken into account.

Many of the valuation methods outlined in this chapter will require the assistance and guidance of an economist, especially if primary studies are required to gather and analyse data. When time and resources prevent such studies, benefit transfer may be an appropriate alternative. See the section on benefit transfer below. This technique should be applied with caution, and again will require the services of an economist with expertise in non-market valuation.

Finally, when dollar value of impacts have been described, discounting of their values is essential. The basics of discounting are described in Appendix F.

Valuing impacts on the environment

The Total Economic Value (TEV) framework (Pearce, 1993; Barbier et al. 1997; Pascual 2010), is a useful way to capture the total value of environmental goods and services, and thus how these might be affected by an invasive species. An example of how the framework has been used in the invasive species context is given in Emerton and Howard (2008). We base our discussion of the TEV framework on the Office of Best Practice Regulation (2016) guidelines.

Under the TEV framework the value of environmental goods and services is the sum of the environment's *use* and *non-use* values. Use values are associated with aspects of the environment that are directly useful for production and consumption activities, such as extraction of raw materials or physical products; and non-use values are associated with experiences that occur in the valuer's mind. The TEV framework is firstly used to categorise the impacts as use and non-use, and subsequently to understand the appropriate technique that should be used to attribute a value.

Use values

Use values may be further classified into:

- *direct use values* – these result from the direct human use of the environment. Examples are 'consumptive' use activities such as fishing; and 'non-consumptive activities' such as using the environment for recreation activities or tourism. Since these consumptive activities are linked to the economic system, market values should be used to evaluate the damage that a pest-incursion would have incurred if left

unmanaged (see section on market prices below). For non-consumptive activities, revealed preference techniques should be used (see below)

- *indirect use values* – these are the values that people hold for the regulation services provided by species and ecosystems. Specific examples include pest control, carbon sequestration, water purification and soil fertility. This use of the environment is indirectly linked to the economic system, so while it is possible to derive a market value, it is a more difficult process. The defensive expenditure approach should be used to evaluate indirect use values of the environment as described below.

Non-use values

Non-use values of the environment, for example, the existence of a pristine beach, are not linked to economic production or consumption, but because they influence human well-being they need to be considered when the environment is valued. Non-use values may be further categorised as:

- *altruism/bequest value* – this is the value that an individual attaches to the fact that others (whether in this generation or future generations) will be able to benefit from the environment.
- *existence value* – this is satisfaction gained by the knowledge that an environmental asset exists.

Stated preference techniques should be used to evaluate these non-use values as described below.

Valuation methods

Once the different impacts have been categorised according to the TEV framework (Figure 10) the next step is to choose the appropriate technique for calculating values for those impacts. Impacts are relatively easy to value when market prices are available – the market price is an estimate of an individual's *willingness to pay* for an additional unit of a good or service (or to avoid a cost). When summed over all people this becomes the community's willingness to pay to obtain a benefit or avoid a cost. When there is no market for a particular good or service, as is often the case for environmental goods and services, it becomes necessary to estimate the willingness to pay for these non-market goods indirectly. Two broad groups of 'non-market valuation' methods have been developed for this purpose: i) those that use *revealed* preference techniques; and ii) those that use *stated* preference techniques.

Revealed preference techniques seek to elicit peoples' willingness to pay for a good or service by observing their actual behaviour in real, related markets, while stated preference techniques involve directly surveying people's hypothetical behaviour in carefully constructed markets for the environmental good/service in question (OBPR 2014).

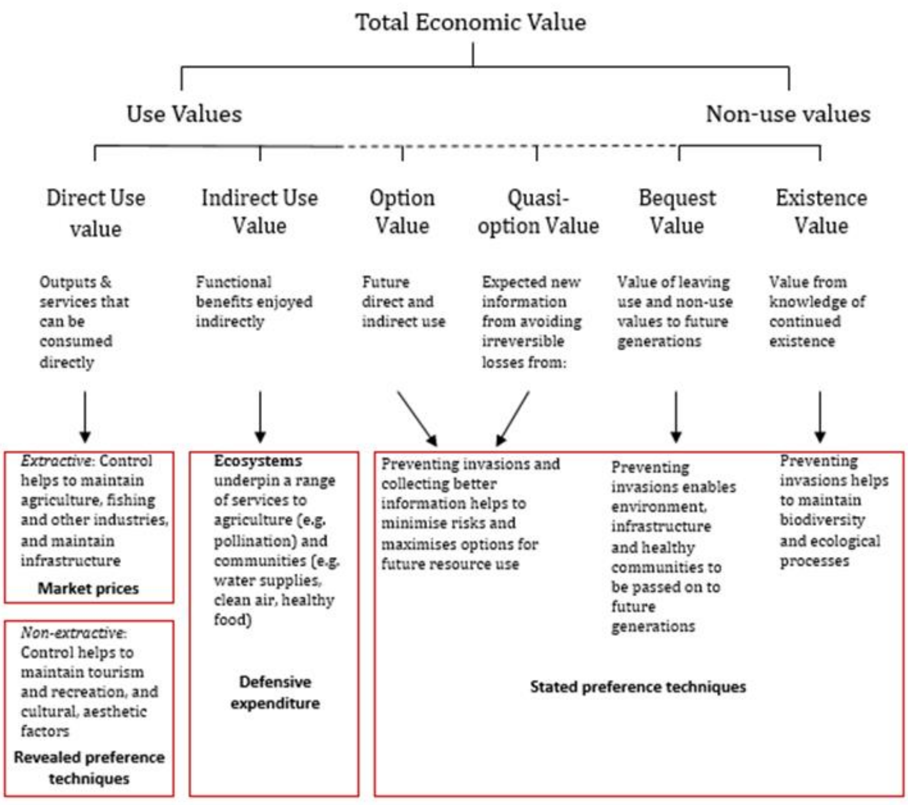

Figure 10. Total Economic Value. (Modified with permission from a presentation by John Rolfe.)
Note: Revealed and stated preference techniques and defensive expenditure are the non-market valuation methods that have been developed to value environmental goods and services when market prices are not available.

Market prices

The easiest and most commonly-used method to value a good or service is to use its market price. For frequently traded goods and services, prices will reflect true scarcity and thus (marginal) value. Current market prices will also be a reasonable guide to future prices. Sources of information for market prices include government statistics and market reports (see Appendix A).

The use of market prices is appropriate to value resources and products that are harvested directly from marine ecosystems, such as the losses occurring to a fishing or aquaculture operation from a pest incursion. Note that the value of direct production losses should be calculated, rather than the total value of the industry that is affected.

Defensive expenditure

The defensive expenditure approach should be used to value the regulation services provided by marine species and ecosystems. Relevant regulation services in the marine context would include cycling and filtration of wastes, flood and storm protection, gas and climate regulation (Beaumont et al., 2007; Barbier, 2013).

Under the defensive expenditure approach, the expenditure undertaken to maintain (defend) the existing level of the ecosystem service from a marine pest incursion may be viewed as a value of that service (Sinden and Griffith, 2007). Values inferred from defensive expenditures are thus based on observable behaviour. This approach uses *surrogate* market prices – the

actual market price of a related good or service - to value the service that is non-marketed (Barbier et al., 1997).

Criticisms of this approach include that it will only give a minimum estimate of the value of the ecosystem service in question, and it may also be difficult to identify an activity that can be used as a proxy for the regulation service provided by the environment.

Revealed preference methods

Revealed-preference techniques are used to value impacts on the non-extractive, direct uses, of the environment, such as tourism, recreation and aesthetic impacts. These methods infer value of the environment from observed behaviour and market interactions – market 'proxies' provide information on the value of a non-market good (OBPR 2016). The two main revealed preference techniques are the *travel cost method,* used for recreation impacts and *hedonic pricing* used for housing/lifestyle impacts. The defensive expenditure approach is also a revealed preference technique as described above.

Hedonic Pricing

The hedonic pricing method is most often used to estimate values associated with environmental quality and amenity value that affects the price of residential properties. The basic premise of the hedonic pricing method is that the value of a good or service is related to its characteristics. For example, in the current context, the high values of beachfront properties relate to the characteristics of and proximity to the beach, access and associated amenities, in addition to house structure, age, and neighbourhood. Each of these characteristics has an implicit value. Therefore, we could value the individual characteristics of the property, such as quality of the beach it is situated near, by looking at how the price people are willing to pay for the house changes when, for example, the beach and its marine ecosystem become invaded by a marine pest.

Applying the hedonic pricing method to a marine-pest incursion would involve data collection and a subsequent multiple regression analysis of house prices and their determinants (Commonwealth of Australia, 2006). This would involve a significant amount of time and expertise and is thus unlikely to be appropriate when undertaking a BCA in the time-limited response context. Existing hedonic pricing studies may be transferrable if the supply and demand conditions are the same. The scientific literature should be searched to identify studies that are potentially transferrable through a method known as benefit transfer (see section on benefit transfer below). ENVALUE (http://www.environment.nsw.gov.au/envalueapp/) is also a source of studies that may be transferrable. An economist with expertise in hedonic pricing analysis and benefit transfer should always be contacted to provide guidance.

Travel cost method

Under the travel cost method the costs of travel to enjoy the natural environment are used as a measure of how that environment is valued. This method is useful when the environment or recreational site has no entry fee, or a fee that is nominal or which rarely fluctuates. The travel cost method is based on the premise that the time and travel expenses incurred to visit a particular site represent people's willingness to pay – the price of – access to the site. The travel cost method has application in the marine pest context because it may be used to estimate the economic impacts resulting from loss of existing recreational site, or changes in environmental quality at a the site, that result from a marine pest incursion.

There are a number of ways to apply the travel cost method (see for example King and Mazzotta, 2000), and most of these require the collection of at least the following:

- number of visits from a particular location (could define by postcode);
- demographic information about people from each location;
- round-trip mileage from each location;
- travel costs per kilometre; and
- the value of time spent travelling, or the opportunity cost of travel time.

The data collected on the costs incurred by each individual in travelling to the recreational site or amenity reflect the value of the site to visitors. When combined, the observed travel costs for a large number of individuals allow estimation of a demand curve (Figure 11). In the current context the demand curve shows the relationship between the number of visits and the cost of those visits, and reveals information about the value of the environmental asset (Rolfe and Dyack, 2011).

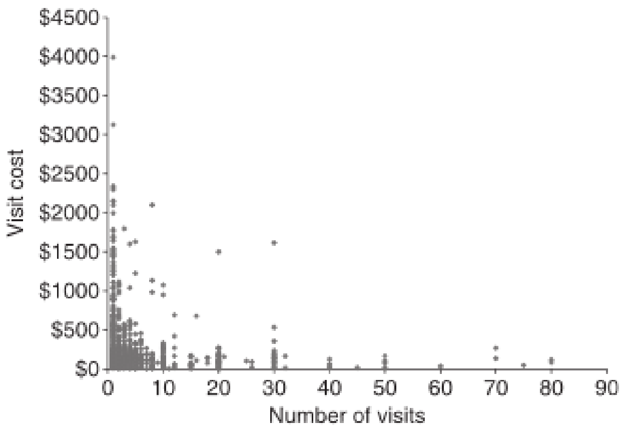

Figure 11. Trip cost vs visit rate for recreational users of the Coorong, Australia, collected using a visitor interception survey. Source: Rolfe and Dyack (2011)

For the purpose of valuing the impact of a pest on a particular site, it is important to know how the demand curve shifts (how people's 'demand' for visits to the site will change) in response to the presence of the pest. Economic theory tells us that a reduction in the quality of the recreational site will shift the demand curve to the left. To understand the size of the shift and thus its value, travellers can be asked some 'contingent behaviour' questions. Typically travellers would be asked about the likely effect on their travel following a change in access to the site. The magnitude of the shift is then used estimate of the change in value of the site. An example of where the travel cost method are used to value marine and freshwater sites include Rolf and Dyack (2011).While the travel cost method is a relatively cheap and uncontroversial technique for environmental valuation, there are a number of challenges with its application. For example, a critical assumption of the travel cost method is that the trip has a single purpose. If a trip has more than one purpose, travel costs must be allocated between each purpose (Commonwealth of Australia 2016). Furthermore, if a marine pest changes the quality of a marine park rather than causing the loss of the whole park, the analyst must either estimate the visits that would occur with the improved or draw on estimated values of activities in similar parks.

Stated preference methods

Stated preference techniques are used to value non-use aspects of the environment –values that individuals attach to the fact that others will be able to benefit from the environment (altruism/bequest value), or the satisfaction that an environmental asset actually exists (existence value). The two main stated preference techniques are *choice modelling* and the *contingent valuation*.

Contingent valuation

Using contingent valuation (CV), people are asked directly about their willingness to pay (WTP) for improvements in particular environmental goods and services. To understand WTP, people are asked (once) in a survey, to compare a business-as-usual scenario (no extra cost) with an improvement scenario (extra payment). To elicit accurate answers, a CV survey must first establish the nature of the good to be provided, and the way in which payment would hypothetically be made, for example in user fees, higher local taxes, contributions to a non-profit environmental fund etc (Commonwealth of Australia, 2016).

The question itself may be asked in several different ways. An example of a question asked in a CV survey, to elicit WTP to avoid three major pest incursions, is given in Figure 12 (Rolfe and Windle, 2017). Note that different costs were assigned to random respondents. The result of the CV survey was that mean WTP to avoid three major pest incursions in next 10 years was $306 per household.

Issues with CV studies (Commonwealth of Australia, 2016) include:

- the possibility that respondents will not answer honestly, and may exaggerate the value of something if they do not have to pay for it;
- information bias that may arise when answers depend on the information provided about the environment;
- respondents may ignore possible budget and other constraints; and
- the willingness of the respondent to accept the premise of a CV.

Nevertheless, CV studies do produce reasonable values when the results are compared with those derived from hedonic property price and travel cost studies (Commonwealth of Australia, 2016).

Q15. Foreign diseases and pests that have entered Queensland in the past 10 years include:

- Equine Influenza (horse flu) – major outbreak in 2008
- Papaya fruitfly – first detected in 1995; eradicated in 1998
- Sugarcane smut – first detected in 2006; outbreak not fully eradicated
- Red imported fire ants – first detected in 2001; outbreak not fully eradicated
- Citrus Canker – first detected 2004; eradicated in 2009
- Black Sigatoka (banana disease) – first detected 2001; now eradicated

Increasing quarantine inspections and surveillance could reduce the rate of new disease and pest imports to about half the current rate. If it cost an additional $260 per household per year, would you be willing to participate? This would be $260 **each year** for the next **10 years** to avoid approximately 3 serious foreign pests and diseases entering into Queensland.

Please answer this question bearing in mind how much you are able to pay (after taking into account all your other commitments) (please tick one)

☐ Yes ☐ No ☐ Not sure

Figure 12. An example of a question asked in a CV survey. Source: Rolfe and Windle, 2017.

Considerable expertise is required to develop a CV survey, analyse the data and validate the results. If there is time for such a survey to be undertaken, an economist with expertise in this technique would be required to assist with this task.

Choice modelling

In choice modelling studies, respondents are presented with a number of alternatives and asked to choose between them. As was the case with CV, choice modelling presents a business-as-usual option, and improvement options at an extra cost. CM differs from CV in that it describes the situation of interest in terms of attributes; it varies improvement options over different levels; and respondents are asked to complete a series of trade-offs (Rolfe and Windle, 2015). As a result, CM generates much richer information than CV.

The term ‘choice modelling’ embraces four main ways of making choices (Commonwealth of Australia, 2016):

- Choice experiments: the respondent is usually asked to choose between two alternatives and the status quo.
- Contingent ranking: the respondent ranks a series of alternatives.
- Contingent ranking: the respondent scores alternatives on a scale of say 1 to 10.
- Paired comparisons: the respondent scores pairs of scenarios on a similar scale.

CM was used to value additional protection against Red Imported Fire Ants in Brisbane (Rolfe and Windle, 2015). The sample choice sets from the study are shown in Figure 13. The CM experiment generated separate values for private homes (health); public areas (amenity and recreation), bushland (non-use) and eradication policy (instead of containment).

The advantages of CM (John Rolfe *pers. Comm.*) are that it:

- is flexible and allows precise scenarios to be valued;
- captures separate values for attributes and labels
- is forward looking (does not rely on past data)

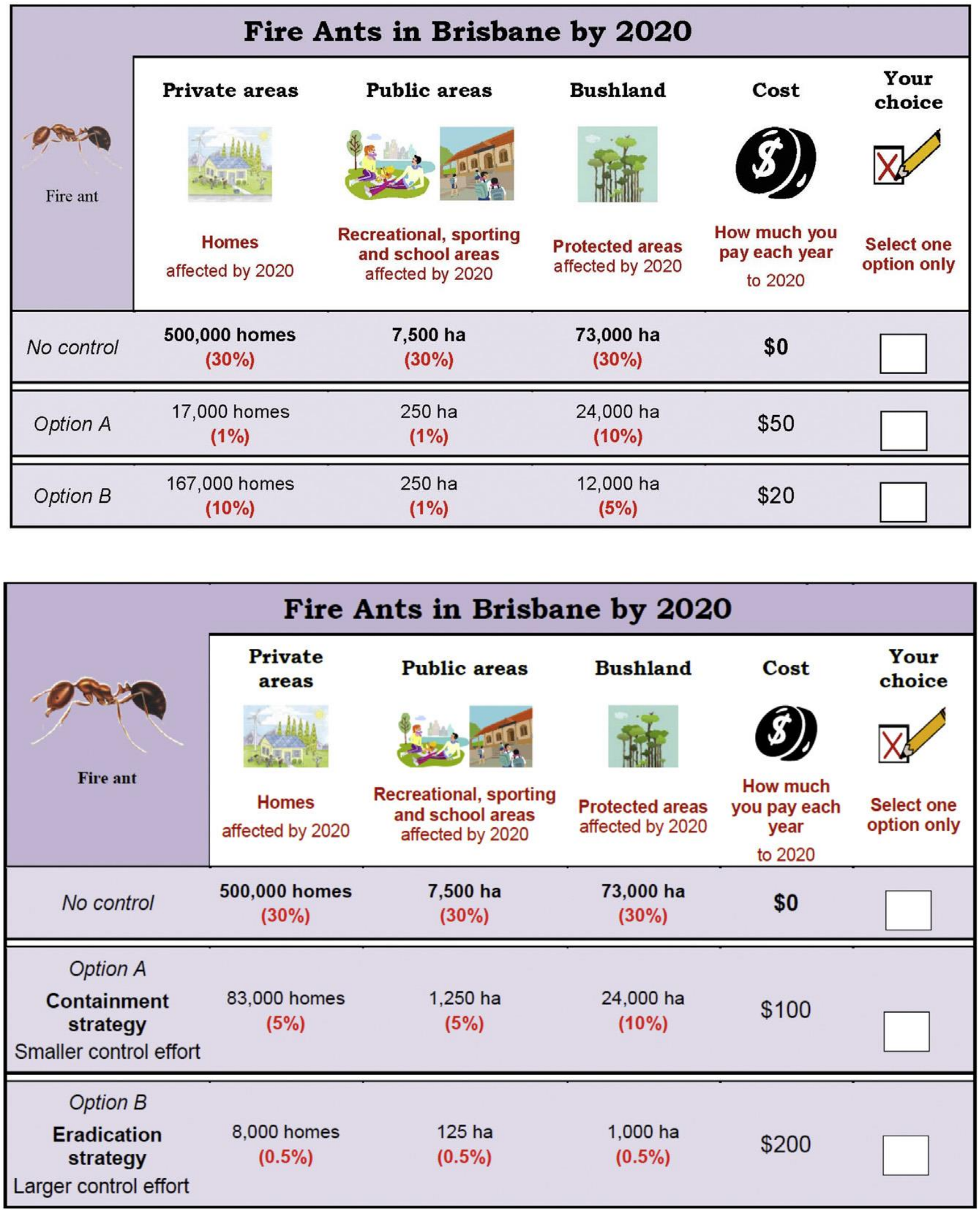

Figure 13. Sample choice sets from Rolfe and Windle (2014).

- captures non- use values (e.g. biodiversity protection); and
- can also capture recreation and amenity values.

However, poorly designed surveys can generate biased results and it is not possible to validate estimates of non-use values. CM studies usually take significant time and resources to undertake, and these may not be available in the response phase for a marine pest incursion.

Benefit Transfer

In the initial phases of responding to a marine pest incursion it is usually not possible to spend time on primary studies required in many of the valuation methods mentioned above.

Instead, analysts are sometimes able to use findings from similar studies to calculate values of avoided impacts, through a process known as benefit transfer. Benefit transfer involves transferring existing estimates of non-market values from a study site to the target site, where the sites are considered broadly similar. Values from the study site may be adjusted for differences in income, prices and demographic variables. Studies that might be appropriate to use in benefit transfer may be located on EVRI (Environmental Valuation Reference Inventory), a searchable database containing a large number of non-market valuation studies from across the globe. If undertaking benefit-transfer appears to be an option, an economist with expertise in this process should assist with this task.

In order that appropriate data is available to undertake benefit transfers in the future, primary non-market valuation studies, undertaken 'pre-emptively', could provide a pool of data from which to make inferences about likely impacts of marine-pest incursions once an incursion is notified (see for example Mazur et al., 2017).

Valuing impacts on people

Invasive species may have a range of impacts on human health, infrastructure, social and cultural amenity. As described in Appendix D, examples of marine pests affecting human systems include their impacts on human health through stinging or poisoning; impacts on harbour infrastructure or power plants through fouling. Marine pests may also impact on business activities; these impacts are covered in the section on market prices above.

Impacts on infrastructure

Typical impacts include the fouling of water-cooling intakes in industrial plants. When a marine pest species damages infrastructure, the value of the damage is calculated as the expenditure required to bring the particular piece of infrastructure up to the same standard as before the incursion occurred. It should also include losses incurred as a result of shutdowns required for clean-up and repair of equipment, for example. These losses can be calculated quite simply using market prices, such as labour costs, equipment purchase costs and loss of revenue. Connelly et al. (2007) list 12 expenditure categories for controlling zebra mussel in US drinking water treatment facilities. These include:

- Lost production and revenues
- Chemical treatment
- Filtration or other mechanical exclusion
- Mechanical removal

Similar expenditure categories could be expected for fouling species in a similar coastal facility in Australia that used sea water, for example Gladstone power station.

Impacts on social amenity

The NEBRA defines social amenity as "*any tangible or intangible resources developed or provided by humans or nature such as dwellings and parks, or views and outlooks*". These may be negatively impacted by marine species, for example, when an invasive algae covers a beach that was used for recreation. These impacts are 'non-consumptive activities' under the classification of 'Direct use values' in figure 10. As such, *revealed preference* techniques are appropriate as valuation tools.

Cultural impacts

Many coastal regions around Australia are important to Aboriginal and Torres Strait Islander peoples that maintain cultural values for land and sea country. Cultural heritage since European settlement in the marine and coastal environment that may be threatened by invasive marine species is likely to be predominantly shipwrecks. To date there has been no documentary evidence of impacts by invasive marine species on any cultural values in Australia, however. Costing impacts on cultural values are likely to only be amenable to a descriptive analysis in the response context.

Impacts on human health

Where marine pests cause negative impacts on human health, the value of these impacts may be calculated using information on:

- The likelihood of the impact occurring
- Average medical costs involved in treatment
- Number of days off work required for recovery
- Average wages.

Valuing impacts on business activity

Examples of the impact of marine pests on business activity include loss of yield in commercial aquaculture operations, or the time spent de-fouling infrastructure. The value of these impacts is readily calculable in dollar terms from a range of information sources (see Appendix A). Impacts over time should be predicted based on spread models. When undertaking the calculations of impact it is important to do the following:

- List all relevant assumptions on prices, quantities, spread parameters used in the analysis – these will be reported with the BCA.
- Note which values are most uncertain – sensitivity analysis will be required to check the influence of these values.

Appendix F. Discounting and recommending an option

Because BCA normally involves comparing benefits and costs that arise at different points in time, they must be compared in 'present-value' terms through a process known as *discounting*. Discounting is the process by which a future outcome (cost or benefit) is converted to a *present-value* monetary value. The present value is thus the equivalent value today of a future benefit or cost. By discounting, we are acknowledging that a dollar received today is not worth the same as a dollar received tomorrow, because today's dollar could be invested and earn interest. This means that the further into the future an impact occurs, the less weight it is given compared to a unit of impact that occurs today.

A future value is converted into a present value using the *discount rate*, *r*. The formula for calculating the present value, *PV*, of a future payment, received in time period *t* is:

$$PV = FV \frac{1}{(1+r)^t} \qquad (1)$$

Where *FV* represents the future value of the benefit or cost. Time is generally measured in years, with $t = 0$ representing the current year. Note that the expression $1/(1+r)^t$ in equation (1) is known as the *discount factor*.

An example of how future, 'nominal', values of benefits and costs should be converted to present values, is given in Table 8. The example shows a set of hypothetical costs and benefits involved in an 11-year eradication program of a marine pest. Costs and benefits should be calculated for each year of the program (see Appendices B and E on how to do this). In the current example, labour and chemicals (columns B and C) represent the only costs of the eradication program, while the benefits of the eradication program are the avoided losses that would have occurred from biofouling, and from the interruption to tourism activities (columns D and E). The *net benefit* in a given year (column F) is then calculated as benefits minus costs for that year. The discount factor for a particular year is

Table 8. An example of how costs and benefits are discounted over time

	A	B	C	D	E	F	G	H
1								
2	Discount Rate (*r*)		0.07					
3								
4		Costs ($'000)		Benefits ($'000)				
5	Year	Labour	Chemicals	Avoided biofouling	Avoided loss of tourist amenity	Net Benefit ($'000)	Discount factor (r=0.07)	Discounted net benefits ($'000)
6	0	50	10	10		-50	1.00	-50
7	1	50	10	20		-40	0.93	-37
8	2	10	5	40		25	0.87	22
9	3	10	5	80	50	115	0.82	94
10	4	10	5	160	100	245	0.76	187
11	5	10	5	160	200	345	0.71	246
12	6	10	1	160	200	349	0.67	233
13	7	10	0	160	200	350	0.62	218
14	8	10	0	160	200	350	0.58	204
15	9	10	0	160	200	350	0.54	190
16	10	10	0	160	200	350	0.51	178
17	TOTAL = Net Present Value							**1484**

multiplied by the corresponding net benefit to give the *discounted net benefits* for that year (column H). The sum of these values is known as the *net present value* (see below).

Where it is difficult to value all costs and benefits in dollars, non-monetised costs and benefits should be listed along with some indication and justification of whether they will be large or small relative to the monetised impacts.

The discount rate

The choice of discount rate makes a significant difference to the attractiveness of a given pest management program, particularly when most of the costs are incurred at the start of a program, while the benefits (avoided losses) are received in the distant future. The OBPR currently recommends using a discount rate of 7 per cent in regulatory cost-benefit analysis ($r = 0.07$), with sensitivity analysis using values of 3 and 10 per cent to reflect the uncertainty in the value of *r* (Commonwealth of Australia 2014). In our current example, discount rates of 0.03, 0.07 and 0.1 result in net present values (NPV) of $1937, $1484, and $1226 respectively (Table 9). The lower the discount rate the higher the NPV and thus the more attractive the policy will be.

Table 9. Discounted net benefits and NPV for a range of discount rates.

Year	r = 0.03	r = 0.07	r = 0.10
0	-50	-50	-50
1	-39	-37	-36
2	24	22	21
3	105	94	86
4	218	187	167
5	298	246	214
6	292	233	197
7	285	218	180
8	276	204	163
9	268	190	148
10	260	178	135
NPV:	**1937**	**1484**	**1226**

Sensitivity analysis on the discount rates should be undertaken by using discount rates that are higher and lower than the rate initially chosen. The Office of Best Practice Regulation currently recommends using discount rates of 3 and 10 per cent in the sensitivity analysis (Commonwealth of Australia 2014).

Comparing the costs and benefits

The National Framework for Biosecurity BCA (NEBRA Schedule 4, Attachment 4A) suggests two possible decision criteria: net present value and benefit-cost ratio and requires an explanation for which is chosen (Key Requirements 2.1 (f)). The techniques are similar in that both compare the present value of costs and benefits. The difference is that while net present value simply compares the difference between the costs and benefits, obtained by subtracting one from the other, benefit-cost ratio is the quotient obtained by dividing the benefits by the costs. Misleading results can arise if two or more options are compared using the benefit-cost ratio technique (Campbell and Brown, 2007) so it is recommended that the net present value technique is used.

Net present value

The net present value (NPV) of an option is the present value of benefits minus the present value of costs (cell H17 in our example in Table 8). When NPV is positive, a proposal is considered to be economically efficient and the community as a whole would be better off from its implementation. When more than one policy is being considered to solve a particular problem, the policy resulting in the highest NPV should be chosen.

Benefit-cost ratio

The benefit–cost ratio (BCR) is another method that can be used to rank alternative policies or courses of action. A BCR is the ratio of the benefits of a proposal relative to its costs, where both are expressed in present-values terms:

$$BCR = \frac{\sum_{t=1}^{T} B_t (1+r)^{-t}}{\sum_{t=1}^{T} C_t (1+r)^{-t}} \qquad (4)$$

where B_t and C_t represent the benefits and costs, respectively, that accrue in year t, r is the discount rate and T is time horizon of the evaluation. For a project to be acceptable the BCR must have a value greater than one. Note that when the BCR is greater than 1, the NPV is positive (greater than zero) and, vice versa. When more than one project is being considered it is important to note that the BCR and NPV approaches may rank projects differently – the BCR is biased towards small projects. We therefore recommend the objective of maximising NPV in ranking alternative management options.

Sensitivity analysis

The BCA (and NPV) presented to decision-makers should be based on the most plausible values of costs and benefits. There will, however, be many parts of the BCA where there is significant uncertainty and it is crucial to the rigour of the decision-making process that these uncertainties be explored properly, through sensitivity analysis.

Sensitivity analysis is undertaken to demonstrate how changes in different variables will affect the overall costs and benefits of the proposed management action. It shows how sensitive predicted net benefits are to different values of uncertain variables and to changes in assumptions (OBPR 2016). Importantly, it tests whether the uncertainties identified actually matter. It also identifies critical assumptions.

Sensitivity analysis needs to be undertaken systematically and presented clearly. A common approach is to undertake a w*orst/best case analysis*. In this method the BCA is re-run where uncertain variables take on i) the least favourable of a plausible range of values and ii) the most favourable of the plausible range of values. If the worst case analysis gives a negative NPV, an additional investigation into critical values will be required using either partial sensitivity analysis or Monte Carlo simulation (see OBPR 2016) for more details.

Consideration should be given to undertaking sensitivity analysis of:

- Spread rates over time
- Effectiveness of treatment methods
- The discount rate.

Appendix G. Template for benefit-cost analysis using the guidelines

<table>
<tr><th>Step</th><th>Actions</th><th>NEBRA key requirements</th></tr>
<tr><td>1</td><td>Specify the option(s).</td><td>2.1 Statement of Context</td></tr>
<tr><td colspan="3">Notes.
• Confirm the national incident response plan
• Identify the base case</td></tr>
<tr><td colspan="3">Response</td></tr>
</table>

<table>
<tr><td>2</td><td>Determine the costs of the response action (NBIRP).</td><td>Schedule 4, clause 5.2 (Relevant matters), especially sub-clause (c).</td></tr>
<tr><td colspan="3">Notes
• Use an Excel spreadsheet to break down the response actions into their component parts and cost the time and materials required for each.</td></tr>
<tr><td colspan="3">Response</td></tr>
</table>

<table>
<tr><td>3</td><td>Identify impacts</td><td>2.2 Identification of likely impacts of the threat and proposed response</td></tr>
<tr><td colspan="3">Notes
• Identify all impacts
• Identify and categorise the likely impacts of the pest
• Consider how the impacts will be measured
• Identify the scale of the impact (e.g. regional, national, export-market level)
• It may not be necessary to estimate all possible impacts</td></tr>
<tr><td colspan="3">Response</td></tr>
</table>

4	**Predict the impacts over time.**	**2.2 Identification of likely impacts of the threat and proposed response**
Notes • Use available models to predict natural spread of the pest • Detail assumptions behind modelling • Highlight key uncertainties in spread predictions • Work to 30 – 50 year time frame		
Response		

5	**Attach dollar values to impacts (benefits[1]).**	**2.3 Quantification of impacts of the threat and proposed response**
Notes • Place dollar values on the benefits of management action (=avoided losses) • Place dollar values to the costs of management action • List key uncertainties in the measurement process		
Response		

6	**Discount and compare costs and benefits of alternatives.**	**2.3 Quantification of impacts of the threat and proposed response; Part (c) Explain and justify the choice of discount rate**
Notes • Select an appropriate discount rate • Calculate a discount factor for each year in the future and apply to net benefits		
Response		

7	**Calculate the costs and benefits using net present value.**	**nil**
Notes		
Response		

8	**Perform sensitivity analysis.**	**2.4 Risk and Uncertainty** **2.6 Transparency and accountability**
Notes • Re-run BCA for worst and best case values of uncertain variables		
Response		

9	**Assess the BCA and reach a conclusion.**	**nil**
Notes • The final step in the BCA is summarising results, reaching a conclusion and providing this advice to CCIMPE.		
Response		