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Department of Agriculture, Fisheries and Forestry

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Centre of Excellence for Biosecurity Risk Analysis

CEBRA Project 1301C

Improving the methods used for constructing ballast water risk tables

Project Business Case 10

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DOCUMENT CONTROL

Document Location

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0.1	Initial working draft	Andrew Robinson	July 8, 2013

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EXECUTIVE SUMMARY

Exotic species carried by ballast water could potentially threaten the marine environment of recipient ports. To estimate and manage the risks of these species within Australia, CSIRO and DAFF developed the Australian ballast water risk assessment (hereafter called the BWRA). The BWRA is a modular, species-specific system that estimates the risk that a species could be taken up from one Australian port, transported to another Australian port and successfully establish there, for any given month in the year. Outputs from the BWRA are displayed in large excel tables referred to as "risk tables" and are incorporated into the Australian Ballast Water Management Information System (ABWMIS), DAFF's decision support system for ballast water management, where they are used to automatically assess and respond to ballast water management exemption applications submitted by the shipping industry.

The BWRA code and risk tables are complex and require expert/technical knowledge to run or change base data. Previously this knowledge has been held exclusively by the CSIRO, however an ACERA project (Project No: 1104E) has just been completed that transferred the required knowledge/skills to update and run the risk assessment model and generate risk tables from CSIRO to ABARES. During ACERA project 1104E a number of issues were identified largely concerning module 4 of the approach. These issues require remediation prior to the anticipated national roll-out of the ABWMIS following entry into force of the new biosecurity legislation. These issues, which are described in the body of this proposal, concern the way risk is extracted from the current conceptual and modelling framework developed in earlier projects by CSIRO. The purpose of the current project is to address these issues.

This project implements DAFF objectives to deliver on effective biosecurity controls across the biosecurity continuum, and strengthen stakeholder partnerships through the provision of up-to-date and valid decisions based on risks. The project will strengthen DAFF's ability to identify and effectively target those vessels posing the highest risk of translocating marine pests between Australian ports and will reduce the safety and economic pressures on the shipping industry where entrained ballast water does not pose an environmental risk using the most up-to-date approach currently available to inform ballast water risk decisions in Australia. The project also supports CEBRA's main focus on biosecurity risk analysis and aligns with the current CEBRA priority in relation to the development of new and existing methods and tools to improve biosecurity risk analysis.

The project will also support the implementation and enforcement of the national ballast water management arrangements that will be implemented by the new biosecurity legislation and will assist Australia to meet its obligations as a signatory to the International Convention for the Control and Management of Ships' Ballast Water and Sediments.

1.1 Summary of costs

DAFF Operating Expenses ($)	CEBRA Expenses ($)	Total ($)
0	$90,000	$90,000

1.2 Summary of resources

Required resource (APS level or BA/PM)	Number required	Duration	Notes
CEBRA PM	0.1 FTE	1 year	
DAFF APS EL 1	0.1 FTE	1 year	

2.1 Description of Project

Background

Ballast water discharges from ships are a proven vector for invasive marine species. Several invasive marine species established in Australian waters have life stages that are capable of being translocated in the ballast water of domestically operating ships. To estimate and manage the risks of these species within Australia, CSIRO and DAFF developed the Australian ballast water risk assessment (hereafter called the BWRA).

The BWRA is a modular, species-specific system that estimates the risk that marine pests could be taken up from one Australian port, transported to another Australian port and successfully establish there. Due to the large amount of biological, spatial and environmental data assessed in the BWRA, the programming language R is used to run risk assessments and the results are displayed in large Excel tables (referred to as "risk tables"). The risk tables are incorporated into the Australian Ballast Water Management Information System (ABWMIS), DAFF's decision support system for ballast water management, where they are used to automatically assess and respond to ballast water management exemption applications submitted by the shipping industry.

The BWRA code and risk tables are complex and require expert/technical knowledge to run or change base data. Previously this knowledge has been held exclusively by the CSIRO, however an ACERA project (Project No: 1104E) has just been completed to assist DAFF in preparing to maintain and use this resource in the future by transferring the required knowledge/skills to update and run the risk assessment model and generate risk tables from CSIRO to ABARES. Having this capability in house allows for DAFF to update biological parameters as data becomes available and generate risk tables based on the latest available information, reducing reliance on contracting technical expertise.

During ACERA project 1104E a number of methodological issues were identified that require remediation prior to the anticipated national roll-out of the ABWMIS following entry into force of the new biosecurity legislation. These issues focus around the development and interpretation of the risk models from the available data, rather than the data themselves or the science that supports their usage.

Currently the ABWMIS is only used by the Victorian Government to support their domestic ballast water management requirements, however, it is expected to be rolled out nationally to support biosecurity management decisions for Australian domestic vessel movements once the new biosecurity legislation enters into force.

Under the new legislation vessels will be required to manage their ballast water prior to discharge in Australian ports by conduct of a ballast exchange outside of Australia's territorial seas. The new legislation will allow for vessels to apply for an exemption to the new requirements where their domestically sourced ballast water presents a low risk of marine pest translocation. The ABWMIS has been developed to read the risk tables produced by the BWRA and automatically assess and respond to ballast water management exemption applications for individual vessel and voyage combinations. Vessels on voyages assessed to be low risk are not required to travel outside of the territorial seas to conduct a ballast water exchange prior to ballast water discharge in their next port of call.

For the risk tables to be fully effective, they rely on 1) up-to-date species presence and range data, which is provided by the States and Northern territory through port monitoring surveys, and 2) current temperature data. The risk tables currently used to support the Victorian requirements do not incorporate recent port monitoring surveys and are generated using an outdated temperature dataset. In ACERA project 1104-E, CSIRO, IMSP, ABARES and ACERA worked collaboratively to update and streamline the original BWRA methods developed by the CSIRO to generate the risk tables. A key outcome of this project was that ABARES acquired the necessary knowledge and tools to amend the BWRA Code and base data as new information comes to hand and generate new risk tables, based on this data, using the BWRA framework.

During this project, however, a number of issues were identified that require remediation prior to the anticipated national roll-out of the ABWMIS. Firstly, issues with module 4 of the approach concern the way risk is extracted from the current conceptual and modelling framework developed in earlier projects by CSIRO; these may have implications for the estimate of risk of species establishing in ports given introduction and hence the overall risk of transferring marine pests between Australian ports, and secondly, an issue was identified with the way the current version of the ABWMIS reads the risk tables and determines risk for voyages that depart a port in one month and arrive in a port in a subsequent month.

Addressing how risk is extracted from the current conceptual and modelling framework, together with ensuring that the risk tables incorporate up-to-date port monitoring and temperature data, should allow more effective targeting of those vessels representing the highest risk of translocating marine pests around and into Australia and should reduce the safety and economic pressures on the shipping industry where entrained ballast water does not pose an environmental risk.

Addressing the issue regarding the limitation of the currently ABWMIS system and how it reads the risk tables should ensure that when the system is rolled out nationally it is able to appropriately determine the ballast water risk for voyages that depart a port in one month and arrive in a port in a subsequent month, within the assumptions of the current conceptual and modelling framework.

Using the most up-to-date BWRA to generate outputs for incorporation into ABWMIS is critical as the system will provide the primary mechanism for the assessment of ballast water management exemption application submitted by the shipping industry. The new biosecurity legislation contains provisions for the Director of Biosecurity to arrange for the use of computer programs for making decisions on the grant or refusal of exemption applications and the ABWMIS has been developed to serve this purpose. Without this functionality, biosecurity officers would need to manually assess and respond to exemption applications, which would require significant resources and may result in undue delays to vessels.

2.2 Project Implementation

There are two phases to this project.

Phase 1 aims to address the issues identified in ACERA project 1104E (Zhao et al. 2013), regarding the existing BWRA methodology (Hayes et al. 2007 – 2009), and to refine the methodology accordingly so it can generate risk tables that more accurately estimate the risk of transferring marine pests between Australian ports.

The following issues with original BWRA methodology were identified during ACERA project 1104E, which have implications for the estimate of risk of transferring marine pests between Australian ports.

Marine pest species require appropriate conditions at every stage of their lifecycle to progress to the next stage and eventually establish a new population. A critical component of the BWRA is the calculation of how much of the lifecycle is likely to be completed given propagules are delivered via ballast water into a new port in a particular month. In the BWRA it is assumed that if a species can complete at least 80 percent of its lifecycle then there is a risk it will establish. The BWRA calculates the percentage of the lifecycle completed in two different ways. (1) For a subset of ports at which there are data available from Bureau of Meteorology's (BOM) SEAFRAME tidal gauges (n=15 excluding Cocos Island; http://www.bom.gov.au/oceanography/projects/abslmp/data/index.shtml), the lifecycle is simulated directly based on life history parameters of the species and daily maximum and minimum sea surface temperatures. These life history temperature tolerance data are now held in an Excel spreadsheet ("AllSpeciesDate.xlsx"). (2) The results from these simulations are then used to develop statistical models that relate the percentage of the lifecycle completed to latitude (a proxy for sea surface temperatures) for each month of the year. Generalised linear models (GLMs) are used if the relationship between survival and latitude is monotonic (e.g. either increasing or decreasing), or generalised additive models (GAMs) are used where the relationship is non-monotonic (e.g. low survival in low and high latitudes with high survival in middle latitudes). These models are then used to predict the percentage of the lifecycle completed for the remaining ports for each month based on their latitude. Hence, we end up with a prediction of the percentage of lifecycle completed for each species in each of the 129 ports given arrival in each month of the year, amounting to 129 x 7 x 12 = 10836 predictions.

Direct simulation of lifecycle completion for a subset of ports for each species is achieved using a stochastic model that progresses the species through its lifecycle stages based on the daily synthetic sea water temperature data, which is stochastically generated from time series models that have been developed for that port (see below). For intertidal species (e.g. *Crassostrea gigas*), there is an intention to include air temperature also, but this part of the simulation model is not yet fully developed. The models account for the fact that there are critical temperature thresholds outside which lifecycle stages cannot survive. Temperature can also influence how quickly a species progresses through a lifecycle stage. The models were constructed in the open-source statistical environment R (R Development Core Team, 2011).

There is an issue with the way risk is calculated based on these lifecycle simulations. When the method was originally developed, using the mean was justified by the tight confidence limits around it. However, in the original report the authors mistakenly present the confidence interval for the estimate of the population mean, rather than the simulation quantiles. When the latter is presented we see that variation arising from the simulations can be large. This has significant implications for the use of the mean for estimating whether there is a significant risk of lifecycle completion or not. In one example we have explored we see that the mean for the percentage lifecycle completed for *S. spallanzani* only rises above 0.8 for a few days of the year, but the upper simulation quantile is above 0.8 for over 200 days of the year. The latter is probably a better estimate of the risk and this issue needs consideration. Setting the threshold in this way for example would mean that an introduction is considered risky if a certain percentage of the simulations indicated that at least 80 percent of the lifecycle was completed. This project will explore alternative methods of defining risk from the simulations models, explore their effect on the subsequent statistical models of Percentage life-cycle completed ~ latitude, and explore the ultimate affect on the estimate of risk relative to the original method. Potential changes will be discussed with the MPSC.

A second issue that was identified concerns the implementation of the time series modelling and subsequent use for predicting species survival. The sea temperature simulations are currently generated by first decomposing the time series into a seasonal component, a trend and the residuals using the stl function in program R. ARIMA models are then applied to the residuals to account for autocorrelation of daily temperatures. When the 1000 sea temperature simulations are generated they use the first 3 years of the stl fitted seasonal and trend components and then use the generated values from the ARIMA model. In cases where there was a significant trend in the sea temperature data over these first 3 years, this results in substantially different estimates of the percentage of lifecycle completed for species introduced on 31 December vs. the 1 January. This should not be the case. A similar problem occurs when using the air temperature data, although in the case of air temperature the current methodology uses the raw air temperature data rather than fitting any statistical models. One solution to this issue would be to randomly select the start point of the introduction from within the entire temperature time series (although not so close to the end that you would run out of data) i.e. if you were modelling a 1 January arrival date, you would randomly choose a 1 January from within the time series rather than always using the 1 January at the start of the time series.

An additional issue concerns the sea surface temperature measurements used in the BWRA. The current temperature data used to determine species survival dates from 1999-2009. Ideally this data should be current and updated yearly using a moving "window" of these data in the order of 10 years.

For phase 1 of this project the researchers will:

- Derive a new methodology for simulating temperature time series data for both sea and air temperatures so that introductions at the beginning of a calendar year do not produce outcomes substantially different from introductions at the end of a calendar year.
- Fully explore the simulation profile based on the existing lifecycle models for the different species in the different ports and determine whether the current method is the most appropriate to reflect the risk of species establishing in ports given their introduction
- Determine how this new methodology affects the statistical fitting methodology for all the other ports and derive appropriate statistical models
- Produce program R code that implements these new methods in the generation of ballast water risk tables
- Generate tables using the new code based on the current port survey data and 1999-2009 temperature data, and compare results with the tables derived under the previous methodology
- Incorporate up-to-date temperature data into the BWRA and generate tables using the new code based on the current port survey data and compare results with the tables derived using the 1999-2009 temperature data

Phase 2 aims to determine appropriate outputs from the BWRA that could be incorporated into a redeveloped ABWMIS to resolve current system limitations regarding the determination of ballast water risk when a vessel leaves an Australian port in one month and arrives in its next Australian port-of-call in a subsequent month.

The BWRA consists of four modules that each addresses a specific step in the ballast water invasion cycle:

- Module A - the probability that the donor port is infected by the species of concern based on data gained through port monitoring data and CCIMPE range extension reports. Where no port monitoring has occurred a species is taken to be present if it is able to complete more than 80% of its life-cycle in any month (from Module D).
- Module B - the probability that the vessel becomes infected by the species of concern based on data regarding when planktonic life stages are in the water column and available for uptake
- Module C – the probability of journey survival in ballast tanks based on species-specific data of survival in ballast tanks, where available. Currently 100% survival is assumed for all species.
- Module D – the probability of life-cycle completion in the recipient port based on data regarding the eduration and temperature tolerances of each species life-stages and the temperature in the recipient port. If the mean proportion of a species life-cycle completed

in the recipient port reaches or exceeds 80% for a month it is assigned a high risk.

Outputs from each of the 4 modules are combined to generate a final set of risk tables for each of the 7 species of concern. These risk tables assign a high (1) or low risk (0) of translocating the species of concern between each Australian port pair combination for each month of the year i.e. the assumption with current construction of the tables is that uptake from the donor port and introduction to the recipient port occurs in the same month. The ABWMIS can only use the information in this form, and therefore does not properly account for risk when a vessel departs a donor port in one month and arrives in the recipient port in a subsequent month.

For example, *Crassostrea gigas* and *Sabella spallanzani* are not present in the water column from July to September and November to February, respectively, and therefore any ballast water taken onboard during these months should be low risk for that species when discharged in a donor port irrespective of whether the species is able to complete more than 80% of its lifecycle in the recipient port. This is currently not the case and may change the risk profile of some voyages depending also on the risks from other species.
For phase 2 of the project the researchers will:

- Determine an appropriate format of the individual outputs from each module of the BWRA to address the issue of month to month voyages.

2.3 Project Outcomes

This project implements DAFF objectives to deliver on effective biosecurity controls across the biosecurity continuum, and strengthen stakeholder partnerships through the provision of up-to-date and valid decisions based on risks.
The project will further develop the capacity within ABARES to maintain the BWRA and generate risk tables when required and in a timely manner, if ABARES are nominated as the external collaborator.
Improving the accuracy of the BWRA will strengthen the ability to identify and effectively target those vessels posing the highest risk of translocating established marine pests between Australian ports through ballast water discharges.
Project outputs will be used to support the implementation and enforcement of the national ballast water management arrangements that will be implemented by the new biosecurity legislation and will assist Australia to meet its obligations as a signatory to the International Convention for the Control and Management of Ships' Ballast Water and Sediments.
The incorporation of accurate and up-to-date BWRA outputs in the ABWMIS, and provision of the ABWMIS to the jurisdictions, has a number of benefits:

- This will enable the rapid assessment of domestic ballast water management exemption applications. Without this functionality biosecurity officers would need to manually assess and respond to exemption applications which would require significant resources and could result in undue delays to vessels.
- This will also reduce safety and economic pressures on the shipping industry where entrained ballast water does not pose an environmental risk. A risk-based ballast water exchange approach using the BWRA outputs is expected to cost the shipping industry approximately $ 5.3 million per annum to meet the new domestic requirements. Not having the ability to risk assess vessels would mean that ballast water exchange would be mandatory, which is expected to cost the industry approximately $24 million per annum.

ACERA project 1104-E – the current project builds on previous work conducted by ACERA, ABARES & IMSP under ACERA project 1104E- Ballast Water Risk Tables
Biosecurity legislation development / Entry into force of the BWM Convention – implementation of the risk tables into the ABWMIS and subsequent national roll-out of the system is dependent of entry into force of the biosecurity legislation and BWM Convention
VMS redevelopment / ABWMIS development – implementation of the phase 2 project outputs is

dependent on DAFF developing and maintaining a suitable IT system that can be made available to the States and Northern Territory to support biosecurity management decisions for domestic vessel movements once the biosecurity legislation enters into force.

2.4 Project Objectives

This project has two main objectives. The first objective is to address the issues identified in ACERA project 1104-E concerning module 4 and refine the BWRA methodology accordingly so that it is more likely to accurately estimate the risk of a marine pest establishing in an Australian port given its introduction there, given the current conceptual and modelling framework developed in earlier projects. Once this is done, the refined BWRA will be used to generate new ballast water risk tables for approval by the MPSC and subsequent incorporation into the current version of ABWMIS. These issues are outlined in the project plan.

The second objective of this project is to address the issue identified above regarding the inability of the current ABWMIS system to correctly determine risk for certain species of concern when ballast water is taken onboard during one month and discharged into an Australian port in a subsequent month.

2.5 Project Deliverables

- Deliverable ongoing – project initiation meeting (July 2013) and progress meeting every two months or as required
- Deliverable 1 – Refine existing methodology to address issues identified for Phase 1 (4 months)
- Deliverable 2 – Development of new R code to implement new methodology from deliverable 1 (2 months)
- Deliverable 3 – Generation of new risk tables using new R code based on current port survey and temperature datasets (1 week)
- Deliverable 4 – Generation of new risk tables using new R code based on current port survey dataset and updated temperature dataset (1 week)
- Deliverable 5 – Determination of appropriate format of BWRA outputs to address issue of month to month voyages (2 months)
- Deliverable 6 – Provision of a draft final project report (2 months)
- Deliverable 7 – Provision of final copy-edited report (1 months)
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2.6 Milestones

Phase/Milestone	Responsibility	Timeframe & dates if available
1- Project inception meeting	1- IMSP – Matthew Gregg	1- July 2013
2- MPSC agreement to proposed changes to BWRA methodology	2- CEBRA	2- Late 2013
3- MPSC endorsement of revised methodology	3- IMSP – Matthew Gregg	3- Early 2014
4- MPSC endorsement of new risk tables generated using new methodology and updated temperature dataset	4- IMSP – Matthew Gregg	4- Early-mid 2014
Implementation of new risk tables into the ABWMIS	5- IMSP – Matthew Gregg	July 2014

2.7 Project Budget

Project Budget

	Year 2013-14 $	Year 2014-15 $
CEBRA	0.1 FTE AR Travel $5000 External Collaborator $85,000	
DAFF		
Total CEBRA costs	$90,000 + 0.1 EFT	
Total Project costs	$90,000	

Literature Cited

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