Overview of ACERA/CEBRA Projects

A summary of project outputs and outcomes

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October 20, 2018

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1 Introduction

This document covers projects performed by or on behalf of the Australian Centre of Excellence for Risk Analysis (ACERA) and its successor the Centre of Excellence for Biosecurity Risk Analysis (CEBRA). For simplicity, and because the organizations mostly share core personnel, we shall only refer to CEBRA. ACERA was funded by the now Department of Agriculture and Water Resources (the Department, DAWR) and the University of Melbourne. CEBRA is funded by the Department, the Ministry for Primary Industries (the Ministry, MPI) and the University of Melbourne.

The projects and reports listed under each of the nine research topics are grouped by their funding period: ACERA I (2006-2009), ACERA II (2009-2013) and CEBRA (2013-2016). In November 2014, the Department qualitatively assessed the research impact of 19 CEBRA completed biosecurity research projects. The findings from this Biosecurity Research Adoption Snapshot are included in this review of all CEBRA projects.

CEBRA was instigated to support the Department's move towards a risk-based approach to Biosecurity regulation. CEBRA now supports the Department and the Ministry by developing biosecurity risk analysis tools and research findings that span the biosecurity continuum of pre-border, border, and post-border activities. CEBRA's priorities are guided by the objectives set out in agreement with its funding partners. It has reviewed existing methods and developed new ones relevant to biosecurity, engaging the necessary skills from a range of external partners. Projects have involved contributors from government, universities, the CSIRO and the private sector with backgrounds ranging from ecology to veterinary science, human medicine, mathematics, economics and sociology.

CEBRA has collaborated extensively with end users in both DAWR and MPI to improve adoption of methods and to increase the impact of research outputs. Most CEBRA projects include scientists from the Department or the Ministry in the research and analysis, which enhances research outcomes and improves the uptake and outcomes of research and development. Below, all references to CEBRA work are collaborations between Department and Ministry staff and University of Melbourne staff or other external scientists. Researchers have prepared final reports for project sponsors, the great majority of which are freely available on CEBRA's website, and made the research findings available to a wider audience by publishing in peer-reviewed international scientific journals. A complete list of journal articles since the inception of CEBRA can be found on the Centre's website.

2 Inspection efficiency

With the reform of the biosecurity sector the Department is moving towards a risk-based approach to Biosecurity regulation. This means, among other things, a balance of targeted allocation of inspection resources towards pathways according to their risk levels and resources towards pathways for the purposes of monitoring their risk. Efficient distribution of limited resources to optimise risk reduction requires scientifically designed approaches. CEBRA produced a range of tools to assist the Department in making more informed resource allocation decisions for more efficient intervention.

Outputs from these projects included tools for identifying risk levels of different individual or combined import pathways and for developing sampling strategies (namely, Continuous Sampling Plans) for the inspection of various commodities (2.1, 2.2, 2.3, 2.7) some of which have been operationalised. For example, CEBRA tools were used to introduce risk-based surveillance to the inspection of aircans, sea containers, courier documents, and international vessels. Ongoing work will extend the usability of Continuous Sampling Plan technology (3.6). CEBRA developed an analytical approach to using endpoint data that is now used to great effect in the international passengers and mail pathways. Adoption of indicators proposed by CEBRA for the measurement of passenger and mail intervention6 has improved the Department's reporting of operational performance to internal and external stakeholders (2.4). The Department's prescription for the risk-based management of ballast water by domestic vessel transits has been simplified and strengthened by easier generation of up-to-date risk tables allowing more effective targeting of high-risk transits (2.5, 3.3). A follow on project compared the use of tide gauge temperature data with the use of satellite sensed sea surface temperatures. It recommended to use satellite data in simulating life cycles of specific marine pests as part of the Australian ballast water risk assessment. Outputs from the simulation model underpin the development of risk tables and subsequently inform management directions for vessels. In essence, vessels with a high likelihood of transferring marine pests need to manage their ballast water before arrival in the recipient port (3.9).

CEBRA reviewed data management and analysis processes for at the border quarantine control activities and developed a tiered risk management system that can be integrated into the operational framework of the Australian Quarantine and Inspection Services (AQIS, these services have since been absorbed into divisions within the Department). It developed spreadsheet products further and recommended structural and analytical improvements, as well as future work (1.1, 1.2).

CEBRA also introduced and tested tools for analysing large amounts of inspection data for predicting the outcomes of different intervention activities (3.1). A scoping study found that incentives for biosecurity compliance might be a feasible approach for speeding up the import inspection process for compliant importers, reducing their regulatory and financial burden (3.4). Continuing this work, a laboratory economics experiment investigated behavioural responses of stakeholders to changes in biosecurity control strategies. It found that the level of information about inspection rules and targeted feedback on regulatory performance influenced importers' choice of supplier (3.7). DAWR adopted these findings and made changes to its operations by providing feedback reports to importers. A field trial will build on these results and test the effect of reduced inspections on importer behaviour on two plant-product pathways (3.12). CEBRA used an inspection experiment to assess the detectability of certain pests in consignments of oranges, providing a framework for further work on improving allocation of inspection resources for fresh produce consignments (2.6).

To improve understanding of inherent biosecurity risks with mail and travellers import pathways CEBRA investigated issues related with the design and execution of existing end-point surveys. These surveys are required to estimate leakage rates which is the amount of biosecurity risk material crossing the border after intervention. While design of surveys is robust the review identified issues with their execution and provided recommendations for corrective actions (3.2). Another project confirmed that the existing performance indicators for these pathways are still best practice and recommended to apply them to all import pathways (3.11).

Over the course of a couple of projects CEBRA developed and trialled a sampling framework for an on-arrival health surveillance system for imported ornamental fish (2.8, 3.5). The design of a full surveillance system and a software component for this project are currently under development (3.8, 3.13).

The Department inspects plant products for export to a standard specified by the importing country, such as a random sample of 600 units or sampling of 2 percent of the consignment. However, with smaller consignments, CEBRA identified that when the 2 percent option is chosen and <600 units are sampled, Australia's obligations under the respective International Standard for Phytosanitary Measures are not satisfied. It recommends to require a random 600 unit sampling, also for mixed consignments. Mixed consignments could be split into lines and sampled at a rate of 600 units per line. However, in contrast to importing plant products, a compliance-based sampling scheme using CSP algorithms is not suitable for sampling of consignments for export (3.10).

Inspection of imported plant seeds is usually destructive and often requires large sample sizes, making importation of small seed lots (<2500 seeds) unfeasible. Seed importers in New Zealand currently have the option to source bigger seeds lots, but only from countries that are declared free from the regulated diseases listed in the Import Health Standard. CEBRA investigated an alternative testing protocol, considering biosecurity risk for the whole pathway. The study demonstrated the impact of lot size on the leakage rate, which is the proportion of contaminated seeds in the lot that are not detected. One output of the project was the development of a web-based application (R shiny app) for convenient calculation of sample size based on species and lot size (3.14).

Table 1: ACERA I - Inspection efficiency projects

Ref.	Project no.	Title
1.1	0804	Robinson, A. et al. (2008): AQIS import clearance data framework
1.2	0804a	Robinson, A. et al. (2009): Import clearance risk framework

Table 2: ACERA II - Inspection efficiency projects

Ref.	Project no.	Title
2.1	1001A(A-I)	AQIS import clearance risk-return case studies. Reports: Robinson, A. et al. (2011): A - External container inspection B - Rural destination inspection D - Seaports E - Unit loading devices F - Reportable documents I - Performance indicators
2.2	1001B	Extension of 1001A. Robinson, A. et al. (2012): Imported plant product pathways (Study J)
2.3	1101C	Robinson, A. et al. (2014): Plant quarantine inspection and auditing across the biosecurity continuum
2.4	1101D	Robinson, A. et al. (2013): Adoption of meaningful performance indicators for quarantine inspection performance
2.5	1104E	Zhao, S. et al. (2013): Ballast water risk table reconstruction
2.6	1106C	Perrone, S. et al. (2013): Detectability of arthropods in fresh produce consignments
2.7	1206F	Arthur, T. et al. (2014): Statistical modelling and risk return improvements for the plant quarantine pathway
2.8	1206G	Ornamental fin fish import reform program. Holliday, J. and Robinson, A. (2013): A sampling framework and trial for the surveillance program

Table 3: CEBRA - Inspection efficiency projects

Ref.	Project no.	Title
3.1	1301A	Clarke, S. et al. (2015): Data mining - report on first cohort of case studies
3.2	1301B	Chisholm, M. et al. (2015): Analytical assessment of endpoint surveys
3.3	1301C	Continuation of 1104E. Arthur, T. et al. (2015): Updating the methods for ballast water risk table construction
3.4	1304C	Rossiter, A. et al. (2016):Incentives for importer choices
3.5	1305A	Ornamental fish import surveillance system. Robinson, A. and Hood, Y. (2015): Risk-based management for imported ornamental fin fish
3.6	1305B	Plant-product pathways and the continuous sampling plan (in progress)
3.7	1404C	Continuation of 1304C. Rossiter, A. et al. (2018): Testing compliance-based inspection protocols (main report) and (supplementary report)
3.8	1405A	Continuation of 1305A. Ornamental fish import reform - health monitoring program
3.9	1501C	Summerson, R. et al. (2016): Ballast water risk assessment. Exploring new method for estimating risk: using satellite sea surface temperature data; incorporating vessel voyage data
3.10	1501E	Robinson, A. (2017): Compliance and risk-based sampling for horticulture exports
3.11	1501F	Hoffmann, M. et al. (2016): Performance indicators for border compliance
3.12	1504C	Continuation of 1404C. Testing incentive-based drivers for importer compliance (in progress)
3.13	1505A	Continuation of 1305A and 1405A. Ornamental fish import reform - risk-based on-arrival fish health surveillance and pathway analysis system (in progress)
3.14	1606A	Lane, S. et al. (2018): Sample size calculations for phytosanitary testing of small lots of seed

3 Post-border surveillance and area freedom

Biosecurity surveillance fulfils different purposes. It is critical for early detection of invasive species incursions, for control and eradication efforts following an incursion, for managing of disease outbreaks and for providing evidence of pest/disease free status of Australian commodities for export.

CEBRA worked on a range of projects addressing the different purposes of surveillance. It provided advice on the design of optimal survey strategies for detecting invasive plant species including a novel method for determining the average survey time needed to detect weeds within a native vegetation community (4.4). For the ongoing measure of the progress of a weed eradication program CEBRA developed an Excel based monitoring tool with a graphic output (5.1). The damage of outbreaks of foot-and-mouth disease (FMD) can be substantially reduced by early detection. CEBRA found that bulk milk testing on top of passive surveillance is currently not economically justified prior to an incursion, due to high costs of testing and a low frequency of outbreaks. However, bulk milk testing is well-suited for post-outbreak active surveillance to shorten the length of time and size of an epidemic (6.1). CEBRA is currently applying a simulation approach combined with an economic optimisation framework to determine the right mix of appropriate active and enhanced passive surveillance for detection of FMD (6.2). To support prioritisation of surveillance of movements of pests and pathogens from infected properties CEBRA developed a simulation model that is flexible to be used in different outbreak scenarios but needs to be adapted for each situation. It was developed as a standalone library within R, which is free, open-source statistical software (5.3, 5.4).

Another aspect of outbreak management is preparedness, such as having up-to-date farm livestock demographics information. CEBRA tested different approaches for modelling counts of livestock units or cattle and, as one of the main finding of this study, highlighted the need for a single database for national level animal demographic data. The study identified the strengths and weaknesses of the available national-level data sets that underlie biosecurity response and disease preparedness, enabling decision-makers to make more informed future decisions about farm livestock demographic information (6.3).

Scientific evidence of pest free status is important for assurance to trading partners. CEBRA confirmed the suitability of a new method for determining pest free status in relation to plant pests and diseases and invasive plants species. It was originally developed for assessment of animal disease status (4.2). In an alternative technical approach for establishing area freedom for animal disease management, and building on this new method, CEBRA presented analogous analysis methods that can be simpler to implement while providing the same results (4.3). CEBRA has reviewed tools and methods for managers to plan, implement and evaluate post-border surveillance activities and has also developed guidelines and training materials for these tools (4.1, 5.1, 5.2). A current CEBRA project aims to address the prioritisation of plant pests for surveillance in Australia (6.4).

CEBRA reviewed the use of new technologies for rapid, field-based testing in the early detection of major emergency animal diseases, such as avian influenza, foot-and-mouth disease, anthrax, classical swine fever and mad cow disease. The project outputs are relevant to the office of the Australian Chief Veterinary Officer, who chairs the consultative committee on emergency animal diseases in the event of an emergency animal disease outbreak (5.2).

Table 4: ACERA I - Post-border surveillance and area freedom projects

Ref.	Project no.	Title
4.1	605	Control charting for biosurveillance. Reports: Fox, D. (2009): Statistical method for biosecurity monitoring and surveillance Fox, D. (2007): Statistical methods for biosecurity monitoring and surveillance. Control charting
4.2	703	Martin, T. (2008): Combining disparate data sources to demonstrate pest/disease status
4.3	807	Hood, G. (2009): Alternative methodologies for establishing pest and disease freedom
4.4	906	Garrard, G. et al. (2009): Determining necessary survey effort for detecting invasive weeds in native vegetation communities

Table 5: ACERA II - Post-border surveillance and area freedom projects

Ref.	Project no.	Title
5.1	1004A	Post-border surveillance techniques: review, synthesis and deployment. Hester, S. (2011): Post-border surveillance techniques: review, synthesis and deployment Hester, S. and Herbert, K. (2011): MoniTool - an eradication monitoring tool -manual Hester, S. (2012): Report on strategies for adoption and potential further applications
5.2	1004B	Post-border surveillance techniques: review, synthesis and deployment Reports: Sims, L. (2012): The use of new technologies for rapid, field-based (point-of-care) testing in the detection of emergency animal diseases Cox-Witton, K. et al. (2011): Zoo based wildlife disease surveillance pilot project Hester, S. and Sergeant, E. (2013): Sub-project 2E 'Proof-of-freedom' toolbox
5.3	1006B	Implementing risk-based trace priorities in BioSIRT. Report: Potts, J. et al. (2012): Model-based search strategies for plant diseases: a case study using citrus canker (Xanthomonas citri)
5.4	1206B	Potts, J. et al. (2014): TRACE: An R-package to trace pest spread via multiple dispersal mechanisms

Table 6: CEBRA - Post-border surveillance and area freedom projects

Ref.	Project no.	Title
6.1	1304A	Cost effective surveillance of foot-and-mouth disease Report: Kompas, T. et al. (2015): Optimal surveillance against food-and-mouth disease: the case of bulk milk testing in Australia
6.2	1404A	Continuation of 1304A. Cost effective surveillance of foot-and-mouth disease (in progress)
6.3	1502C	Continuation of 1402C. van Andel, M. et al. (2015): Estimation of national-level farm demographic data for preparedness of highly-infectious livestock disease epidemics
6.4	1502D	Criteria in prioritising plant pests along the biosecurity continuum (in progress)

4 Import risk analysis

Import risk analysis investigates risk in terms of likelihood and consequences that would result from the import of one or more particular commodity from one or more particular regions. It estimates risk of entry, establishment and spread of pests and diseases associated with imported commodities. Import risk analysis is science based and typically pathway based, looking at all hazards associated with the arrival of a commodity in Australia. Risk assessment methods can be quantitative or qualitative (7.3) but qualitative methods dominate in import risk assessment protocols internationally.

CEBRA developed a framework based on a quantitative model that follows the structure of a qualitative assessment method. It incorporates quantitative assessments based on expert opinion and defines how uncertainty should be handled, offering greater transparency (7.4). An assessment of duration and volume of trade in import risk analyses showed that decisions for each pest should be made case-by-case (7.2). CEBRA also evaluated a range of tools for import risk analysis and assessed in which situations they may improve the scientific consistency and reliability of risk analysis (7.8). In a risk-based approach to biosecurity management, comparing the levels of investment in inspection efforts with the associated levels of risk provides guidance for managing different import pathways with given resources. Import pathways can be complex. CEBRA developed a method to assess the effectiveness of mitigation methods, such as mixing of materials, or the risk of incursion under these circumstances (7.5).

The results of CEBRA's review of 13 broad categories of biological products of animal origin in terms of their relative risk to biosecurity included recommendations for risk management, providing a basis for further review and prioritisation of resource allocation (8.2). CEBRA also reviewed the use of different techniques for identifying the nature and causes of risk. These techniques, usually used by the engineering industry, were assessed for their potential application in biosecurity operations. Potential areas of use were highlighted (7.1).

CEBRA developed a sampling approach for identifying intercepted pests and worked out improvements around data entry and feedback mechanisms between different operational areas. These project outputs improved the quality of data collected by the Operational Science Program and provided a more robust foundation for decision-making about interventions required for various commodities and pathways. The project also led to changes to the Australian Import Management System and Incidents Client and enabled better communication between the two systems. It also resulted in more complete data capture. Streamlined data entry saved staff time and improved data quality for risk analysis (8.1).

CEBRA assessed the rate of entry of microscopic spores of pathogenic fungi, using Guava Rust as a case study. This project resulted in the development of new environmental sample collection methods and statistical methods for different analysis requirements (8.3).

CEBRA reviewed the appropriate use of manufacturer's declarations (MDs) for a range of products that are regularly imported and discovered shortcomings in current business practices. The project found that in some cases the use of MDs was supported by other controls and considered appropriate. In other cases the use of MDs as currently practised was not appropriate. CEBRA developed strategies for minimising the risk of misuse of MDs and proposed a generic approach to the use of manufacturer's declarations (8.2).

Table 7: ACERA I - Import risk analysis projects

Ref.	Project no.	Title
7.1	606	Review of risk identification and analysis systems - Phase 1 risk identification. Cross, J. (2011): Tools for anticipating potential problems in biosecurity applications
7.2	702	McCarthy, M. et al. (2007): Review of the use of period of trade and trade volume in import risk analysis
7.3	705A	Issues in quantitative and qualitative risk modelling with application to import risk assessment. Hayes, K. (2011): Uncertainty and uncertainty analysis methods
7.4	705B	Barry, S. (2011): Putting the quantitative into qualitative import risk assessments
7.5	705C	Barry, S. and Lin, X. (2011): Risk in complex pathways: propagation of risk via zero inflated distributions and mixing
7.6	708	Performance of Australia's risk analysis system (final report confidential)
7.7	709	A comparison of quarantine risk analysis systems (final report confidential)
7.8	901	Demonstrating risk analysis capabilities. Burgman, M. (2010): Comparing biosecurity risk analysis systems Burgman, M. (2010): Demonstrating risk analysis capabilities

Table 8: ACERA II - Import risk analysis projects

Ref.	Project no.	Title
8.1	1101E	Sampling for invasives. Robinson, A. et al. (2014): Sampling interceptions for identification
8.2	1101F	Appropriate risk management measures for different categories of imported biological products. Buckley, D. (2013): Relative risk of different categories of imported biological products of animal origin Buckley, D. (2013): The use of manufacturer's declarations as a biosecurity control for import of biologicals
8.3	1206A	Pathway risk analysis. Holliday, J. et al. (2013): Multi-pathway risk analysis: a case study of Puccinia psidii

5 Decision-making

Managing Australia's biodiversity requires robust approaches to decision making, especially for investments into longer-term programs. Decision makers weigh up competing interests when allocating limited funding or resources. CEBRA has reviewed or developed frameworks and methods for supporting the decision-making process in biosecurity management.

Different frameworks and tools can support formal decision-making. Some are in the form of graphic depictions of relationships between variables (a network). In those networks causal relationships can be based on subjective estimates or prior data but uncertainty applies in both cases. CEBRA developed an approach that allows managers to use these networks and determine how much input estimates (e.g. resources) would have to change before the output (decision) would change (9.1). For a specific class of multi-criteria methods for environmental decision-making CEBRA pointed out pitfalls when decision makers do not use those methods correctly (9.3). CEBRA also developed a method for reducing the complexity of models of alien biota without compromising on interpretation capability (9.4).

Another framework developed by CEBRA provided a coherent structure in which to address crucial and urgent management issues relating to the detection, control, containment and eradication of invasive species — taking into account budget constraints and uncertainties around species occurrence and habitat (9.2). In related work, CEBRA also developed a spatially explicit decision support tool for managing invasive species across a landscape and for prioritising of management efforts (9.9).

An important task for managers is to prioritise investment. Multi-criteria decision analysis tools, for example, can be used for assigning funding priorities or determining the best management technique. CEBRA applied a simple multi-criteria decision analysis framework with the objective of prioritising pests on the basis of their impacts on economy, environment and society in general. The framework proved to be useful in clarifying strategic decisions for determining pest priorities and could be applied across different taxonomic groups. However, the application of such a transparent and structured participatory process should always be accompanied by active involvement of stakeholders (9.6). In another study using multi-criteria decision analysis CEBRA tested a specific decision facilitation technique and found that it can complement other methods capable of enhancing the communication of complex information to decision makers in long-term management of invasive species (9.7). CEBRA also trained selected practitioners in the use of multi-criteria decision analysis and other approaches to structured decision-making and established a Community of Practice (9.8).

In the context of biodiversity values CEBRA examined uncertainty in vegetation condition measures, which provide an index of site quality and are used to guide cost-effective investment towards improving biodiversity values. A simulation analysis revealed the most cost-effective actions for an example woodland ecosystem (9.5).

Environmental risk assessment includes uncertainties in information and also in process while decision makers need to transparently communicate criteria and decisions to stakeholders. CEBRA combined the advantages of decision networks (a model of the world) with that of geographic information systems (GIS - provide spatial explicit data about the world) into an ArcGIS software tool. The tool supports developing spatial models as decision networks and the handling of data parameters and their uncertainties. It was tested in a practical application, for the management of invasive environmental weeds (9.10).

To address current limitations of decision support tools CEBRA developed a five-step prototype framework, providing the structure for combining subjective predictions of cause-and-effect elicited from experts with the value judgements of decision-makers. The focus of this framework is on estimating expected consequence. CEBRA illustrated application of the framework within three broad biosecurity decision contexts. In another aspect of this project, CEBRA identified the most appropriate tools and methods for characterising impacts of invasive pests on primary production, amenity and the environment, which were evaluated in a biosecurity setting (10.1).

Cost-benefit analysis and MCA are two decision-making frameworks that are applied to maximise net benefit or utility in decision-making. However, the two frameworks differ in many aspects (e.g. rationality, goal, data requirements). CEBRA created a list of factors influencing selection of CBA or MCA as the major decision support tool for biosecurity management. As scientific opinion about the two frameworks on their universal applicability has shifted towards a complementary perspective, CEBRA also provided guidance in the form of decision trees on complementary use of both (10.4). Applied in practice, benefit-cost analysis (BCA), for example, is an important part of the decision making process immediately after an incursion was detected. Under the National Environmental Biosecurity Response Agreement (NEBRA), a BCA should consider whether the costs of a national biosecurity incident response would be outweighed by the benefits. Knowing how time critical initial response is for the success of eradication or containment of an oubreak, CEBRA developed a guide for preparing a BCA for a marine pest incursion in short time. The set of notated guidelines provides step-by-step advice that is suitable for non-economists alike (11.7).

Decision-makers need to make appropriate pest management decisions over time. CEBRA developed a support tool, implemented as an Excel spreadsheet, for making decisions on eradication and control activities after pest incursion. The generic model was applied to two case studies (10.3).

The Risk-Return Resource Allocation model used in the Department estimates risk and cost given specified biosecurity investment scenarios. CEBRA developed an approach for directly comparing the uncertainty around model predictions under different investment scenarios, allowing decision makers to gauge how much confidence they can place in the results (11.1).

CEBRA reviewed the Pest Categorisation Questionnaire, a decision-support protocol that informs cost-sharing arrangements in the event of a pest incursion. The review identified weaknesses in the protocol and suggested solutions. It informed a later review of the Emergency Plant Pest Response Deed, the overall agreement the decision-support protocol is part of (10.2).

In recent work CEBRA developed baseline consequence measures for the expected damages from an incursion of three invasive species of concern into northern Australia via the Torres Strait islands pathway. The consequence measures for papaya fruit fly, citrus canker and rabies enabled estimation of the annual or cumulative costs over a period of incursion for states or growing regions. These baseline measures can help inform cost-benefit analysis, portfolio allocation models and other modelling techniques (11.2).

Foot-and-mouth disease (FMD) is the most serious threat to the livestock industry. CEBRA developed (i) a software platform for invasive species spread, (ii) a local and optimal active surveillance measure for FMD (using bulk milk testing) after a potential incursion and (iii) a key vaccination protocol and optimal buffer zone /correct countermeasures against FMD should an incursion occur (11.3). In a related project, CEBRA expanded the functionality of the existing Australian Animal Disease model (AADIS) to support FMD preparedness and post-outbreak surveillance and management. Hypothetical outbreak simulations in different jurisdictions tested the effects of different approaches for disease control and post-outbreak management on duration and size of an outbreak, sampling effort, cost of surveillance and loss of trade costs. The project demonstrated how modelling functionality can effectively support policy development around important issues after an FMD outbreak (11.6).

Entering somewhat uncharted territory, CEBRA is working on two projects that aim to inform current biosecurity investment policy at national level. The main objectives of the two multiple-year projects are to develop frameworks for (i) estimating the monetary value of the national biosecurity system, and for (ii) evaluating its health, which means its performance against agreed performance criteria. During the first phase, both projects produced comprehensive literature reviews and a logic model and description of the national biosecurity system. A logic model is a graphic representation of the system and depicts the relationships among inputs, activities, outputs and outcomes, as well as its elements. It is a powerful communication tool that has not been done before on national level. Furthermore, the first year reports of both projects detailed the project scope and the proposed analytic framework to be applied throughout the life of the projects (11.4, 11.5).

Table 9: ACERA I - Decision-making projects

Ref.	Project no.	Title
9.1	601	Qualitative modelling and Bayesian network analysis for risk-based biosecurity decision making in complex systems. Burgman, M. et al. (2008): Reconciling uncertain costs and benefits in Bayes nets for invasive species management Dambacher, J. M. (2007): Qualitative modelling and Bayesian network analysis for risk-based biosecurity decision making in complex systems
9.2	604	Optimal allocation of resources to emergency response actions for invasive species. Possingham, H. and McCarthy, M. (2009): Optimal allocation of resources to emergency response actions for invasive species Rout, T. et al. (2008): Using sighting records to declare eradication of an invasive species Hauser, C. and McCarthy, M. (2008): Targeting monitoring for pest management: an optimisation approach Hauser, C. et al. (2007): Optimal allocation of resources to emergency response actions for invasive species
9.3	610	Steele, K. et al. (2008): Uses and misuses of multi-criteria decision analysis (MCDA) in environmental decision-making
9.4	704	Hearne, J. (2007+2009): Simplifying models of alien biota
9.5	706	Evaluating vegetation condition measures for cost effective biodiversity investment planning. Lawson, K. and Gorrod, E. (2009): Evaluating vegetation condition measures for cost effective biodiversity investment planning Gorrod, E. and Keith, D. A. (2008): Observer variation in field assessments of vegetation condition: implications for biodiversity conservation Moilanen, A. (2007): How much compensation is enough? A framework for incorporating uncertainty and time discount when calculating offset rations for impacted habitat
9.6	707	Principles for prioritising non-primary industry target pest threats. Baker, J. and Stuckey, M. (2008): Principles for prioritising exotic pests
9.7	803	Tools to assist long term and strategic pest management. Cook, D. C. (2009): Deliberative methods for assessing utilities
9.8	809A	MCDA practitioner network - business proposal. Christian, R. (2009): Community of practice for structured decision-making: phase II
9.9	902	Strategies for managing invasive species in space: deciding whether to eradicate, contain or control. Chades, I. (2009): Strategies for managing invasive species
9.10	905	Pullar, D. et al. (2011): Combining GIS and Bayesian networks in test-action strategies for risk assessment

Table 10: ACERA II - Decision-making projects

Ref.	Project no.	Title
10.1	1002A	An improved resource allocation framework through better characterisation of consequences. Walshe, T. et al. (2012): A review of current methods and tools used by biosecurity agencies to estimate consequence impacts on primary production, amenity, and the environment Cook, D. et al. (2012): Potential methods and tools for estimating biosecurity consequences for primary production, amenity, and the environment Rout, T. et al. (2012): Time preference and value of information in the context of estimating consequences
10.2	1002B	Improved estimation of consequences resulting from pests and diseases. Jordan, H. et al. (2013): Measuring the cost of human morbidity from zoonotic diseases Hemming, V. and Walshe, T. (2011): A decision framework for estimating consequence impacts under operational conditions. Case study: review of the emergency plant pest categorisation questionnaire
10.3	1004C	Cacho, O. and Hester, S. (2013): Post-border decision-support tools: A tool to support the decision to switch between eradication and containment of an invasion
10.4	1102C	Kompas, T. and Liu, S. (2013): Comparing multi-criteria analysis and cost benefit analysis for biosecurity: procedures, applications and the measurement of consequences

Table 11: CEBRA - Decision-making projects

Ref.	Project no.	Title
11.1	1304B	Handling uncertainty in the Risk Return Resource Allocation (RRRA) model. Mascaro, S. (2014): Making robust decisions with a model subject to severe uncertainty
11.2	1405C	Torrest Strait risk and resource allocation project. Kompas, T. et al. (2015): Baseline 'consequence measures' for Australia from the Torres Strait islands pathway to Queensland: Papaya fruit fly, citrus canker and rabies
11.3	1504D	Continuation of 1404D. Garner et al. (2017): Using decision support tools in emergency animal disease planning and response: foot-and-mouth disease
11.4	1607A	Dodd, A. et al. (2017): Year 1 Report: Valuing Australia's Biosecurity System
11.5	1607B	Schneider, K. et al. (2018): Evaluating the Health of Australia's Biosecurity System
11.6	1608D	Garner, G. et al. (2018): Incorporating economic components in Australia's FMD modelling capability and evaluating post-outbreak management to support return to trade
11.7	1608E	Summerson, R. et al. (2018): Methodology to guide responses to marine pest incursions under the National Environmental Biosecurity Response Agreement

6 Expert judgement

Obtaining expert opinion in a structured way - expert elicitation (EE) - is a common approach if environmental data are poor or unattainable. Although EE is a powerful tool its efficacy depends on careful consideration of the process and factors that influence judgement elicitation.

CEBRA combined different elicitation strategies into a single comprehensive procedure and provided training to a range of professionals (12.1). This tool is being adopted by a range of disciplines internationally. EE has been used as part of other CEBRA projects. For example, in a novel application of the method, for the risk assessment of pest incursion through vessel biofouling, CEBRA asked experts to rate the relative risk of different scenarios. The method proved suitable for ranking relative risks and presents an advance in an area where the use of process-based models has not been feasible. It is an expert-based model for evaluating risk biosecurity risk (likelihood of marine pest establishment) based on vessel biofouling management, history of recent hull survey vessel movement history and the characteristics of Australian ports. Results from this project have been incorporated into departmental protocols (13.1).

CEBRA reviewed and evaluated existing methods for extreme risk analysis used in a range of disciplines. It concludes that evaluations of extreme risks should be supported by quantitative analysis, even in data poor environments, but that the most effective strategies give preference to qualitative reasoning in final conclusions (12.2). Uncertainty is a part of risk analysis. CEBRA provided theoretical reasoning for the use of non-probabilistic methods for non-statistical uncertainties instead of relying on probabilities as the only basis for representing uncertainty (12.3). This work included reviewing formal consensus methods by applying them to a pertinent pest management problem, namely prioritising of non-indigenous non-primary industry pest threats. Issues with formal group aggregation methods were categorised to allow decision-makers to choose the appropriate method for a particular context (12.3).

CEBRA developed a new method that supports the iterative process of modelling of incursion risk and illustrated the approach in a case study. The method includes EE and allows experts to re-evaluate their opinion after seeing the likelihoods generated by the model, which used their opinion as an input (12.4). CEBRA also developed an approach, based on expert judgements, that overcomes difficulties around the construction of scoring systems for risk analysis (12.5).

Table 12: ACERA I - Expert judgement projects

Ref.	Project no.	Title
12.1	611	Eliciting reliable expert judgements. Burgman, M. (2010): Eliciting expert judgements: process manual Speirs-Bridge, A. et al. (2008): Reducing overconfidence in internal judgements of experts Carey, J. and Burgman, M. (2008): Linguistic uncertainty in qualitative risk analysis and how to minimise it Burgman, M. et al. (2007): Qualitative modelling and Bayesian network analysis. Eliciting expert judgements: literature review
12.2	602	Franklin, J. and Sisson, S. (2007): Assessment of strategies for evaluating extreme risks
12.3	607	Evaluation and development of formal consensus methods. Colyvan, M. and Regan, H. (2009): Evaluation and development of formal consensus methods Colyvan, M. (2008): Is probability the only coherent approach to uncertainty? Steele, K. (2008): Survey of group 'consensus' methods
12.4	705D	Kuhnert, P. and Barry, S. (2011): Bayesian learning and synthesis through the elicitation of risk: BLASTER
12.5	705E	Barry, S. and Lin, X. (2010): Point of truth calibration: putting science into scoring systems

Table 13: CEBRA - Expert judgement projects

Ref.	Project no.	Title
13.1	1402A	Barry, S. C. et al. (2015): Development of an expert-based model for improved biofouling risk assessment

7 Risk communication

Risk communication involves communication of probability information among parties involved in biosecurity management. As people have different educational backgrounds and experience in working with probability information communication of risk analysis outputs can lead to misunderstandings.

CEBRA undertook a review of relevant literature and found that the understanding of probabilities can be enhanced by presenting natural frequencies (x out of y instead of percentage) and by visual representation of probability data (14.1). Other research highlighted the importance of comprehensive stakeholder analysis as the basis for stakeholder engagement. The proposed stakeholder analysis and mapping tool is a means to improve the effectiveness and public acceptability of risk assessment processes and to facilitate risk management (14.2). The use of mental models proved a useful tool for capturing communities' level of knowledge and understanding of biosecurity risks and should be part of any communication strategy (14.3). CEBRA also provided training in the use of plain English in biosecurity risk documentation. Experimental workshops showed that clear prose improved reader comprehension and reduced reading time, which is important for communication in science, policy and decision-making (14.4). These developments were advanced recently in a project aimed at improving the transparency of reasoning and the use of data in risk assessments based on argument maps. These developments are currently being deployed in MPI and DAWR.

Table 14: ACERA I - Risk communication projects

Ref.	Project no.	Title
14.1	608	Caponecchia, C. (2007): Strategies for the effective communication of probabilities
14.2	609	Gilmour, J. and Beilin, R. (2007): Stakeholder mapping for effective risk assessment and communication
14.3	801	Gilmour, J. et al. (2009): Using stakeholder mapping and analysis with a mental models approach for biosecurity risk communication with peri-urban communities
14.4	805	Thomason, N. et al. (2009): Plain English for risk communication

8 Spatial modelling

The increase in international trading and passenger volumes and in imports from a growing number of countries increases the risk of arrival and establishment of invasive species and diseases. To reduce these risks, regulators may aim to effectively monitor movements and detect species incursions as early as possible. Predicting the spread of potential pests or diseases using spatial modelling can assist in managing risk by implementing surveillance strategies and in mitigating the ecological and economic impacts by control/eradication programs.

CEBRA developed spatially explicit models for invasive species that in combination with simple optimisation tools help decision makers to find the desired balance for surveillance programs in terms of cost, resources and probability of success (15.2). A review of spatial models for estimating the likelihood of animal pest occurrence and potential suitable habitat in marine and terrestrial environments formed the basis of further research in these areas (16.1).

The number of methods developed for modelling of geographic species distribution is increasing as their application expands as well, requiring the need for choice of method to be matched to application. CEBRA compared the performance of different modelling methods and provided advice on development of criteria for performance evaluation. A workshop with spatial analysis experts hosted by CEBRA focussed on developing methods for predicting spatial distribution and movements of invasive species leading to the emergence of innovative ideas and collaborations relevant for risk/hazard identification (15.1).

CEBRA currently directs research efforts into developing risk maps along entry pathways for more informed decisions around surveillance resources (16.3). Other research explores alternative approaches to habitat suitability modelling for invasive pest species and develops practical guidance for identifying the most appropriate tools and approaches for predicting species distribution (16.2).

Table 15: ACERA I - Spatial modelling projects

Ref.	Project no.	Title
15.1	603	New spatial analysis methods for improved hazard/risk identification Elith, J. and Graham, C. (2008): Do they?/How do they?/Why do they differ? - on finding reasons for differing performances of species distribution models
15.2	806	Cacho, O. (2009): Application of search theory to weed eradication programs

Table 16: CEBRA - Spatial modelling projects

Ref.	Project no.	Title
16.1	1302A	Burgman, M. et al. (2014): Evaluating spatial analysis tools for surveillance and monitoring in marine and terrestrial environments
16.2	1402B	Barry, S. et al. (2017): Tools and approaches for invasive species distribution modelling for surveillance
16.3	1502E	Mascaro, S. and Thiruvady, D. (2018): Exposure pathway model for forest surveillance: stage 2

9 Citizen science

Citizen science is about engaging community experts to participate in science-based activities in the context of biosecurity. Activities involve communication, detection and reporting of pests, weeds and diseases and monitoring. Typically, community experts are government officers, scientists, retirees, tradespeople, and representatives from conservation, Landcare and wildlife groups.

Engaging members of the community to participate in biosecurity surveillance can provide a significant contribution to biosecurity detection. CEBRA found that the use of 'Science Cafes', discussion forums aimed at engaging the general public, were a potentially useful way of engagement, as community members were already interested in and enthusiastic about volunteering in biosecurity detection (17.1).

CEBRA investigated the value of community surveillance (also known as passive surveillance) in the management of invasive species. Available data was complemented by simulation and estimations showed a $52 return per 1$ invested into community engagement. The return in investment was measured as the savings in active surveillance caused by the presence of passive surveillance. Another aspect of this project looked at the likelihood of members detecting a new or emerging pest or disease and influencing factors (18.1). The Department deemed some of the project outputs beneficial for states and territories for their emergency response coordination efforts.

Table 17: ACERA I - Citizen science projects

Ref.	Project no.	Title
17.1	802	de Chazal, J. (2008): Bioscurity: improving detection by enlisting community detectives

Table 18: CEBRA - Citizen science projects

Ref.	Project no.	Title
18.1	1004B	Post-border surveillance techniques: review, synthesis and deployment. Cacho, O. (2012): Valuing community engagement in biosecurity surveillance Hester, S. and Garner, G. (2012): Post-border surveillance techniques: review, synthesis and employment, Phase 2 synthesis

10 Biosecurity intelligence

Intelligence gathering is the screening of different sources of information for signals of emerging issues, the fostering of foresight activities to help anticipate future problems and the analysis of social networks. Intelligence research develops and tests tools to assist governments and other managers to minimise the threat of future biosecurity incursions.

CEBRA sponsored and facilitated a number of workshops that aimed to improve foresight skills in DAWR (19.2). An external expert ran workshops over several years, involving Department officers from a range of contexts.

CEBRA assessed online systems for biosecurity intelligence-gathering and analysis against the Department's needs (19.1), providing the platform and support for the subsequent development of a web based International Biosecurity Intelligence System (IBIS) for plant and animal (aquatic and terrestrial) biosecurity. This system incorporates a worldwide network of members and a database. It is open source and uses a combination of automation, a software robot scouring the Internet, and crowdsourcing to collect and classify biosecurity information. As a strategic intelligence tool for biosecurity IBIS is now part of the daily intelligence activities performed by specialist staff in the Department. It enhances the Department's capability of early warning, better planning and response mechanisms to deal with emerging biosecurity threats. Follow on projects further improved IBIS (20.1). A current project also investigates whether software could be used to identify biosecurity risks associated with Internet commerce, a pathway that facilitates long distance dispersal of alien species (20.2).

Table 19: ACERA II - Biosecurity intelligence projects

Ref.	Project no.	Title
19.1	1003A+B	Lyon, A. (2010): Review of online systems for biosecurity intelligence-gathering and analysis
19.2	1103C	Intelligence and foresight workshops

Table 20: CEBRA - Biosecurity intelligence projects

Ref.	Project no.	Title
20.1	1503A	Continuation of 1303A + 1403A. Intelligence gathering and analysis: International Biosecurity Intelligence System IBIS (in progress)
20.2	1503B	Chisholm, M. (2017): Intelligence tools for regulated goods traded via e-commerce

11 Other projects

Table 21: ACERA I - Other projects

Ref.	Project no.	Title
21.1	904	Caley, P. (2010): Uncertainty analysis in qualitative risk assessments: quantifying the effects of uncertainty in responses to key weed risk assessment scoring questions

Table 22: CEBRA - Other projects

Ref.	Project no.	Title
22.1	1405D	Illegal logging sampling strategy. Robinson, A. and McMaugh, T. (2015): Report on uptake of analysis and advice