FELLOWSHIP SUMMARY REPORT

Mark J. Ducey

Title: Alternative Models for Biosecurity Surveillance and Monitoring

Theme 2, Managing Risks in a Connected World

Host Institution: University of Melbourne, Centre for Excellence in Biosecurity Risk Analysis

Host Collaborator: Dr. Andrew Robinson

Dates: 22 October, 2018 to 14 December, 2018

I hereby consent to my report report being posted on the Co-operative Research Programme's website, or alternatively, a short paragraph about my fellowship which could be used anonymously

Objectives and Importance of the Project

Non-native, invasive plant pests (including plants, insects, and fungal pathogens) cause losses to agriculture and forestry of billions of dollars per year in the OECD countries alone, often representing 2-3% of GDP in developed economies. Minimizing the effects of invasive plant pests requires effective biosecurity measures at international borders, including ports of entry. Most phytosanitary surveillance depends on the ISPM-6 and ISPM-31 guidelines of the International Plant Protection Convention (IPPC). These guidelines set out the goals and objectives of phytosanitary surveillance in the context of international trade, and they emphasize the importance of scientifically-defensible sampling during the inspection process, but they provide limited guidance on sampling procedures for detection of biosecurity risk material (BRM).

In practice, most statistically-designed surveillance depends on rules of thumb (such as the "600-sample rule"). The computational methods associated with commonly-used approaches have been well-described in the literature, but less attention has been paid to the underlying foundations of sampling. This can lead to confusing or even contradictory interpretations of key terms such as bias and independence, with important consequences for what is considered an acceptable sampling design, or what constitutes a valid inference after data have been collected. These distinctions become especially important when reality departs from an idealized case of simple random sampling within homogeneous consignments. Although the problem is grounded in deep theory, the results are practical: acceptable sampling methods may be rejected, or inappropriate ones accepted; computational methods may be applied to data for which the assumptions of those methods cannot be justified; decisions about the prevalence and risks associated with BRM may be incorrect; BRM monitoring programmes may fail to meet their design criteria; and unnecessary costs may be incurred in the surveillance and monitoring process.

Moreover, the 600-sample rule and similar approaches typically focus on the tactical problems detecting BRM and substantiating freedom from BRM at the individual consignment level. However, other strategic objectives are also important to surveillance efforts. These include 1) learning about the biosecurity risk associated with a pathway; 2) detecting changes in risk along a pathway; 3) estimating and minimizing the aggregate propagule load associated with a pathway, to minimize the probability of post-border incursion and successful invasion; and 4) identifying when modification or corrective action is warranted on an entire pathway, not just individual consignments.

Under this proposal, Dr. Mark Ducey traveled to the Centre of Excellence for Biosecurity Risk Analysis (CEBRA) at the University of Melbourne, while on sabbatical from the University of New Hampshire in the U.S.A. There, he developed a new collaboration with Dr. Andrew Robinson and his team, including postdoctoral associate Dr. Raphaël Trouvé, focusing on the theoretical foundations for sampling in phytosanitary biosecurity, informed by concrete applications, and with an eye toward supporting the goals of international policy and implementation of best practices as reflected in ISPM-6 and ISPM-31.

Achievement of Objectives

The overall aims of this fellowship were:

1. Develop simple, transferable models of biosecurity surveillance at the border, that incorporate formal statistical learning about risk along a pathway as consignments are sequentially inspected over time.
2. Compare and contrast the practical and theoretical consequences and insights arising when alternative frameworks are used to model imperfect information.
3. Illustrate and explain those consequences and insights using data on actual consignments and pathways reflecting Australian biosecurity experiences, and test proposed sampling alternatives using data that reflect a range of consignment and pathway characteristics.
4. Disseminate the results using targeted methods both to the research and biosecurity policy communities.

Aims 1-3 were achieved, with progress on dissemination anticipated to continue through the remainder of calendar year 2019 (as outlined below).

Major Achievements

Work while Dr. Ducey was in Melbourne focused on developing simple, transferable models that incorporate learning about risk on a pathway (Aim 1), and comparing and contrasting alternative frameworks including classic design-based inference, frequentist model-based inference, Bayesian inference, and emerging perspectives such as Dempster-Shafer theory and imprecise probability theory (Aim 2). With support from Dr. Robinson and Dr.

Trouvé, Dr. Ducey developed a review paper (totaling approximately 15,000 words, or over 40 pages) addressing theoretical foundations, practical consequences, and errors or confusion in the biosecurity surveillance literature that could impact the costs or outcomes of phytosanitary biosecurity efforts. The issues addressed in the review were set within a general conceptual context for biosecurity surveillance (Figure 1.) During the development of this review, we identified several challenges and their solutions that had not previously been addressed in the literature. These include

A. Exact solutions for the required sample size to substantiate freedom from BRM at a stated prevalence, when certain kinds of clustering are present. Previous attempts to address this in the literature assume a simplifying approximation, which turns out to be conservative and therefore entails unnecessary costs when used to plan surveillance programmes.

B. Confusion in the literature, and in guidance contained in ISPM-31, over the conditions under which inhomogeneity in BRM prevalence within a consignment (such as the tendency for BRM to be higher in certain regions of a container, or in certain crates or other portions of a consignment) make simple random sampling or other straightforward alternatives appropriate. Some widely-cited sources state that inhomogeneity invalidates any statistical assessment. However, this assertion is not grounded either in the design-based or model-based theories of survey sampling. In practice, complete elimination of inhomogeneity can never be guaranteed; we identify a number of valid strategies and illustrate them with concrete examples.

C. Clarification of the possibilities for Bayesian inference and inference from imprecise probabilities, when clustering of BRM is present but the degree of clustering is unknown.

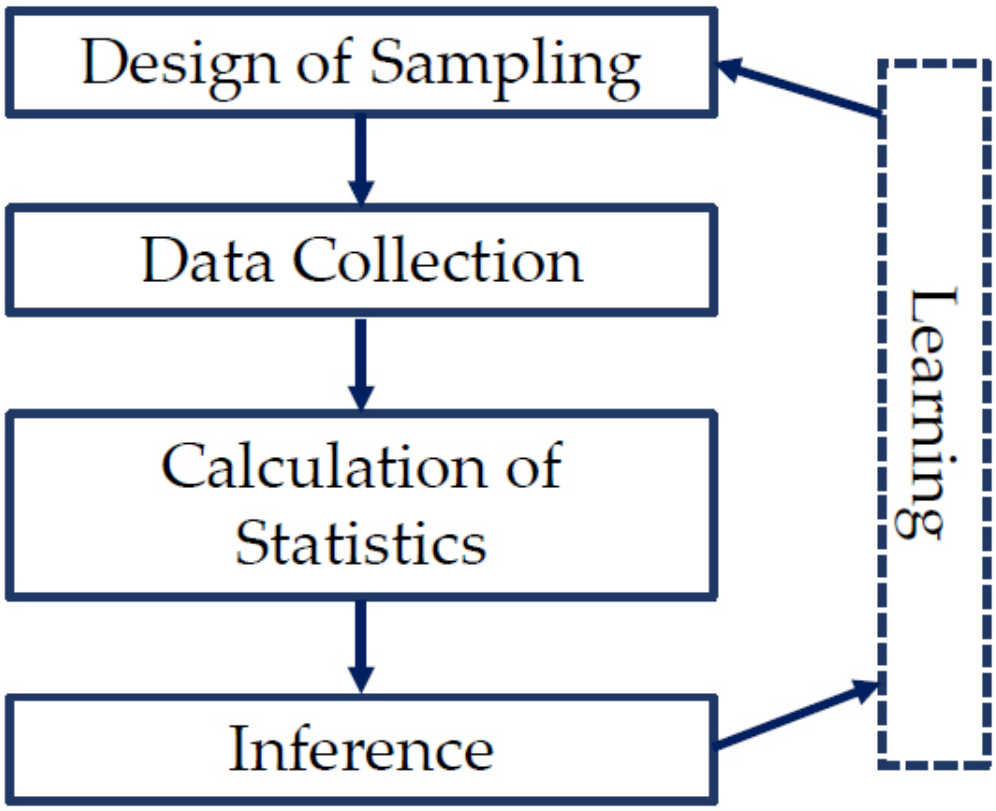

Figure 1. General conceptual framework for biosecurity surveillance at the border. "Inference" can include estimating the prevalence of biosecurity risk material (BRM), substantiating freedom from BRM in a consignment or pathway, or deciding whether or not to intervene or take corrective measures for an individual consignment or an entire pathway.

As part of the work in Melbourne, Dr. Ducey collaborated with Dr. Trouvé and Dr. Robinson to develop illustrations and simulations of a number of the approaches and techniques outlined in the review paper, using real data on a range of agricultural commodities (including cut flowers, seeds, and vegetables) identified in concert with CEBRA partners and stakeholders. These simulations are ongoing and support the achievement of Aim 3 of the proposal.

Follow-Up Work

As outlined in the timeline for the original proposal, dissemination and outreach is a major component of the follow-up work to the visit. We have a number of dissemination products under active development, including:

1. A simplified version of the review paper, to be submitted in late April 2019 as a book chapter.

2. Peer-reviewed journal articles addressing each of the three challenges (A, B, and C above), as well as an overview article focused on the distinction between the two primary modes of survey sampling inference (design- and model-based) and their implications for the design, implementation, and interpretation of biosecurity surveillance programmes. We expect to submit these papers in May through September of 2019.

3. An extended version of the review paper, containing extensive details on simulations using stakeholder data, to be disseminated as a CEBRA report. These reports are directly used by CEBRA partners, including agencies responsible for biosecurity in Australia, New Zealand, and other OECD countries. This report is planned for release no later than August 2019.

4. A short summary, to be submitted as a Policy Brief of the Carsey Institute at the University of New Hampshire in September 2019. Carsey Briefs are widely circulated and cited by non-technical policy audiences in the United States, and we hope that development of a policy brief will help broaden awareness of biosecurity challenges in general.

To push the final objectives forward, and make plans for future work, we are expecting that Dr. Trouvé and Dr. Robinson will travel to the U.S. to work with Dr. Ducey at the University of New Hampshire in September or October of 2019. Work during that visit will focus on completion of any remaining manuscripts, and the development of proposals for follow-on activities.

Policy Applications and Social Benefits

The most immediate policy relevance of our work is the identification of areas in which the existing guidance under the ISPM-31 standards could be strengthened and brought into line with sound statistical practice. The guidance as currently written may be leading some agencies to design programmes that are unnecessarily complex and expensive, or adopting unreliable subjective sampling approaches in the mistaken belief that sound objective procedures cannot be applied to potentially inhomogeneous consignments. We hope that by identifying these challenges, and making specific, concrete suggestions for appropriate procedures, we can strengthen the performance and reduce the cost of programmes designed to meet the phytosanitary goals of ISPM-31. As a

result, the overall propagule load of invasive species and the number of post-border incursions should be reduced. This will lead, in turn, to reduced impacts of invasive species on agricultural and forest systems, including reduced losses, as well as costs of elimination, adaptation, and mitigation, over the long term.

More broadly, the clarification of the theoretical basis for inference from sample-based biosecurity programmes opens the door to new alternatives, including those that explicitly include learning about past prevalence of BRM within a biosecurity pathway, using forecasts for profiling and other decisions about allocation of surveillance resources, and detecting and responding to changes in prevalence as they occur. Our work is not meant to be the final word on the subject, but an opening word in a set of much longer conversations among a diverse group of stakeholders. We are looking forward to participating in those conversations.

Relevance to Objectives of the CRP

As had originally been hoped, this project has led to immediate, practical guidance on biosurveillance activities, along with theoretical developments to support further efforts at improving the efficiency and effectiveness of plant biosecurity at the border. Using stakeholder-provided data, we have been able to illustrate how improved techniques have the potential to save costs and improve outcomes.

The project completed under this fellowship directly supports the objectives of Theme II, Managing Risks in a Connected World. The work focused directly on the ability of biosecurity agencies to quantify, manage, and set appropriate policies around trans-border movement of invasive pests, insects, and fungal pathogens. As the developments initiated in this project take shape, we expect new, transparent, adoptable approaches for the design of surveillance programmes to become available. When formal surveillance processes can incorporate learning from past data as part of the design-and-inference cycle, governments and managers will be better prepared to anticipate, avoid and react to biosecurity threats arising in a changing economic and ecological climate. By minimizing the overall propagule pressure along different biosecurity pathways, governments and managers will be better able to minimize the attendant risks and impacts of costly post-border incursions and successful invasions.

Satisfaction

The fellowship was highly satisfactory and will lead to a number of positive changes for Dr. Ducey going forward. The new collaborations developed at CEBRA will be durable, and we are already contemplating development of follow-on proposals to funding sources in both Australia and the U.S.

For Dr. Ducey, an important outcome has been the broadening of knowledge and skills directly related to biosecurity. Although Dr. Ducey has worked on biosecurity-related questions before, and especially those related to the spread and monitoring of incursions post-border, this has been his most focused work on the critical aspects of biosecurity at the border. A long-term outcome of this fellowship will be the growth of biosecurity issues as an important part of Dr. Ducey's research and teaching portfolio in his work at his home institution.

Advertising of the CRP

I first became aware of activities related to the Co-operative Research Programme through attending a conference that had partial OECD support, and subsequently became aware of the fellowship programme through a colleague who had applied for a fellowship in a previous cycle. When I decided to apply, I found that the best source of information was the Co-operative Research Programme website.