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RESEARCH SERIES 1/2015

Biology is not Alone: The Interdisciplinary Nature of Biosecurity

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Cover design by Penny Thomson
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On the cover is the Australian tachinid fly (*Trigonospila brevifacies*), a parasitoid of other insects, specifically larvae of a number of Lepidoptera. It was introduced into New Zealand as a biological control agent for pest leaf roller moths, is also known to affect non-target and non-pest species, and to compete with native parasitoids.

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Biology is not alone: The interdisciplinary nature of biosecurity

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Abstract

Recognition and management of anthropogenic environmental impacts as 'biosecurity' is a relatively new concept to our society. Although biosecurity risks are based on biological impacts, biosecurity management is truly interdisciplinary-transdisciplinary since the definition and interpretation of risk and adverse effects are socially constructed, and the outcomes and management of the risks can have significant social and economic impacts. The New Zealand biosecurity strategy is very clear that the responsibilities for environmental risk management lie with society as a whole. The authors explore how disciplines other than biology may contribute to the understanding of biosecurity risks, their management and mitigation. This paper outlines the interdisciplinary-transdisciplinary nature of biosecurity, with an emphasis on the social and economic elements.

Keywords: Biosecurity; biology; sociology, psychology, geography, communication, Māori, economics.

Introduction

Biosecurity has been defined as "the exclusion, eradication or effective management of risks posed by pests and diseases to the economy, environment and human health" (Biosecurity Council 2003). The biological component of biosecurity draws on knowledge relating directly to the invasive alien species in question – including whole organism biology, taxonomy, ecology, pathology and epidemiology (Davis 2009). However, it must be remembered that biosecurity is not just applied biology. A wide range of non-biological disciplines, such as chemistry, economics, education, engineering, geospatial information systems, information technology and management, modelling, psychology, risk analysis and sociology are integral to the inevitably multidisciplinary approach required in the management of invasive alien species (Murray & Koob 2004; Cook et al. 2010; DAFF 2012).

The Biosecurity Science, Research and Technology Strategy for New Zealand (MAF Biosecurity New Zealand 2007) recognised the need for:

- increased understanding of societal and cultural attitudes to biosecurity risks and management measures;
- integration of Mātauranga Māori with biosecurity science;
- increased understanding of the impacts of human behaviours on biosecurity measures;
- improved understanding of the effects on biosecurity of changing demographics, societal and cultural values;
- assessment of the impacts on biosecurity issues of changing lifestyles;
- building capacity for applying behavioural and economic science to biosecurity;
- identification of areas where education will contribute to desired biosecurity outcomes.

Preparation for, and response to, biosecurity risk in New Zealand is now led by the Ministry for Primary Industries. The task to protect economic, environmental, human health, social and cultural values is a partnership-based approach, initiated in 2014 with the establishment of the Government Industry Agreement for Biosecurity Readiness and Response (GIA). This partnership represents close integration of the capabilities and resources of government and industry agencies to maximise biosecurity outcomes (GIA Secretariat 2013).

Although the need for establishing an interdisciplinary partnership-based approach to managing biosecurity risks may be evident in the policies of governmental agencies, the difficulties inherent in achieving this should not to be underestimated. The failings of communication between science and the humanities have long been recognised as an impediment to the resolution of problems (Snow 1959), particularly the style and level of writing and a sense that scientists tend to be secretive, leading to misconceptions of how they work (Castell et al. 2014). Such barriers still exist, preventing the key role of science in environmental management to be recognised (Veríssimo & Pais 2014).

The education sector has a key role to play in pre-empting, and so minimising, any barriers to interdisciplinary or systems approaches to management. Historically, at both tertiary and secondary (W. Folkhard pers comm.) level teaching, biosecurity education has been limited to the consideration of invasive species in biology/science curricula, but clearly expectations of the Biosecurity Science, Research and Technology Strategy for New Zealand (Biosecurity New Zealand 2007) requires increased ecoliteracy across society, and significant shifts in existing environmental paradigms.

Biosecurity issues are generally anthropogenic. This offers the opportunity for the issues to be explored through geography, psychology, sociology and economics as well as biology, with mitigation approaches drawing on the full spectrum of current and emerging technologies. Biosecurity has to be seen, and delivered, as a truly interdisciplinary concept. The intention of this paper is to explore how disciplines other than biology may contribute to the understanding of biosecurity risks and their management and mitigation.

Discipline areas

Technology, computing and engineering

The recognition of the potential for technology to play a role in NZ is well established (Goldson et al. 2002; Guy 2014). The array of technological tools that are employed in biosecurity, for example traps, toxins, physical barriers, identification devices and remote sensing (MAF 2008; Veitch et al. 2011), is extensive and under constant development, requiring close collaboration between developers and biologists. For example:

- Traps are required to be reliable and durable in the field, to meet animal welfare standards, and to be easy for operators to maintain (Thomas et al. 2011). But they are not cost-effective over large inaccessible areas if they remain non-functional after triggering. The development of self-resetting traps is a move to improve the cost-efficiency for operations in remote locations (Parliamentary Commissioner for the Environment (PCE) 2011). Even with the development of self-resetting technology, however, traps are unlikely to be sufficiently efficient to manage high pest populations in favourable breeding seasons.
- Toxins continue to play a crucial role in the management of pests in New Zealand, particularly over large areas where access is limited. The development of 'better' toxins is considered an imperative, as they must be effective and address safety concerns from both social and biological perspectives (PCE 2011). The addition of repellents to toxins to reduce the impact on non-target species (eg. kea (*Nestor notabilis*), Orr-Walker et al. 2012) is an example of the research that can inform improved operating procedures.
- The use of fences to manage movement of animals is certainly not new, but the development of predator-exclusion fences in New Zealand in a biosecurity context has been rapid (Burns et al. 2012). There is evidence of conservation gains through use of fences, and significant gains in community engagement and conservation advocacy (Burns et al. 2012). The New Zealand experience with predator-exclusion, and the development of the associated technology this has generated, has been applied in conservation projects internationally (Young et al. 2012). There is debate, however, over the efficacy of this technology over the longer-term and for management at a landscape level. From a conservation perspective, fences create isolated populations, which are unlikely to considered self-sustaining, and the high financial investment required for the construction and perpetual maintenance of predator-exclusion fences may counter the conservation benefits (Schofield et al. 2011; Burns et al. 2012).
- Genetic analyses can be used to inform the outcomes of management practices for invasive species. Genotyping has been used following management operations to identify source populations (and therefore invasion pathways) of new individuals, and to distinguish between survivors and reinvaders at a treated site (Russell et al. 2010; Veale et al. 2013). This technology is considered to be a feasible tool for conservation managers to assess the movement and source of pest individuals where time and resources are limited (Russell et al. 2010).
- Remote sensing technologies offer valuable cost-effective tools for mapping and monitoring invasive species as well as providing modelling mechanisms for predicting areas susceptible to invasion

(Underwood & Ustin 2007). This can contribute to pre-invasion risk assessments through the ability to quantify likelihood of species establishing and spreading, and also help to focus surveillance efforts.

- The development of "cyberinfrastructure" (Magarey et al. 2009) to collect and share data and to potentially provide analysis. Accessible databases or websites already exist, with examples including virtual herbaria such as the Australian Virtual Herbarium (http://avh.chah.org.au/) and the New Zealand Virtual Herbarium (http://www.virtualherbarium.org.nz), where plant occurrence records from across Australasia can be accessed online and Naturewatch (http://naturewatch.org.nz/), a site where scientists and the general public can record photographs and observations on any organism. This had lead to the increased importance of citizen science. A citizen scientist is an amateur who records observations or collects other kinds of scientific data as part of a larger project (Silvertown 2009). Citizen scientists participate in a range of ecological studies, including those involving invasive species; such studies have become more accessible with the development of mobile computing, targeted species identification software, and online databases for recording observations (Dickinson et al. 2012). One example in New Zealand is the New Zealand Garden Bird Survey, which was started in 2007 to monitor population trends in native and exotic birds in home gardens, with the primary objective of collecting data, but also to involve the public in science and raise awareness of conservation and the environment (Spurr 2012). Some questions have been raised about the accuracy of data generated through citizen science projects (Crall et al. 2011), and properly designed studies with appropriate support and validation of data is essential. The need for more effective surveillance mechanisms may be achieved through mobilising citizen scientists to engage through existing cyberinfrastucture.

As biosecurity threats change, the associated technology required for mitigation of the threats must also keep pace (Mumford et al. 2006). Commercial incentives may ensure the long-term sustainability of businesses where compliance with biosecurity regulations is obligatory (Ministry of Agriculture and Forestry 2005), and also for businesses involved in research and development of new technologies.

Geography

Studies of the physical environment and human geography bring together key elements of biosecurity – people and the environment they live in and affect. The invasibility of our islands, and the degree of impact by alien species, are a combination of human movement accompanied by the inevitable accidental hitch-hikers, novel habitats generated by development, and deliberate introductions made in an ecoliteracy vacuum. Topics such as climate and climate change, population demographics and movements, trade patterns and mapping tools all have application to biosecurity. Propagule dispersal is a discrete stage in the invasion of alien species (Lockwood et al. 2007), and humans are deliberate or inadvertent agents in this movement, or change the environment to facilitate species to move themselves. Thus attributes of human societies – migration, travel, development, trade, lifestyles – can all contribute to the rise in biosecurity issues.

Geographic Information Systems (GIS) is a powerful tool for processing and data analysis where the understanding of spatial relationships is critical. The application of GIS to environmental management is ever

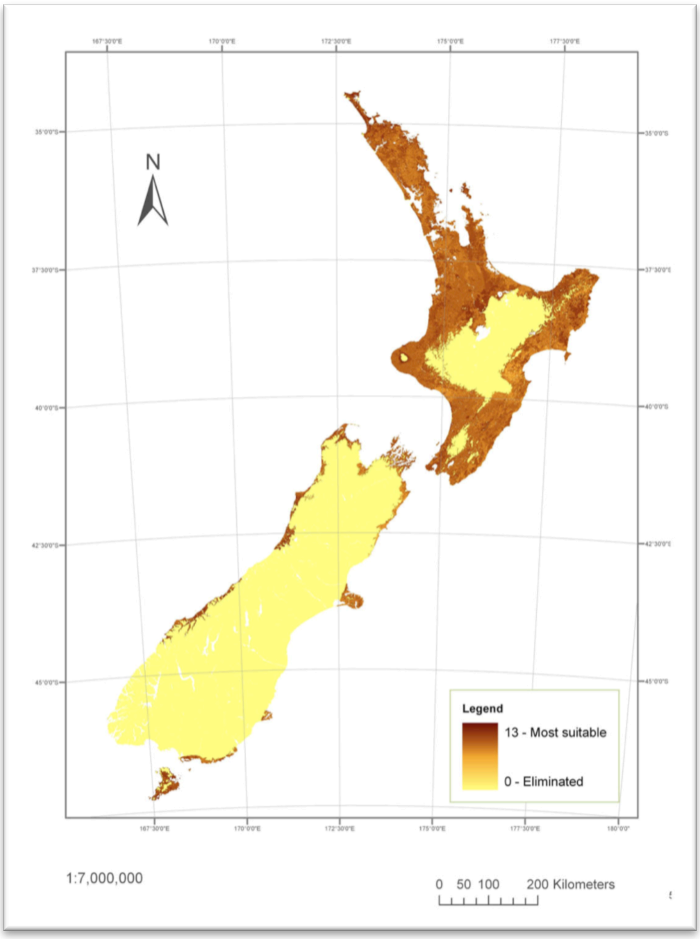

Figure 1.
GIS-generated map of the potential distribution of the giant African snail (*Achatina fulica*) in New Zealand (Cooling & Galbraith 2006, reprinted with permission).

growing, including biosecurity. For example, GIS can be used in biosecurity to model potential distribution of invasive alien species before they arrive (e.g. Cooling and Galbraith 2006), likely spread when they have arrived (Vink et al. 2011), and potential future distribution under different climate change scenarios (e.g. Sheppard 2013; Hager et al. 2014). This modelling can then inform management of borders and pathways for specific species. An example of this is shown in Figure 1.

Sociology, psychology and communication

People are intrinsically part of biosecurity, at both the pre- and post-border stage and as part of the problem and part of the solution (Bewsell et al. 2012). Understanding and influencing human behaviour is an essential part of managing biosecurity risks. Not all people understand the need for biosecurity awareness. International travellers are exposed to legislated biosecurity obligations as they enter New Zealand, but making the link between personal behaviour and national security can be difficult. For example, Bewsell et al. (2012) asked travellers who had entered New Zealand within the last 12 months a series of questions about what information they had seen about biosecurity requirements and whether that had influenced their behaviour. They concluded that "highly involved" individuals understood biosecurity requirements and the consequences of not following these, but that communicating effectively with individuals with "low involvement" was more difficult.

The need for a wide range of methods to communicate biosecurity concepts to the general public is well recognised (Sharma et al. 2014), with past New Zealand campaigns employing media advertising, distribution of display material, fact sheet distribution and face-to-face interactions with stakeholders (Patston 2006; Dyer 2008). In New Zealand in 2011, a government education campaign was carried out in an attempt to control the invasive freshwater alga didymo (*Didymosphenia geminata*), which relied on the use of imagery, with the main things that influenced behaviour being seeing a poster (51%) or a brochure (48%) (Thorpe 2008). Invasive species have received the attention of artists with group exhibitions such as 'The Weeds Drawing Project' - a collaboration between the Manukau School of Visual Arts in New Zealand and Newcastle University in Australia (Thompson & Hansen 2010) and the recent (2014) 'The Kauri Project: Poster Series', an exhibition to raise awareness about kauri dieback. Artists have also explored biosecurity themes in collaboration with scientists, with examples from painting (e.g. 'Inflorescence', an exhibition by Hamish Foote and a collaborative, illustrated article on invasive plant and animal species (Foote & Blanchon 2013)) and photography (e.g. 'Fallen', an exhibition by John Pusateri and a collection of contextual essays (Pusateri 2008)).

The failure of the public to recognise biosecurity as being important to national security has been identified as a weakness for biosecurity in New Zealand (PCE 2000). This is reinforced by research that has demonstrated a wide range of perceptions of pests within New Zealand (Fraser 2001; Fraser 2006; Russell 2014) (Fig. 2) and varying attitudes to their control (Farnworth et al. 2014).

This breadth of public perception towards pests generates a comparable breadth in options and issues for the management of invasive species, particularly where the pest also represents a resource to some groups. Management for species not yet established within our borders is even more problematic since impacts are uncertain, and unlikely to be tangible prior to the species' establishment. Contingencies for the management of such species will be based their invasive behaviour in other countries, or may be based on purely theoretical grounds if the species is not invasive elsewhere. Such contingencies, although ideally based on scientific knowledge, may also be subject to value judgements.

Human perceptions of what constitutes a pest are driven by a host of formative factors and agents, and are, in turn, a powerful determinant of behaviour. An investigation of the range of possible influences, whether cultural, experiential, religious or economic, presents a worthwhile challenge for social research. For example, the unresolved debate about the status of kiore (Pacific rat *Rattus exulans*) (Roberts 1992; Haami 1992) highlights the need to integrate and manage differing cultural values and traditions. For some Māori, kiore is a taonga and so its use and protection is an Article Two issue under the Treaty of Waitangi. For many scientists and conservationists, however, the kiore remains a predator endangering indigenous plant, bird, reptile and invertebrate species (Campbell & Atkinson 1999; Towns & Broome 2003; Gibbs 2009). An agreement between Ngātiwai and the Department of Conservation to protect and monitor a population of kiore on the Marotere Islands (Northland) while eradicating them from a larger nearby island, Taranga or Hen, is perhaps a good example of how differing values can be accommodated (Parrish 2008).

Walker and Wass (2006) have highlighted that excluding Māori from decision making in environmental and conservation management will typically lower the standard of the decisions and the effectiveness of their implementation. 'Co-management' approaches provide opportunities to develop management processes and achieve outcomes that serve both conservation and cultural imperatives. 'Strong' co-management, defined as *"...involv[ing] two or more parties who share decision making in an equitable fashion"* (Moller et al. 2000), has had some success in New Zealand and elsewhere (Moller et al. 2004; Gutiérrez et al. 2011). Devolution of power to indigenous or other communities is likely to be politically contentious (Moller et al. 2000), and integrating scientific knowledge and methods with traditional ecological knowledge and practice is certain to be fraught with difficulties and challenges, particularly when limited by an inflexible statutory framework (Dodson 2015). The advantages, however, are potentially significant (Dodson 2014), including the acknowledgement of the constitutional relationship established by the Treaty, the availability of many generations of observation and management experience enriching 'conventional' scientific knowledge (e.g. Lyver et al. 2008), and the goodwill of an affected community who may participate in implementing, monitoring and enhancing compliance with biosecurity management strategies.

Since biosecurity management decisions are informed by risk assessment, they will involve judgements on risk and impacts, many of which, although based on sound biological theory and fact, will be value-based and will therefore never satisfy everyone. For example, demands for the eradication or control of possums in New Zealand have at different times come from growers of crops, conservationists concerned for indigenous forests, and the dairy industry wanting to control bovine tuberculosis (PCE 1994, 2011). Varying perceptions of 'risk' associated with possums will generate equally varied proposals for preferred management strategies, and tolerance (or not) for the use of particular mechanisms (e.g. 1080 poison (PCE 2011)).

The risk management process offers a mechanism for prioritisation of management options. This approach can accommodate biological, social and economic perspectives:

> *"Risk management is both a culture and a process. While the process is directed towards managing risks, one of the steps…is concerned with analysing impacts…on the organisation or activity being assessed…by adopting a broad perspective, risk management can be used as a framework for addressing a wide range of social, health, environmental, cultural, economic and technical impacts."* (Gough 1992)

Economics

Government and exporters aspire to maintain New Zealand's reputation of a *"reliable, safe and sustainable food exporting country"* (Ministry for Primary Industries (MPI) 2014). The prevention of incursions and the management of existing invasive alien species has high financial costs. The estimates of New Zealand's total biosecurity expenditure for 2008, both defensive expenditure and output losses at national and regional levels, was $3391 million (Giera & Bell 2009). The costs of recreational losses and environmental impacts (eg biodiversity loss) are not incorporated into this figure. Overseas, the magnitude of costs are similar. McLeod (2004) estimated that the total annual economic and environmental costs to Australia of 11 vertebrate pest species was AU$719.7 million annually, including control costs and production losses.

There are key questions that must be posed about what role public and private sector interests should play

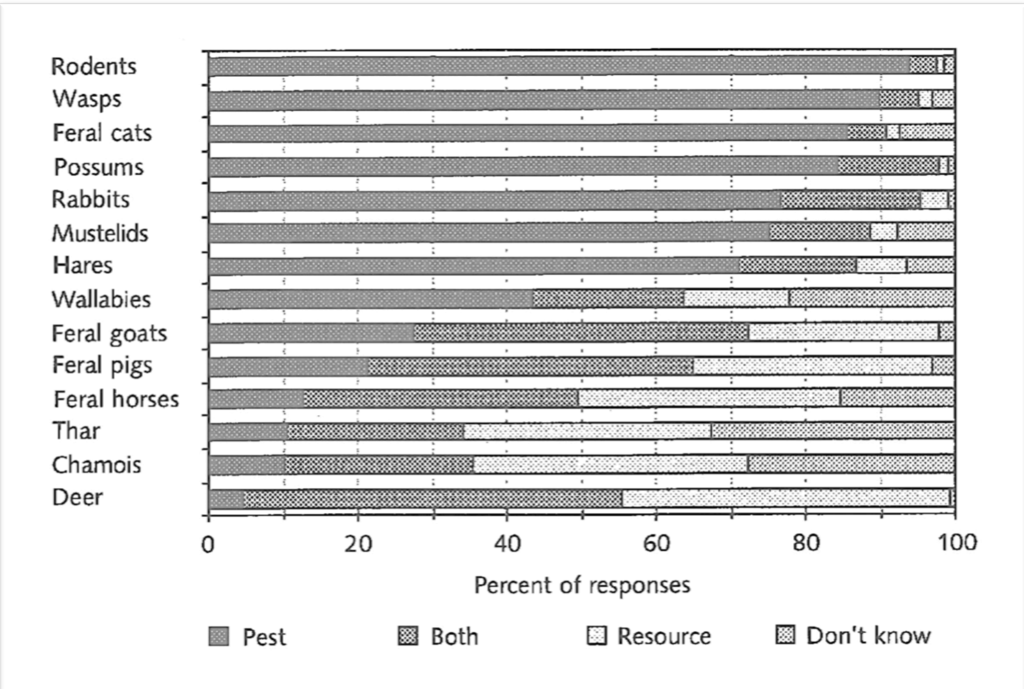

Figure 2.
Perceptions of wild animals as pests or resources (Fraser 2001, reprinted with permission).

in meeting these costs. What is the appropriate balance between investing in border protection and other mechanisms to prevent the incursion of unwanted organisms, and establishing contingency funds for emergency responses that may be infrequent but very costly? A decision to accept a certain level of incursion, or biodiversity loss, may be defensible in terms of economic efficiency, but would such an assessment be acceptable in terms of social or economic imperatives?

Pinfield (2001) identifies the economic costs and benefits of investment in biosecurity from a domestic (New Zealand) perspective:

Benefits:

- the reduction in production losses (or in biodiversity, or in health status) associated with controlling or eliminating incursions;
- the removal of any biosecurity restrictions that have been imposed on the country by export markets.

Costs:

- the compliance and administrative costs of assembling information on the presence and distribution of pests and unwanted organisms;
- the costs of vaccination, fumigation or poisoning, and of the precautionary destruction of livestock;
- the value of the livestock destroyed;
- the compliance and administrative costs of movement controls;
- collateral damage, for example by biological control agents to indigenous flora or fauna;
- the costs of monitoring and enforcing compliance with the biosecurity programme.

Biosecurity breaches can translate directly and rapidly into measureable economic costs, particularly in international markets, and a number of recent relevant biosecurity incursions have had a significant impact on New Zealand. The first of these was the establishment of the varroa mite (*Varroa destructor*) in New Zealand in 2000 (Zhang 2000). The varroa mite exclusively attacks honey bees, which has the potential to disrupt pollination of crops and pastures and honey production (Howlett & Donovan 2010). Estimated costs have ranged from $365-$661 million between 2003 and 2028 (Anon. 2002) including between $198 million and $433 million in the South Island alone (Simpson 2003).

The second more recent example is that of Psa-V (*Pseudomonas syringae* pv. *actinidiae*), a bacterial disease of kiwifruit. The bacterium was first identified in a New Zealand kiwifruit orchard in 2010, after an incursion in Italy (Greer & Saunders 2012), and particularly affects the gold kiwifruit, which represent one third of the value of a nearly $1 billion industry in New Zealand. The estimated cost to the kiwifruit industry is between $310 and $410 million over a 5 year period (Greer & Saunders 2012).

Foot-and-mouth disease (FMD) is a biosecurity risk that is well recognised - and feared - by authorities and farmers alike, but the unprecedented shock to the New Zealand economy of an outbreak is unlikely to be appreciated by the general public. The potential economic impact of a FMD outbreak to New Zealand

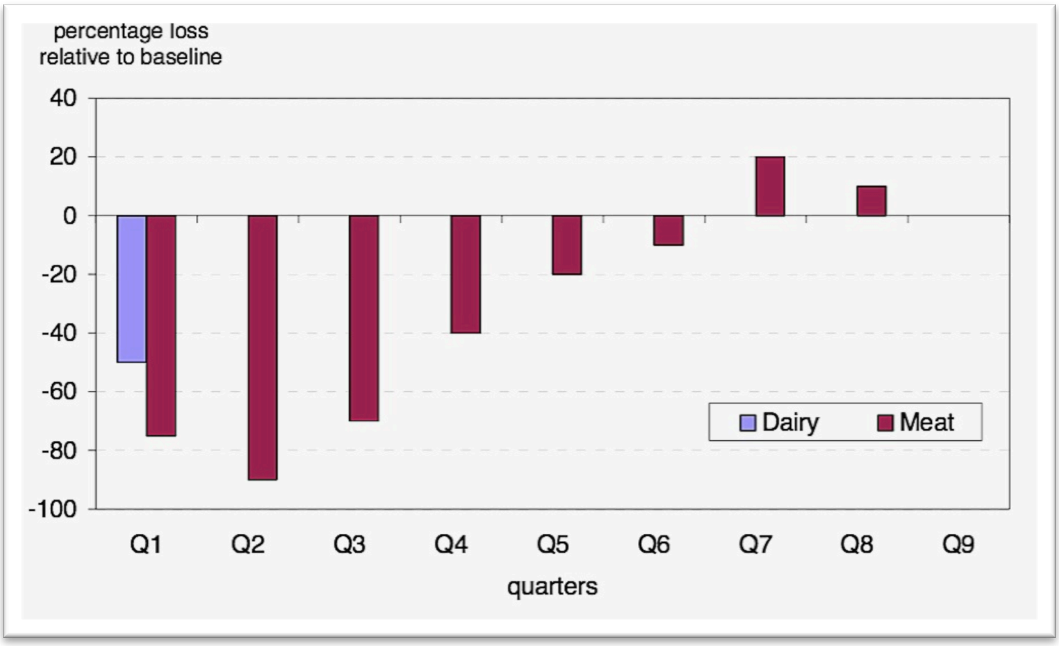

Figure 3.
Projected impacts of a FMD outbreak in New Zealand on the dairy and meat volumes (Gereben et al. 2003, reprinted with permission).

makes sobering reading. Gereben et al. (2003) estimated (at time of publication) the cumulative loss in GDP of around $6 billion in year 1, and $10 billion after 2 years. This impact is largely due to immediate import bans imposed by trading partners, with associated impacts on export prices and the exchange rate. Figure 3 illustrates these projected impacts.

More difficult to measure, but of significant impact, are the less tangible social costs of biosecurity measures. Community cohesion could be sorely tested as a result of restrictions imposed on travel, forced and rapid changes to lifestyles, and individual and collective anxiety about health and welfare issues. Evidence for this comes from analysis of the 2001 FMD outbreak in the United Kingdom that labelled the event a national disaster, with effects on human physical and mental health enduring long after the nation's economic recovery (Mort et al. 2004).

In risk management, accepting risk (i.e. doing nothing) is always an option. The costs of adopting a 'do nothing' option in biosecurity management, however, may ultimately be higher than funding initial incursion management and may be on-going indefinitely (Smith & Clough 2000). Management best practice should, ideally, emerge from balancing calculated risks and cost benefits, although risk and benefits will differ depending on which sector of society is being considered. The costs of biosecurity have to be met somehow, either through taxes or cost to consumers. But where and how costs are applied will always generate an interesting debate (PCE 2000).

As in all areas of public and private expenditure, it is important to establish accountability and some means of measuring the effectiveness of the commitment. While biophysical indicators will provide an important part of the overall picture, social and economic indicators must also be part of the mix informing decision makers about the success or otherwise of management strategies and practice (PCE 2000; Smith & Clough 2000).

Voluntary environmental accords have been implemented increasingly since the 1990s (Higley & Lévêque 2001), with application to a range of environmental problems associated principally with pollution. Voluntary accords may point the way to 'least cost' control methods of environmental management (Collins et al. 2004), and have being implemented in New Zealand to achieve biosecurity outcomes. The National Pest Plant Accord (Biosecurity New Zealand 2006), launched in October 2006, is a voluntary, non-statutory agreement between the Nursery and Garden Industry Association, Regional Councils, the Department of Conservation and Biosecurity New Zealand, aimed at preventing the sale, propagation and distribution of plants that pose an environmental threat. The Treasure Islands initiative is also a voluntary accord, initiated by Auckland Council and Department of Conservation to implement biosecurity management awareness for the islands of the Hauraki Gulf (Cook 2014). However, while voluntary accords diminish costs associated with monitoring and compliance, they do demand a high level of shared understanding and willingness within and between stakeholder groups to engage in their development. This may pose a significant challenge to both political and economic interests, though not insurmountable with collective engagement (Office for the Community and Voluntary Sector 2011).

Although cost-benefit analysis provides a powerful analytical tool in cases where an economic value can be readily determined, the assignment of other 'values' is less easily resolved. Non-market valuation methods such as travel cost or 'willingness to pay' (Costanza et al. 1997) may go some way to assigning economic values to iconic landscapes, especially if linked to key industries such as tourism and recreation. The aesthetic and cultural values assigned to these landscapes are less readily quantifiable (Swaffield & McWilliam 2013), and yet authorities from both central and local government are obliged to consider these when determining what levels of funding and other resources to apply to biosecurity. For example, defending indigenous biodiversity in the conservation estate is an ongoing and costly activity - witness attempts to eradicate, or a least limit, the spread of wilding pines in areas including the central North Island's volcanic plateau and the South Island's high country (Froude 2011).

Communities exposed to real and measurable economic risk will always be more highly motivated to invest in management strategies than a community that does not share the immediate exposure. Effective advocates for funding and other resources for management will be those who succeed in identifying all of the actual and potential risks to the wider community.

Conclusion

Current educational philosophies recognise the importance of interdisciplinary learning to facilitate "a comprehensive and coherent understanding of the world" (Bereiter 2002). Biosecurity by its very nature at the interface between ecology and humanity is interdisciplinary or transdisciplinary, incorporating a wide range of sciences and social sciences. Biology, in particular can generate solutions, but without consideration of human behaviours and economic realities, these are unlikely to be effective. For biosecurity to be accepted as the responsibility of society as a whole, a paradigm shift to acknowledge the integration of our natural and production environments into the national economy is required - a similar paradigm shift as that required to sustain sustainable living (Mitchell & Craig 2000). This paradigm shift can be facilitated, at least in part, through increased ecoliteracy, delivered and explored through across a spectrum of disciplines in education institutes at all levels.

The *Perspectives in Biosecurity Research Series* is intended to address the interdisciplinary nature of biosecurity. It is an occasional electronic series of research papers with broad academic scope, covering all aspects of the field of biosecurity, including (but not restricted to):

- invasion biology and ecology;
- invasive species identification/diagnostics/records/modelling;
- management and eradication/control;
- biosecurity law and policy;
- relationships between human society and invasive species;
- technological advances and applications;
- communication of biosecurity concepts to public and practitioners;
- recognition of the differing values inherent in a population of diverse cultures that will impact on management for biosecurity outcomes.

Biosecurity is already interdisciplinary, and with the fusion of the knowledge and skills of scientists and practitioners in many fields, and the involvement of the community, is arguably transdisciplinary. It merely needs to be recognised, delivered and communicated as such.

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