A hidden science that protects New Zealand's primary industries, environment and health

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While some areas of science get a lot of attention in the media – for example medical research and astronomy – other areas that are important to New Zealand get very little. The purpose of this, the first of a series of occasional papers, is to highlight some of our more hidden science efforts. In this paper we focus on biosecurity – an area where we have a broad and critical collaborative effort involving Crown Research Institutes and university staff working alongside national and local officials and private firms. It is a science area which people think little of when all is going well, and is only heard of in crisis situations. But as this paper points out, effective biosecurity requires an expanded and continual multidisciplinary scientific effort involving disciplines as diverse as neural network modellers and climate scientists. That we have been as prosperous as we have been in recent decades is in no small part based on our scientific approach to biosecurity and its implementation.[1]

Background

The term 'biosecurity', in New Zealand and Australia at least, broadly refers to the need to prevent the establishment of unwanted organisms in both our terrestrial and aquatic environments. These unwanted organisms can harm our food industries, human and animal health, and the flora and fauna of the conservation estate. Thus, biosecurity is of immense and particular importance to the protection of New Zealand's primary industries, environment and public health. Without it, New Zealand would be over-run with all kinds of

[1] The discussion presented below is in part based on a chapter in a recently published book (*Future food farming New Zealand Inc., meeting tomorrow's markets* [Eds, A. Emerson and J. Rowarth], NZX Ltd, Wellington, New Zealand, 124p) focused on the pastoral sector, and on discussion with leading aquatic biosecurity scientists. The same principles apply to all parts of New Zealand biosecurity.

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aggressive weeds, pests and diseases, leading to severe productivity and biodiversity losses well as serious damage to public health and well-being.

Biosecurity also covers the eventuality that, should an incursion occur, coordinated attempts are made to first 'contain' the threat while deciding whether it is possible to eradicate it or, if not, then at least develop methods and procedures to 'control' it. Obviously by far the best approach is to stop such unwanted species arriving in the first place.

It is worth noting that the meaning of the term 'biosecurity' in the USA and Europe is rather different. In that part of the world it usually refers to the ongoing effort being made to prevent the 'misuse' of biotechnology for terrorist purposes, such as the anthrax attacks which occurred in 2001 in the USA. Indeed, as a result of this confusion, more than one Australasian has turned up at the wrong scientific meeting!

In the last 10 years, biosecurity in New Zealand has been appreciably stepped up. In 2004, the Ministry of Agriculture and Forestry (MAF) created a division known as MAF Biosecurity New Zealand (MAFBNZ) with the specific purpose of managing biosecurity across all major sectors of the economy and environment. MAFBNZ is far the largest part of MAF, comprising about 1000 staff out of a total of 1300, and is charged with leadership of the New Zealand biosecurity system. Its responsibility covers facilitating international trade, protecting the health of New Zealanders and ensuring the welfare of the country's environment, flora and fauna, marine life and Maori resources. The consolidation of responsibility for biosecurity under a single agency followed a major review of the biosecurity system and development of a national biosecurity strategy.

This intensification of effort has manifested itself in many ways. There is now widespread use of sniffer-dogs and X-ray machines at airports, the application of import health standards for shipped goods and ballast water, the appointment of accredited inspectors at sea container unloading sites, stepped up funding for research and the creation of a Professorial Chair in Biosecurity at the Lincoln University-based Bio-protection Centre of Research Excellence. There is now a determined effort to engage the public's co-operation in all areas of biosecurity.

Introduction

There are few, if any, countries in the world that require excellent biosecurity more than New Zealand. There are three compelling reasons for this. The first is that New Zealand's biota is susceptible to invasion having evolved in an island ecosystem, the second is that New Zealand is very dependent on its primary industries, and the third is that there is an obligation to protect the country's remaining extraordinary and rare biodiversity.

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An estimated 2200 species of terrestrial alien invertebrates are known to have established in New Zealand. Around 90% of the country's invertebrate pests have arisen from these exotic introductions. It is also significant that, notwithstanding any further biosecurity failures (which there will be), the cost of these existing exotic pest impacts to New Zealand's primary industries is very high. The impact of alien invertebrate plant pests has been calculated to be around $880 million per year. When animal health impacts (e.g. gut parasites) are added to this, the figure increases to around $2 billion per year. The Reserve Bank has estimated that a foot-and-mouth outbreak alone could cost the economy $10 billion. Thousands of jobs would be put at risk and the economy would take years to recover.

The susceptibility of New Zealand's productive and indigenous ecosystems

New Zealand's history of isolation makes its ecosystems very susceptible to invasion and biosecurity catastrophe. Conversely though, such isolation has also resulted in relatively few of the notorious pests and diseases that occur elsewhere; at least so far.

Typical of island ecology, New Zealand supports unique terrestrial and aquatic ecosystems. These include the fragile remnants of ancient indigenous habitats that evolved for 80 million years before the arrival of humans a mere 1000 years ago. Today these remnants are often juxtapositioned with what are now the extensive areas of heavily-modified, economically-vital 'productive ecosystems'. Notably, the latter comprise partial transplants of agricultural ecosystems evolved elsewhere. Such areas are very species-poor (e.g. ryegrass clover pasture or apple orchards) and, without proper pest management regimes, have the potential to maintain enormous numbers of exotic pest species. The preservation and protection of both the productive and indigenous ecosystems are essential to New Zealand's future.

Glossary	
Biological control	Reduction of a pest population by utilising a natural enemy of the target organism such as a predator, parasite or disease
Endemic	Description of a species that is unique to a particular geographical location
Endophyte	An organism (often a fungus) that lives within a plant without having a detrimental effect on its host and confers adaptive advantage such as insect resistance
Exotic	Description of a species that has been introduced to a new geographic location, often as a result of human activity
Guild	A group of species that exploit the same class of environmental resources in a similar way.
Indigenous (or native)	Description of a species (or ecosystem) that is present in a particular location as a result of natural processes
Invasive species	A colonising non-indigenous species that can actually or potentially have adverse effects on ecosystems
Niche	The set of environmental conditions to which a species is best adapted

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Parasitoid	A parasitic insect species that develops on, and eventually kills, another insect species
Pheromone	A chemical released by an organism that causes a specific reaction in another organism of the same species – such as attracting a mate
Phytosanitary control	Plant quarantine procedures intended to prevent the introduction and/or spread of pest species
Vector	An intermediate host for a parasite or pathogen
Zoonosis	An infectious disease of animals that can be transmitted to humans

More generally, there is a very large (and often complicated) theoretical literature on why island ecologies are so susceptible to invasion by exotic species. In essence though, these isolated ecologies comprise species that have well adapted to the local ecosystems, and as such are not necessarily well able to withstand challenges from exotic plants and animals that have evolved in broader and more exposed ecosystems elsewhere. Thus, in evolutionary terms, New Zealand, being the 'last bus stop on the planet', has only just begun to receive appreciable numbers of invasive plants and animals, including humans. Furthermore, as in other island populations, those terrestrial vertebrate species that did make it to New Zealand relatively early on (birds mainly), have adapted to fill the niches usually occupied elsewhere by mammals. This has resulted in an exceptionally large number of vulnerable, flightless endemic bird species.

Therefore, since the arrival of humans with their various mammals, there has been a very lop-sided contest between these often flightless birds and carnivores such as rats, cats, dogs and weasels. But this dismal contest is actually merely a subset of the sort of events that have been going on at all levels throughout New Zealand's ecosystems. Examples include the spread of gorse, displacing native plant species, and the impacts of exotic insect-killing parasitoid wasps on endemic insect populations. The last example is interesting inasmuch that it is less obvious than the loss of bird species or gorse ingress, but still can have immense implications for ecosystem function and biodiversity.

New Zealand's marine and coastal biotas are also under increasing threat from invasive plants and animals. Over 160 alien species are present in this country's marine environments, although this is almost certainly a gross underestimate. International shipping continues to bring exotic plants and animals into New Zealand waters at an increasing rate, in ballast water and as biofouling attached to vessels' hulls. The impacts of these species on the biodiversity and function of New Zealand's marine environments remain largely unquantified.

The economy and biosecurity

Sustainable primary industries are critical to New Zealand's economic well-being and in fact, in recent years, they have increased in their importance to New Zealand's economy. The

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land-based primary industries now contribute about 63% of New Zealand's merchandise exports. In spite of such critical importance, these industries remain precariously dependent upon a very small group of economically vital exotic species (e.g. ryegrass, apples, grapes, kiwifruit, *Pinus radiata*, sheep and cows) now each confined to a very narrow genetic base. Many of these plants and animals were introduced at the time of European settlement during the 1800s. These species often arrived without their complements of pests and diseases results from the slow 19th century sea voyages; simply because in many cases the pests and diseases did not last the distance.

Other industries and environments face similarly critical biosecurity threats. For example, potential impact of the invasive freshwater alga *Didymosphenia geminata* ('didymo') on municipal, industrial and agricultural water intakes, municipal drinking water, commercial eel fisheries, recreation and tourism in New Zealand has been estimated to be between $39.5 million and $230.3 million over the period 2004-2012.

Aquaculture has recently grown to become a significant primary industry in New Zealand, with an estimated current value of more than $360 million per annum. Plans for its development would see it diversify and grow to produce $1 billion of sales by 2025. Aquaculture is both affected by alien marine pests and is a potential exacerbator of marine pest impacts. Marine farm structures act as 'reservoirs' for alien fouling pests, such as the kelp *Undaria pinnatifida* and the sea-squirts *Styela clava*, *Ciona intestinalis* and *Didemnum vexillum*, while coastal movement of aquaculture equipment, stock and vessels contribute to their spread.

New Zealand's fin-fish aquaculture (largely king salmon, *Oncorhynchus tshawytscha*, culture) is relatively free of the major pests and diseases that have ravaged the industry in other parts of the globe. New Zealand salmon commands premium export prices because, unlike their international competitors, New Zealand farmers currently have no need to use antibiotics, growth promotants or vaccines in their husbandry.

As mentioned above, species-paucity in the production systems result in extreme vulnerability to invasion by exotic species. When invasive plants and animals reach New Zealand they almost inevitably encounter a year-round supply of sometimes thousands of hectares of highly suitable food plants. Further, these crop and pasture ecosystems, full of unfilled niches, are invariably lacking in effective natural enemies and competing species. This means that invaders can establish, thrive and build up to devastating populations far greater than those ever found in their original ecosystems. Obviously the effects can be devastating with the pest populations sometimes being regulated only by the dwindling supply of suitable host plant material. Indeed, exotic plants and animals that are often of merely taxonomic interest elsewhere can become major and persistent pest problems in New Zealand. One example of this is the clover root weevil which in New Zealand has reached populations ten times greater than those found in their centres of origin. A larger

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and more obvious example is possums, which create far more havoc in New Zealand than in Australia where tree species have become resistant to their effects and suppress their rate of population growth. In contrast to the situation with invasive exotic insect pest species, only a few New Zealand native insects, such as grass grub and porina, have switched their attention to introduced agricultural plants and can be considered pests.

Pasture pest arrivals have included the Argentine stem weevil, black beetle, *Sitona* (lucerne) weevil, soldier fly, Tasmanian grass grub, white-fringed weevil, clover root weevil and molluscs. Of the gut worms affecting sheep and cows, root knot, cyst and lesion nematodes have been serious problems. More recently, New Zealand's forage production has been undermined by the establishment and spread of the *Varroa* mite; this bee-attacking species affects pollination and vigour in many economically important plant species including white clover. Currently there also remains concern about bee Colony Collapse Disorder (CCD). This little-understood international phenomenon has now been found in New Zealand; worker bees from a beehive suddenly disappear. The cause of these catastrophic collapses have yet to be determined, although there is some suspicion that it may be associated with *Varroa* mite transmission of a virus. Irrespective, CCD has major pollination implications for New Zealand's all-important primary industries.

Pest and weed outlook

There is clearly an abiding need to keep future invasive species out of New Zealand through effective biosecurity. It is important to note that when a new species establishes in the New Zealand pastoral ecosystem there is no quick fix. The relatively low value per hectare of pasture, the ability to tolerate cosmetic damage (the animals do not care what the forage looks like) and the environmental disruption caused by extensive use of pesticide mean that the options for pest management rely on the combination of plant resistance and biological control. At best, the development of such 'integrated pest management' solutions is slow and expensive and regrettably, often the ecosystem is never restored to what it was before a pest's arrival. The aggregate and corrosive effect of guilds of pests and weeds can only reduce the competiveness of New Zealand's agriculture, irrespective of the quality of pest management strategies.

In marine environments there are few tools currently available to manage the impacts of invasive species. The environmental concerns regarding the use of synthetic pesticides or biological control in aquatic environments limit eradication and control options to relatively inefficient physical removal of only the smallest of infestations. Management is focussed principally on stemming the rate of ingress by new alien species, through treatment of ballast water and fouling on international vessels, but there continue to be new, intransigent arrivals that have potential for large economic and environmental impacts.

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There is no doubt that there are many other alien species that could become major pests and are continuously testing New Zealand's border biosecurity. For example, it is known that there are at least 100 other species of *Sitona* (weevils) in Europe. Based on the impacts of the lucerne weevil (*Sitona discoideus*) and the clover root weevil (*Sitona lepidus*), in this genus alone, there is the potential for immense damage. Similarly, Abalone Viral Ganglioneuritis, a disease that has devastated wild and farmed populations of abalone in Victoria, Australia, would create tremendous economic and cultural damage if it were to infect paua.

Sophisticated analytical techniques can be used to conduct extensive analyses of very large international insect databases. Using the assemblages and global co-occurrence of insects known to occur in New Zealand and elsewhere, this work highlights the types and groups of pests that are well capable of invading New Zealand. This approach is proving useful to operational agencies such as MAFBNZ inasmuch that it helps to indicate where surveillance efforts may be most usefully concentrated. But in the context of complex and often unexpected ecological and eco-climatic responses, choosing any one species over another as a potential pest continues to be problematic as it is difficult to gain consensus.

Irrespective, assessments are ultimately reliant on the existence of data on the global distribution and threats posed by particular species or their functional relatives. The study of aquatic invasions is a relatively young scientific endeavour, with less than two decades of experience. In general, there is a paucity of basic knowledge about marine pests worldwide and a lack of tools to predict their entry, establishment and impacts in New Zealand and elsewhere.

The intensification of biosecurity threats

Coinciding with the ever-present threat of invasion by exotic species, a number of other developments are making it progressively more imperative that New Zealand's biosecurity system maintains and progresses its effectiveness. There are several exacerbating factors.

- The inexorable growth of production on New Zealand farms (e.g. dairy conversions) is making its pastoral ecosystems ever more vulnerable to pest damage. Overall, as farming systems move towards their technical limits, they become more easily disrupted. As a result, what once may have been regarded as minor pest species can now cause disproportionate damage in such fine-tuned systems. Compounding stresses may include maladaptation of pasture species and cultivars to rapid change (e.g. drought onset).
- The ongoing broadening of trade presents its own threats. New partners and ports are located in a wider range of ecosystems and this presents new sites of origin for additional pest and disease threats. Furthermore, new trading partners may not be fully aware of the need for careful phytosanitary compliance. These developments are now

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undoubtedly being compounded with the appearance of free-trade agreements combined with the speed at which increasing volumes of freight can be transported. This applies equally to both sea and air transport and travel.

- Climate change is now a major consideration and is very likely to make issues around biosecurity worse. This is likely to occur in a number of ways:
  - As a result of climate warming, new invasive species are likely to threaten New Zealand more often. In terms of the pastoral sector, such new and/or higher propagule pressure at the border presents increased threats to both pasture plant and animal species. Similarly, warming will lead to the growth of threats of animal disease epidemics and possibly animal-borne diseases affecting animals or humans transmitted via subtropical vector species such as mosquitoes, ticks and midges.
  - As well as increasing the diversity of pests in New Zealand, global warming will lead to an increase in the distribution of pests that establish in this country. For example, tropical grass webworm has been recorded as entering New Zealand on numerous occasions during the last century, but has only consistently caused major problems in Northland since 1999. Black beetle is slowly spreading south along coastal margins into Hawkes Bay and the Manawatu, while Tasmanian grass grub has continued to occupy new areas on free draining soils in the northern North Island (e.g. Hawkes Bay, Waikato, Bay of Plenty, South Auckland) in the last decade. Similarly, increasing temperatures will see the ongoing southward movement of sub-tropical grasses and other warm-zone plant species. Such conditions will also encourage warm-zone garden plants to become naturalised (called sleeper weeds) and result in new invasive weed species.
  - With climate change it is quite possible that there will also be an uncoupling of biological control suppression through the interruption of co-ordination of the pest's and control agent's generations. There are numerous pest, weed and disease species that are suppressed by guilds of control factors (e.g. Argentine stem weevil suppression by parasitoids and endophyte-induced plant resistance, grass grub by soil-borne complexes of micro-organisms) The functioning of these systems is not well understood, but should they fail, the ensuing pest impacts could be severe. Similarly, 'sleeper' pest species (diseases, weeds or invertebrates) could emerge through more rapid heat accumulation or loss of frosts.

The response to newly-established ineradicable pests

As a generality, pest invasions of productive ecosystems cause economic impacts and disruption that are more than additive. Frequently, newly required management for an invasive species compounds with, and disrupts, existing control measures developed for an already-established pest complex. For example, the use of pesticides (synthetic or pathogen-based) can destroy established biocontrol systems based on parasitoids. Alternatively, the need to cultivate frequently (e.g. for weed control) can set back the build up of soil bacteria which help to suppress grass grub populations. Whatever the impacts and interactions, any

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new pest outbreak requires expensive, in-depth research that usually ends up with a pest management system more complex and disruptive than that which preceded it.

Biosecurity and planning

Biosecurity threats to New Zealand continue to mount and there has been growing public awareness of their importance. The role of MAFBNZ to lead the country's biosecurity system has been greatly clarified and organisational progress has been made. For example, in 2007 the MAF Quarantine Service was integrated into MAFBNZ and there have been various other significant internal realignments. In 2009, there were substantial changes to the import health standard for sea containers and a great deal of work has been done on exactly how to systematically prioritise responses to biosecurity challenges. At the same time, there has been the ongoing development of several strategies: *Tiakina Aotearoa Protect New Zealand – The Biosecurity Strategy for New Zealand*, a *Biosecurity Science Strategy for New Zealand – Mahere Rautaki Putaiao Whakamaru* (2007) and a *Biosecurity Surveillance Strategy 2020* (2009). Public accountability for this sort of work has been via several well-attended and more-or-less public 'Biosecurity Summits'.

With this, good progress has been made from an organisational and process point of view. Examples include the use of electronic data and record keeping, attempts to develop data conformity/interchangeability, improved clarity of lines of responsibility, the development of decision-making frameworks and increased collaboration with other agencies such as Customs. However, this is not enough. Reorganisation and streamlining of existing processes can only offer so much.

The integral role of science and technology in seeking improved biosecurity

In order for the quality of New Zealand's biosecurity to continue to improve, science and technology simply must be brought to bear. In the most general of terms this calls for advances in areas such as:

- advanced techniques and technologies for improved surveillance, unwanted organism interception (e.g. sensor technology, pheromonal traps) and ways of speeding up threat identification and origin (often based on forensic technologies such as the use of DNA or isotopes – see the boxes).
- increasingly sophisticated statistical and modelling techniques based on large data sets of mixed origin with which to assess risk. Such work must be based on sound ecological understanding of types of organisms and their likely behaviours and impacts on New Zealand's very unusual ecosystems.
- more socially-acceptable ways of fumigating, containing and eradicating new pests and diseases when they occur.

This need for such scientific input is greatly accentuated by the numerous biosecurity decisions that have to be made under extreme time constraints and usually with incomplete

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information. Neither can New Zealand wait for off-the-peg solutions from overseas. This country's need is almost unique.

Example 1: Diagnostic DNA barcoding

"Imagine a world in which you can know the name of any animal, any plant, any fungus, any organism – on the spot, in an instant, anywhere on our planet." This is the vision of the international Barcode of Life (iBOL) community which aims to use the DNA sequence of a single gene region common to all organisms as a species identifier. For animals this is a mitochondrial gene, cytochrome oxidase I (COI). Technologically this is not dissimilar to the DNA fingerprint used for individual humans, or conceptually, to the use of commodity barcodes. However, it operates in a completely different environment in that there is no single 'fingerprint' or 'barcode' for a species which is represented by a population of biologically/taxonomically-like individuals. There are nevertheless observable and statistically-supported patterns where DNA sequences for individuals of a species are measurably more alike that those of different species.

New Zealand has led the way in adapting this concept for the identification of known high-risk species, using a robustly developed custom built public database of threat species DNA sequences. This is operational for fruit flies and tussock moths, whose poorly differentiated immature life stages are commonly intercepted at the border. Additional similar datasets are now being constructed for other pests, and interestingly not just for border interceptions. Applications now include uses that enable pest species monitoring, offering value at all levels from risk analysis to surveillance to eradication and pest management. Such methodology also makes it possible to distinguish between known closely-related species, therefore enabling the otherwise problematical development of species-specific sex-attractant based surveillance technology or methods such as the sterile insect technique for pest eradication and management.

Further advances for biosecurity will come through iBOL's intent to fabricate a hand-held 'DNA barcoder' and make on-the-spot species identification accessible to anyone, including front-line quarantine officers. The DNA extraction, microfluidic and sequencing nanotechnology and informatic componentry are already available, but require integration and in some cases miniaturization. Partnership between private sector firms and academic researchers is therefore needed.

It is also important to recognise that there is not really any such thing as 'biosecurity science'. Rather, successful biosecurity is an end in itself and can only be supported by a truly integrated range of scientific disciplines. Over the last 5-10 years significant progress has been made in creating an environment that fosters such integrated work. This has been based on multi-organisational and multi-disciplinary approaches drawing on varied funding streams. Of the agencies conducting terrestrial research, the larger is the Better Border

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Biosecurity multi-partner cooperative science programme and the other is the Biosecurity Research Theme that is part of the overall research effort being made at the Bio-Protection Research Centre based at Lincoln University. In the case of the Better Border Biosecurity programme, the Foundation for Research, Science and Technology (FRST) must be acknowledged for its effort in bringing together what were once disparate strands of research. In the marine sector, the Effective Management of Marine Biodiversity and Biosecurity programme, funded by FRST, aims to develop new knowledge and tools for risk assessment, surveillance, and incursion response to marine pests. Other science programmes are focused on aquatic plant pests and pest fish. While such integrated funding is welcome, the science requirement for biosecurity remains vast.

Example 2: Profiling natural abundance trace elements to determine the origin of an exotic pest

Attempting to eradicate high-risk pests detected within the country is an expensive exercise, both socially and economically. Prominent examples have included the forestry pests painted apple moth ($62.4 million in 1999-2005), Asian gypsy moth ($12.4 million in 2003) and fall webworm ($6.7 million in 1999-2005). Unfortunately, these operations were undermined by the discovery of further individuals of the same species after the main eradication exercise had finished, raising the question of whether the finds represented a remnant of the original population or were part of a new and unrelated incursion. These two scenarios have quite different implications, both for judging the effectiveness of the original eradication strategy and for the scale and design of a further response.

In the past, it has been impossible to determine whether a pest has just arrived or has been established for more than one generation. A new approach using the natural abundance of trace elements and their isotopes is showing promise. The principle, simply put, is that 'you are what you eat'. Different geological locations vary in their trace element and isotopic profiles. These profiles are subsequently reflected in the chemical composition of the plants that grow in those locations (because of their uptake of soil nutrients) and then in the composition of the insects that eat those plants, including through to the final non-feeding adult life stages. Using such profiles to track the origin of biological material has been applied in police forensics and food authentication and in studies of animal migration and groundwater contamination. In biosecurity, there is the potential to pinpoint the geographic location where an insect developed. An established population would be expected to have a 'New Zealand' profile, whereas a newly arrived specimen would have a different profile.

Prompted by the painted apple moth incursion, MAFBNZ has trialled this approach using isotopes of hydrogen (δ^2H, deuterium) and carbon ($\delta^{13}C$). However, the results were difficult to interpret, not least because of the very rudimentary understanding of elemental and isotopic variation across New Zealand, in particular ^2H in rainfall. Consequently, a joint project between MAFBNZ and the Department of Conservation to develop a ^2H rainwater

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map of New Zealand is now underway. This also has the interest of a number of other agencies with enforcement roles, including the Food Safety Authority, Police and Customs. In addition, instead of relying on just δ^2H and $\delta^{13}C$, use of multiple trace elements and isotopes allows greater geographic resolution, particularly since new methodology now enables a large number of elements to be concurrently measured in a single insect. Using this method and the tomato bud worm as a model pest species, we have been able to discriminate insect origins within and between New Zealand and eastern Australia, a significant advance on previous ability. We now need to obtain good elemental and isotopic data for other countries from which there is a high risk of pest incursions. In time, we expect this technique to add significant power to an integrative evidence-based approach to exotic pest incursions, including the use of DNA to determine population relatedness.

This highlights the need for the New Zealand science community to work together and have ways of collaborating across disciplines and institutes.

Challenges ahead

Irrespective of progress to date, very big scientific challenges remain for New Zealand biosecurity and its peculiar ecosystems. For example, how best to conduct useful audits of compliance in the face of the huge volumes of freight and passengers streaming into the country? With this will come the need to test and evaluate new technologies: otherwise, progress will be stymied. Thus, research and its subsequent operational uptake are best conducted in a spirit of partnership. In general, science for biosecurity should be driven by the very understandable challenges encountered in the system; such issues must be mutually identified and the required research agreed to. That said, there has to be recognition that biosecurity operational requirements are likely to demand shorter time-horizons than more fundamental investigation. Recognition and accommodation of all these components has increased in recent years.

Finally, a perennial biosecurity challenge for all continues to lurk, particularly in times of economic downturn. That is, how to maintain government and public commitment during biosecurity 'quiet' times when the biosecurity system is not being driven by crisis.

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