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Plant Biosecurity Science in New Zealand

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Gaps in capability and capacity to avoid or mitigate serious pest and pathogen incursions

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Cover photo: Manuka under the microscope.

Foreword

by Richard Gordon, CEO, Manaaki Whenua – Landcare Research

As the world scrambled in mid-2020 to respond to the COVID-19 outbreak, an obvious question to ask was: did we have the capability ready to deal with this new threat? In the fields of biodiversity and biosecurity research in Aotearoa New Zealand – given our recent experience of incursions of Psa in kiwifruit, kauri dieback and myrtle rust disease – the same question needs to be answered: do we have the research capability to help to avoid the next big pest or pathogen threat to our productive and indigenous plant systems?

Asking colleagues in my own and other organisations I received the answer 'Probably not'. So, to meet the need for evidence and guidance I commissioned this report, with significant support from David Hughes at Plant & Food Research, Penny Nelson at MPI, and others in this field.[1] Bill Dyck and Graham Hickling between them bring great experience of NZ's productive and indigenous plant systems, pest and disease epidemiology, and biosecurity. Their report presents a survey and analysis of opinions from professionals across plant biosecurity science in New Zealand, with considerable efforts made to cross-check opinions to ensure they were reasonable. The report presents a clear message that although we have a world-class biosecurity system in Aotearoa New Zealand, there are gaps in our biosecurity research, science and technology capabilities that need to be filled to support that system.

This report is a starting point and additional work is needed. The report focuses on our western science capabilities; but it is not enough to consider how western science addresses the issue. I would like to see an equivalent survey of capabilities to conduct appropriate Māori-led and Kaupapa Māori research to meet Aotearoa's needs and Māori aspirations for plant biosecurity. There are organisations who can conduct this survey with authenticity.

Biosecurity research is especially challenging. Some of the necessary research is directed at estimating and prioritising the risks of incursions that have not yet happened, and some is directed at dealing with the problem when it does happen. Yet more research is aimed at long-term attempts to manage well-established problems. Aotearoa New Zealand has cases where we invested and benefited from research: the skills existed and the work was done in advance to minimise the damage. We also have examples of the opposite, where we did not invest and have suffered the consequences. This report draws lessons from both scenarios.

The report identifies potential gaps in research capability and in the necessary research investment. The report does not seek to assess existing research strategies or programmes, many of which are well-established and delivering great value. Organisations are not to be blamed for gaps, which are usually the result of investment priorities and availability of skills in a complex science system. However, with the information now to hand we can and must manage these gaps. I intend that key stakeholders will work together to ensure that research investment is applied to cover the high priority capability gaps and address the barriers that have prevented this from happening before now. Perverse outcomes must be avoided, such as creating a new gap by shifting resources from one area to another.

I thank the authors for putting aside other responsibilities to undertake this work since May 2020, when the COVID-19 pandemic not only made their work harder but also made it more timely. I also thank the more than 90 people who gave their own time to be interviewed or respond to queries, and without whose expertise the report would not have been possible.

Summary

This review of plant biosecurity scientific capability and capacity was undertaken to answer the following question: 'Does New Zealand (NZ) have the right science capability and infrastructure to avoid or mitigate the next serious biological incursion that would threaten NZ plants, either productive or natural?' NZ has experienced damaging incursions in the past, and we must anticipate, prioritise and prepare for more of these in the future.

We did not attempt to review the entire plant biosecurity system. Rather, this review focuses on scientific capability directed at avoiding or mitigating impacts of invertebrate pests and pathogens of plants. We have not highlighted the many areas where we assess NZ's scientific capability and capacity in this area to be strong or adequate – this report focuses on the gaps.
The reviewers interviewed or corresponded with over 90 biosecurity scientists and science managers and analysed relevant background documents. We conclude that the answer to the question posed is a qualified 'No' (Fig. 1). In certain sectors, NZ's biosecurity science capability and capacity are weak. Even in the many areas of strength there are specific gaps that could expose NZ in the event of a serious incursion.

Within each sector there are areas of strong capability as well as weaknesses. This review focuses on key science capability gaps; these are listed on the following pages, grouped by topic area.

Relative biosecurity science capability by sector

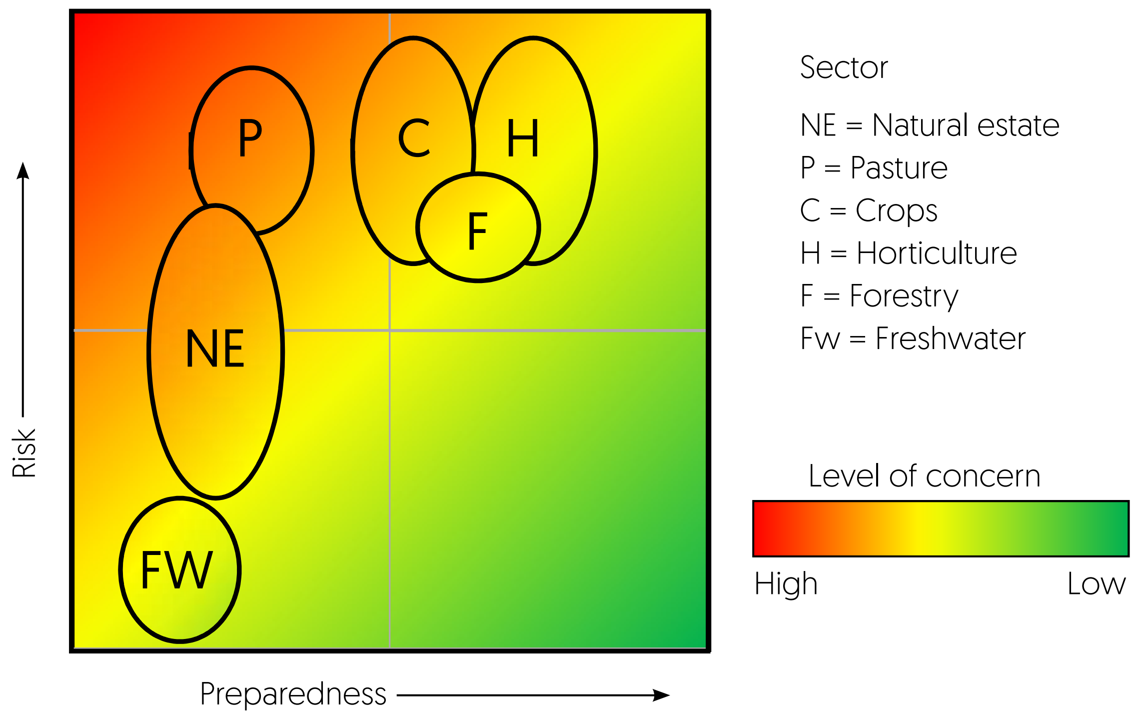


Figure 1. Level of concern about biosecurity science capability in each of the sectors reviewed, based on the perceived risk of incursion by plant pests and pathogens versus the sector's level of science preparedness to avoid or mitigate such incursions. Risk and preparedness were scored subjectively, based on comments received during the interview process plus more than 25 years of biosecurity experience for the senior reviewer. Variation in ellipse height is driven primarily by the diversity of plant species at risk within each sector. Natural freshwater plant communities appear to be at risk primarily from exotic weed and algae incursions, rather than from insect pests and pathogens.

Plant biosecurity taxonomy and bioinformatics

Taxonomy, databases and collections are the backbone of any biosecurity system. If we do not know what an organism is, or whether it is already present in the country, then our ability to recognise incursions of damaging pests or pathogens is compromised.

Key points

- **The Ministry of Business, Innovation and Employment (MBIE) review of collections and databases needs to be completed.**
- **Skilled taxonomists are retiring, and it is difficult to train and recruit in this area.**
- **More taxonomists skilled in a blend of traditional and molecular techniques are needed.**
- **Bioinformatics skills are needed, but the demand here is not unique to plant biosecurity science and so capability could be shared.**

Pastoral agriculture plant biosecurity science

Pastoral plant biosecurity science was identified as one of the most serious capability and capacity gaps. This concern was shared by numerous interviewees.

Key points

- **Pastoral plant biosecurity science capability is very weak, with no plant pathologists, few (mostly late-career) entomologists and nematologists specialising in this research area, and little opportunity for successional planning.**
- **Risks to NZ from emerging pasture pathogens do not appear to have been adequately assessed. This was of concern to some respondents, who felt there could be gaps in NZ's biosecurity system that put our pastures at risk of pathogen incursions.**
- **There is very limited funding available for pastoral plant biosecurity science from either government or industry.**
- **There is a lack of experienced generalists who can address, or even appreciate, the bigger picture of biosecurity at the level of pasture systems.**

Natural estate plant biosecurity science

Natural estate plant biosecurity is highly challenging because of the huge species diversity and large areas that are at risk of incursion. NZ has excellent dedicated scientists in this area, but their efforts clearly are under-resourced.

Key points

- **There is inadequate funding for the scientific capability and capacity needed to understand endemic pathogen–host interactions in our natural estate. We currently have limited information on the endemic fungi, bacteria, viruses and *Phytophthora* in natural areas, which weakens our capability to recognise new incursions.**
- **There is very limited capability and capacity to predict the impact of exotic pathogens (and, to a lesser extent, exotic insects) on our natural estate. *Phytophthora* spp., the bacterium *Xyella fastidosa*, and the fungi *Ceratocystis lukuohia* and *C. huliohia* are examples that pose unknown, but potentially serious, threats to our natural ecosystems as well as to our productive sectors. There are almost certainly other threats that are currently 'unknown unknowns'.**
- **Scientific contributions to plant biosecurity surveillance across our natural estate are currently relatively weak, although NZ does benefit from trans-Tasman collaboration through the Centre of Excellence for Biosecurity Risk Analysis (CEBRA) in Australia.**
- **NZ lacks capacity to assess the social and cultural impacts of a serious natural ecosystem incursion.**
- **The Department of Conservation (DOC) and the Ministry for Primary Industries (MPI) have limited capability and capacity in terrestrial plant biosecurity science in the natural estate and are currently very occupied with kauri dieback and myrtle rust disease.**

Freshwater plant biosecurity science

The review team was unable to identify any scientists focused on the pest and pathogen components of freshwater plant biosecurity. Researchers in this area concentrate on invasive aquatic macrophytes and nuisance algae.

Key points

- **NZ appears to have minimal plant biosecurity capability in the freshwater plant area, other than for invasive aquatic macrophytes and algae.**
- **The significance of this gap is unclear, as the risk that exotic pests and pathogens pose to our freshwater aquatic plants may be relatively low.**

Resistance and resilience for plant production systems and natural ecosystems

Plant resistance science focuses on plant selection and breeding, manipulating the microbiome of the plant and the ecosystem, and to some extent gene modification and editing, to make crops and natural ecosystems resistant to or more tolerant of invading pests and pathogens.

Key points

- **Future pest and pathogen incursions are inevitable, and it is unrealistic to expect to find a magic bullet solution for every problem species. More scientific capacity is needed to develop plant and ecosystem resilience to incursions, especially for commercial crops that have a narrow genetic base.**
- **There is an increasing need to screen plant varieties for resistance against biosecurity threats not currently in NZ. Some of this research and capability sit offshore, depending on the sector and where the relevant germplasm resources are located.**
- **NZ researchers face barriers to importing resistant cultivars and germplasm (e.g. Environmental Protection Authority restrictions and quarantine facility bottlenecks).**
- **This research area will require long-term funding if it is to succeed.**

Risk assessment and prioritisation

Effective biosecurity risk assessment and prioritisation are required to determine how much effort should be spent understanding a particular threat and developing the tools and processes to mitigate risk.

Key points

- **Inadequate risk assessment capacity in MPI may have limited the investigation of emerging risks and the development of import health standards in the past. However there has recently been a significant uplift in additional technical capacity in risk assessment (including emerging risk assessment) and Import Health Standards development. A Biosecurity Intelligence Team was also established to monitor drivers of biosecurity threats and provide early warning of changes in threats and threat forecasts.**
- **The Hazardous Substances and New Organisms Act 1996 (HSNO), as currently implemented, is a significant barrier to scientists rapidly responding to major plant biosecurity incursions.**
- **In contrast to the productive sectors, there does not appear to be funding to support tracking the emergence overseas of exotic organisms that could pose new risks to our natural estate.**
- **Biosecurity risk assessment requires assessing the social, cultural and environmental significance of a threat, as well as the potential economic impacts. Current capability appears to be weak in all three areas.**
- **More formalised networks of national and international collaboration would be useful to industry for better understanding high-risk biosecurity organisms.**
- **There are specific gaps in the science on particular groups of insects and pathogens, which need to be addressed. To some extent these can be covered by international collaboration, but ideally NZ should have its own capability in key areas.**
- **NZ lacks capacity in biosecurity surveillance science. However, there is recognition that we have a strong involvement with CEBRA that helps to address this gap.**

Biosecurity detection technology and control tool development

NZ has innovative scientific and technical capability in computing, machine learning and sensor engineering that can be applied to biosecurity. Regulations and public attitudes are progressively narrowing the use of existing pesticides. Organic agriculture requires new control tools.

Key points

- **There are capability gaps in bridging our (incomplete) biological knowledge of unwanted organisms and the emerging capabilities of engineering/computing technology.**
- **In the context of control tools, there are significant biological knowledge gaps for species not yet in NZ but considered high risk for incursion. There is a need for greater scientific capability to address these gaps.**
- **There are capability gaps in the research extension pathways needed to facilitate the adoption of new technologies by end users.**
- **Alternative pest control methods are needed as regulations tighten and some existing tools are phased out. NZ, being a tiny market for such tools, needs to choose its research targets very carefully.**
- **NZ's pesticide science capabilities lie primarily in the private sector, so access to a 'neutral voice' on pesticide application is an emerging gap.**

Biosecurity coordinators and leaders

Biosecurity responses require coordinators and leaders to be effective. These are not gaps in plant biosecurity science provision per se, but rather skill gaps in the organisations that need to hire staff who understand biosecurity science.

Key points

- **Biosecurity science leaders and coordinators are in short supply. Such skills are especially important in the event of a serious incursion, as teams capable of a 'surge' response will need to be assembled rapidly.**
- **Science leaders are needed in some research fields to build and lead biosecurity-focused science teams.**
- **Biosecurity NZ, a part of MPI, is currently short-staffed in plant science capacity and requires experienced scientists who can work with industry to develop response plans and identify research needs.**

University training and the need for 'system-level' generalists

A recurring theme from our interviewees was that plant biosecurity science has increasingly become the domain of discipline specialists, so that NZ is now lacking scientists with a strong understanding of how to achieve biosecurity at the 'system' level. There is a need for generalists who are experienced at seeing the bigger picture, especially when working across stakeholder/regulator boundaries.

Key points

- **Despite a demand for biosecurity generalists in industry and government, there is a lack of biosecurity generalist training in universities. It has been suggested, and supported by most interviewees, that offering a Master's degree in plant biosecurity would be very useful.**
- **There are systemic reasons why biosecurity generalists are not being produced by universities. For example, MBIE science funding policy and selection criteria have made it difficult for Crown Research Institutes (CRIs) to offer career paths in biosecurity science.**
- **There is a shortage of specialised skill training in some specific areas, including plant epidemiology and pasture pathology.**
- **There is a need for a *Phytophthora* expert at a NZ university.**
- **Two promising international models for university training are the AgriBio university department in Australia and the Forestry and Agricultural Biotechnology Institute (FABI) in South Africa.**

Social science

Most biosecurity managers interviewed highlighted the growing importance of social science research to help increase public awareness of biosecurity risks and to help ensure social licence for management actions.

Key point

- **There are gaps in the range of social science currently being undertaken, but it is not clear whether these are gaps in capability or a lack of focus (and funding).**

Funding – research and infrastructure

There are funding gaps in plant biosecurity science, reflecting in part the larger drivers of biosecurity awareness and science funding strategy in recent years.

Key points

- Plant biosecurity science funding is at reasonable levels in horticulture, forestry, and arable crops, but is low to very low in pastoral agriculture and in the natural estate. There is concern about recent declines in funding support for forestry biosecurity science.
- Given the diversity of horticulture species that are vulnerable to biosecurity incursions, the available investment needs to be stretched in many different directions and whether or not the investment available is reasonable is yet to be determined. Meanwhile, agility and flexibility of scientists able to work across multiple crops and pest/disease systems helps to maintain science capacity.
- There is a need for a national plant biosecurity strategy with clear priorities for the country and identified mechanisms to secure funding from the industry sectors that would benefit. The Government Industry Agreement (GIA) mechanism is meant to do this, but GIA partnerships have been uneven in the extent to which they have funded proactive 'readiness' research.
- Some industries are much less willing than others to fund plant biosecurity science through commodity levies or a Biosecurity Act levy.
- CRIs struggle to secure MBIE funding for applied biosecurity science, despite (in some cases) submitting bids that receive excellent ratings.
- Funding for biosecurity research on the natural estate is in a more precarious situation than in the production sectors, in part because no GIA-type mechanism is available to help leverage government funding. As shown by recent serious pathogen incursions, there is relatively little science funding and readiness to proactively protect even the country's most iconic plant species.

Predictive spread modelling

Predictive modelling of pest and pathogen spread underpins the development of cost-effective surveillance systems for the early detection of unwanted organisms and is needed to predict spread and impacts in the event of an incursion.

Key points

- NZ animal biosecurity is well supplied with outbreak modellers, whereas the plant sector currently relies on a smaller number of key individuals.
- Plant sector modellers use a smaller range of epidemiological approaches than their animal sector counterparts.
- NZ needs more risk modellers to help develop surveillance systems and to model outbreaks in the event of an incursion.
- There is a need to better understand and predict the impacts of climate change on biosecurity risk.
- Capability to incorporate social/cultural components of risk and impact into predictive models is underdeveloped.

Recommendations

- As a next step, the reviewers recommend that a compendium of existing biosecurity-relevant science skills, by discipline, be compiled for all relevant science providers. The compendium should include the identification of plant-systems-level generalists.
- There is also a need for an infrastructure database to identify current strengths and gaps in NZ's key biosecurity scientific equipment and facilities.
- These two compendiums would assist with proactive planning for future serious incursions, including better clarification of the role each science organisation would be expected to play in such an event.
- The reviewers recommend a survey of foundational teaching in general plant biology at university level, and of core subjects available for biosecurity-oriented Masters/PhD students, with a view to identifying teaching gaps and opportunities for subject expansion.
- While recognising that Better Border Biosecurity (B3) is an excellent model, there is a need for improved biosecurity science networks, including international collaborators, that are accessible by industry as well as by government and scientists.

Introduction

The recently published *Australia's Biosecurity Future* report[3] identified five biosecurity 'megatrends' that will increase biosecurity risk to Australia, along with 12 'megashocks' facing the country in the next two to three decades. The report makes 20 recommendations, including a national surveillance programme and long-term investment from government in new technologies and data systems. NZ faces similar threats as our economy is heavily dependent on a sound biosecurity system.

Biosecurity can be defined as 'the exclusion, eradication or management of pests and pathogens that pose a risk to the economy, environment, cultural and social values, and human health'[4]. In NZ, biosecurity is implemented through a risk management system that involves many participants. The system spans activities offshore, at the border, and within NZ (see Appendix 1). In 2016 the Government released NZ's *Biosecurity 2025 Direction Statement*. This statement is a high-level road map for how NZ might update its biosecurity system through to 2025 and beyond. It complements a range of other biosecurity strategies – or at least aspirational aims and objectives – developed by groups such as the National Science Challenge, the Bio-Protection CoRE, B3, Government Industry Agreements (GIAs), MPI, and primary-sector industries.

To be effective, our biosecurity response must be built on a foundation of innovative, up-to-date science. This is acknowledged within the strategies described above, albeit at a relatively high level. The strategies do not assess NZ's capability to address the research needs they identify, so an assessment of capability is needed to better prepare NZ for future biosecurity challenges. The strategies also do not identify a funding mechanism to support the research needs identified – this funding gap is commented on briefly in the 'Review findings' section below.

In mid-2020 the review team was asked to prepare a preliminary review of NZ's *plant biosecurity scientific capability and capacity*. By focusing on plant biosecurity, the intention was to begin addressing an important aspect of NZ biosecurity science while ensuring the scope of the review did not become unmanageable over a short timeframe. While NZ certainly has broad capability in plant biosecurity science, there has been unease that capability (and capacity) is not uniformly available across all primary sectors and does not fully encompass the many biosecurity issues associated with the conservation estate, including freshwater ecosystems. It seemed timely, therefore, to identify gaps that may need filling, particularly those that could increase NZ's vulnerability to serious impacts from a new incursion. There are lessons to be learned from NZ's recent high-profile biosecurity incursions – such as COVID-19, myrtle rust disease (caused by the fungus *Austropuccinia psidii*), kauri dieback, *Mycoplasma bovis*, and *Pseudomonas syringae* pv. *actinidiae* (Psa) – and from similar incursions faced recently by our trading partners.

This review of plant biosecurity scientific capability and capacity was designed to answer the question 'Do we have the right research capability and infrastructure in NZ to avoid and mitigate the next big biological incursion that would threaten NZ plants, either productive or natural?' The scope of the review, and the review team's terms of reference, are summarised in the 'Methods' section. Briefly, we did not attempt to review NZ's entire plant biosecurity system: the focus was on scientific capability and how this is directed towards terrestrial and freshwater plant pests and pathogens. The report does not directly consider mātauranga Māori interests, approaches and gaps, as these topics warrant their own review.

Background

Numerous strategic documents in recent years have acknowledged the importance of science in underpinning NZ's evolving biosecurity system. Few of these, however, include specific statements on research needs in plant biosecurity science. In 2015 MPI published *MPI Science Strategy – Rautaki Putaiao*,[5] which is a high-level assessment of research needs, but it does not include detailed commentary on biosecurity science capability. MPI's *2017 Science Roadmap*[6] is similarly high level, and it highlights the importance of NZ having capability and capacity in several areas – including taxonomy, informatics, and data management – but it makes no assessment of whether current capability and capacity are adequate.

In 2016 NZ's *Biosecurity 2025 Direction Statement*[7] identified five priority areas for future efforts to improve the biosecurity system. These strategic directions (SDs) were labelled:

- SD1: A biosecurity team of 4.7 million
- SD2: A toolbox for tomorrow
- SD3: Smart free-flowing information
- SD4: Effective leadership and governance
- SD5: Tomorrow's skills and assets.

In early 2018 the plant-based sectors participated in a workshop that developed a list of plant biosecurity science priorities (but did not identify capability gaps). That document informed the SD2 Work Plan[8], which included several aspirational goals for plant biosecurity that are relevant to this capability review.

In July 2018 the SD2 Working Group drafted a document entitled *Biosecurity Research, Science and Technology Priorities.* This document is currently incomplete, and again does not address capability needs, but the draft does list priorities for NZ plant biosecurity:

- emerging and future plant biosecurity risks are anticipated, assessed, and managed
- risk pathways for priority threats are known and interventions are optimised to prevent incursions
- our surveillance, detection and diagnostics systems are smart and robust
- research, science, and technology are being used to more effectively eradicate and manage plant pests and diseases
- we have a continually improving understanding of the biology and impacts of priority plant pests and diseases
- we are increasing the resilience of natural, artificial and agricultural habitats and ecosystems to incursions
- we are future-proofing our biosecurity system by tracking and evaluating progress to make the biosecurity system smarter over time.

The SD2 Working Group proposed as a key action that an integrated Biosecurity Science Plan (BSP) be developed and communicated. It was intended that the BSP, which has yet to be written, would include an assessment of biosecurity scientific capabilities and capacity.

The SD5 Work Plan[9] (pp. 3–5) similarly emphasised the need to ensure that NZ's biosecurity system has the skills and assets needed to support an advanced data analysis function. Statements from that plan include:

> *The capability and capacity needs of [New Zealand's] biosecurity system are not well understood. This is increasingly leading to a situation where significant skill and infrastructure gaps are beginning to undermine the effectiveness of the system.*
>
> *To be effective, the biosecurity system must be supported by enough people with the right knowledge, experience and skills at every level and across every function. To ensure this, we will understand the capability needs of the system, invest in the development of the current workforce, and plan for future needs and sustainability.*
>
> *High-quality infrastructure is crucial to effective biosecurity risk management and needs to be well resourced, maintained and accessible. This infrastructure includes laboratories, taxonomic collections (and associated systematics expertise), databases, information technology systems, and policy infrastructure.*
>
> *The Royal Society of New Zealand (RSNZ) National Taxonomic Collections Report found there was inadequate and overall declining support for the national taxonomic infrastructure (research scientists, curators, collections etc.) and that the erosion in investment has resulted in the loss of national capability in specialised expertise.*

The SD5 Working Group concluded that key skills and expertise shortages are looming in several critical areas. Examples given included bioinformatics, ecology, plant pathology, entomology, taxonomy (terrestrial, freshwater and marine), and epidemiology. The group made numerous recommendations, including for increased investment in taxonomic expertise and curation. The group emphasised the need to ensure NZ's distributed network of biosecurity expertise, along with the collections and databases, is seen as 'a national resource of fundamental importance'. The group also emphasised the importance of networks: 'connecting assets and skills nationally and internationally (i.e. networks) is a fundamental element of a successful, resilient biosecurity system.'

The SD5 work plan concludes with calls for several actions relevant to the current review:

- understanding biosecurity system assets and capability needs through baseline assessments, stock-takes and gap analysis across the system
- developing and implementing a Biosecurity Capability Development Plan
- developing and implementing a Biosecurity System Asset Development Plan.

To summarise, the *Biosecurity 2025 Direction Statement* and its associated work plans identify a wide range of scientific capabilities needed to support a world-class biosecurity system. This current review addresses the extent to which we currently have these capabilities in plant biosecurity science.

Methods

The scope of the review, as outlined in the review team's terms of reference, was plant biosecurity science and research for terrestrial and freshwater ecosystems. This included the following topics:

- pre-border, border, and post-border biosecurity
- the conservation estate and productive estate
- insect pests and plant pathogens
- diagnostics and species identification – including traditional taxonomy and molecular methods
- bioinformatics
- biosecurity surveillance science and technology
- eradication/management technologies – chemical, biological, mechanical
- crop and ecosystem resistance and resilience

- social research, including licence to operate
- infrastructure – labs, equipment, computing, quarantine facilities, growth chambers
- links to key capabilities that NZ might not want to duplicate (e.g. CEBRA)
- sources of investment.

Topics considered out of scope were:

- mātauranga Māori (see Foreword)
- weed incursions
- the marine domain
- gaps in databases and collections (MBIE is currently undertaking a review of these)
- specialised international infrastructure held offshore, such as containment facilities for high-risk organisms.

The review team approached the task by interviewing or corresponding with more than 90 key stakeholders involved in plant biosecurity science in NZ, including those in CRIs, universities, government departments, and primary industries (see Appendices 2 and 3). A small number of overseas experts were also contacted, with a focus on determining the extent to which NZ could rely on international expertise for assistance in preparing for, or responding to, a future serious incursion.

The focus of the interviews was to elicit the interviewees' views on potential capability and capacity gaps that would make it difficult to deliver on the goals and objectives of NZ's current biosecurity strategies and relevant science strategies. The review team then corresponded with additional stakeholders, seeking clarification or amplification of topics raised during interviews, and also consulted relevant background documents, including some information from overseas that provided examples of how other countries address the challenge of cross-national biological risk.

This report of findings does not attempt to highlight the many strengths of NZ's plant biosecurity system, in part because that would require evaluation of the calibre of scientists and teams. There are also areas where NZ's capability currently might be considered adequate but not outstanding. This report focuses on areas where interviewees said capabilities need to be strengthened.

The summary of findings below is based on the review team's qualitative impressions gained from the interviews and readings, so our commentary reflects the thoughts and opinions of those surveyed. The team recognises that there will be alternative opinions not recorded here from others we did not interview. This report should be regarded as a discussion document intended to help guide future conversations. Where potential gaps in capability and capacity are highlighted, our intention is simply to promote discussion of the significance of those gaps so that a way forward can be charted.

In almost all cases interviewees were happy to share their views on gaps in NZ plant biosecurity science capabilities, but some preferred not to be directly quoted. For this reason we have avoided attributing statements to specific individuals.

Review findings

This review was undertaken to answer the following question: 'Does New Zealand have the right biosecurity science capability and infrastructure to avoid or mitigate the next serious biological incursion that would threaten New Zealand plants, either productive or natural?' We conclude that the answer to the question posed is a qualified 'No'. In certain areas of biosecurity science NZ's capability and capacity are weak. Even in the numerous areas of strength there are specific gaps that could expose us in the event of a serious incursion. NZ has experienced damaging incursions in the past and we must anticipate more of these in the future. This review identifies areas where NZ's capability to use science to avoid or mitigate these impacts could be strengthened. These key gaps are listed below, grouped by topic area.

Plant biosecurity taxonomy and bioinformatics

Taxonomy, databases and collections are the backbone of any biosecurity system. If we do not know what an organism is, or if it is already present in the country, it reduces our ability to recognise the incursion of a potentially damaging pest or pathogen. Taxonomy has evolved considerably in recent decades, with molecular tools becoming a key component of diagnostics. These tools need to be recognised as complementary to, rather than replacements for, traditional taxonomy.

Molecular diagnostics are critical when identification of pathogens at the species level is not precise enough. Disease in kiwifruit from Psa highlighted this issue: 'We are very focused on defining biosecurity risk at the level of species – but sometimes it is only certain genotypes that are invasive.'

MPI's Plant Health Environment Laboratory (PHEL) is highly dependent on the availability and accessibility of collections and databases. Ideally all the biological samples stored in these collections would be sequenced to make them even more useful, and for certain groups this is becoming policy for newly accessioned material. In addition, NZ sequences are progressively populating global genetic databases. Nevertheless, it is recognised that it would take considerable time and money to sequence all existing specimens, and that some older samples (>20 years) cannot necessarily be sequenced successfully.

> *The greatest taxonomic challenges for biosecurity, not surprisingly, relate to NZ's incomplete knowledge base and interpretation of small to microscopic organisms – arthropods, nematodes, fungi, bacteria, and viruses. For all of these groups, the expected number of yet-to-be discovered species far exceeds the number*

named – both in NZ and globally. Collections, databases, and diagnostic tools are fundamental, along with the experience of specialist taxonomists to accurately identify new incursions. Their knowledge of what is present in NZ is key to discriminating incursions as new.

Several respondents noted the fragility of NZ's taxonomy situation, citing a significant number of taxonomists nearing retirement age, many retired taxonomists working for free, and a difficulty in recruiting young taxonomists for succession. In many institutions the funding of collections themselves appears to be secure, while taxonomists are only partially funded and a sinking lid may be applied to retiring specialists, as is the current situation at Manaaki Whenua – Landcare Research. Concerns were expressed about the delay in MBIE completing their review of databases and collections. Part of the reason for that delay has been the COVID-19 situation, which fortunately has not affected ongoing funding of the collections themselves.

Modern taxonomy involves the application of molecular tools, and taxonomists need to be knowledgeable in their application. Increasingly it also involves the application of bioinformatics to handle increasing volumes of data. Bioinformatics is not unique to biosecurity, but it is becoming increasingly important in many aspects of today's digital society, in which vast amounts of data are collected as a matter of course. Dealing with big data is 'a general problem across science because best practices are evolving so rapidly', so the issue is not seen as biosecurity specific.

Key points

- **The MBIE review of collections and databases needs to be completed.**
- **Skilled taxonomists are retiring, and it is difficult to train and recruit in this area.**
- **More taxonomists skilled in a blend of traditional and molecular techniques are needed.**
- **Bioinformatics skills are needed, but the demand here is not unique to plant biosecurity science and so capability could be shared.**

Case study

Phytophthora kernoviae and *Phytophthora* Needle Blight (PNB)

Significant radiata pine defoliation has been recorded in NZ plantation forests since the 1960s. Scientists struggled to determine the cause of the disease, which came to be named 'physiological needle blight', or PNB. Improvements in diagnostic capability and greater understanding of foliar *Phytophthora* eventually revealed that the disease agent was the native *Phytophthora kernoviae*, which is known to attack a wide range of conifers and angiosperms.[10] The disease is now known as *Phytophthora* needle blight (still PNB); we do not yet know what impacts this pathogen may be having in the natural estate or on horticultural crops.

In 2013 the collaborative Healthy Trees, Healthy Future programme,[11] led by Scion, was initiated to support research addressing the threat of *Phytophthora* species to NZ forests. The programme involves breeding, management and research approaches to combat *Phytophthora* diseases. Nevertheless, the decades of effort that were required to uncover and understand the cause of a radiata pine disease highlight the gaps in our knowledge of exotic and endemic pathogens and their role in the natural estate.

W. Dyck.

Forestry plantation impacted by Phytophthora *needle blight.*

Pastoral agriculture plant biosecurity science

Pests, mainly invertebrates and weeds, are estimated to have cost New Zealand's agricultural sector close to $4 billion per year.[12, 13]

Pastoral plant biosecurity science was identified by the review team as a very significant capability and capacity gap. This gap was verified by numerous respondents, and in fact no-one spoken to argued otherwise.

The review team encountered a perception by some that NZ pastures are relatively resistant to pathogen attack and that insects are the main threat. Furthermore, industry admits that other issues take priority when it comes to biosecurity response and funding, as the pastoral sector is currently under a great deal of pressure from environmental reforms and dealing with animal biosecurity incursions such as *Mycoplasma bovis*. It is also recognised that there is only limited communication of plant biosecurity issues to pastoral farmers in terms of what is needed to protect pasture grasses and other forage crops. Most farmers' biosecurity focus is on animals.

Some respondents commented that relative to pastoral agriculture there is a much greater awareness of plant biosecurity risks – and a greater desire to reduce those risks – in the horticultural and forestry sectors. Of course neither of these sectors is concerned about animal biosecurity and rightfully focuses on plants.

There have been significant biosecurity incursions in NZ pastures in recent years, including some weevil species. Some of these incursions have had major impacts on pasture production, with the annual loss of revenue from clover weevil in the Waikato estimated at around $1,500/ha in 2015.[14]

Ryegrass and white clover are economically the most valuable plant species grown in NZ, and there is clear evidence of the economic impact of biosecurity threats on NZ's agricultural sector. Historically the country had strong plant biosecurity scientific capability in this area, but to a large extent this capability appears to have been wound down. In particular, there are capability gaps in pasture plant pathology as there are currently no pasture pathologists in NZ.

Historically insects have been considered much more of a threat to pastures than have pathogens, although a diverse range of pathogens is known to cause disease problems in NZ pastures. These include nematodes (taxonomically classified with insects in the clade Ecdysozoa but usually thought of as disease organisms), fungi, and oomycetes. In most cases, pasture root diseases are caused by a complex mixture of such pathogens.

> *Although the importance of soil borne disease to pasture productivity is widely recognised, there has been relatively little fundamental or applied research effort aimed at understanding or controlling disease complexes. In New Zealand, the bulk of research efforts were conducted in the mid 1980's through to the early 2000's (Falloon 1985; Skipp and Christensen 1989; Waipara et al. 1996; Watson and Mercer 2000; Sarathchandra et al. 2000), with relatively little work conducted for the past 15 years. This is at odds with the trend for increased value of pasture production on a per hectare basis.*[15]

AgResearch has little forage pathology capability, but if there was a serious pathogen incursion in NZ pasture then pathologists from the Foundation for Arable Research, Plant & Food Research, and Scion could be brought in to assist. However, this assumes a new incursion would be recognised as something new and concerning. Without a pasture biosecurity surveillance system, and with few pasture entomologists and no pasture pathologists, it is questionable whether an incursion would be detected soon enough to contain it.

There are also capacity issues in pasture entomology, as several of the entomologists are at or nearing retirement age and there is only one dedicated pasture nematologist. Recent experiences in Australia with widespread pasture dieback of an unknown cause highlight the kinds of issues that NZ pastoral farming could be facing.[16]

Case study

An emerging risk: Queensland pasture dieback

One of the most recent emerging pastoral risks recorded in MPI's Emerging Risks database was 'Queensland pasture dieback' in 2019. Despite having been first recognised in 1926, researchers are unclear as to the cause of this devastating disease, which has affected tens of thousands of hectares of pasture in Queensland and more recently in New South Wales: 'Pasture dieback is a scourge in contemporary grazing, with the income lost running into billions of dollars.'[17]

Researchers at Queensland's University of Technology recently hypothesised that the cause of the dieback is a mealybug,[18] although they doubt that mealybug feeding alone would cause the damage being seen. They suspect that the bug is interfering with the plants' defence systems and that 'Pathogens such as fungi or viruses may be dormant within the plant or soil, but once mealybugs are present these other disease agents can become more active, exacerbating the damage. Clearly there are unanswered questions.'

Stuart Buck, Department of Agriculture and Fisheries, Australia

Pasture dieback.

Following are some of the comments received from plant biosecurity scientists about NZ's capability to respond to a serious pasture pest or pathogen incursion.

> *NZ would struggle during a new insect incursion to pull capability together to really understand the biology of the insect, the spread, and the potential impact.*
>
> *There is a lack of plant biosecurity generalists who understand the bigger picture and how to make the linkages between production systems and biosecurity threats.*
>
> *If there was a new pasture disease discovered it might take months to build an appropriate team.*
>
> *There is a capacity gap in the leadership skills needed to bring teams together to deal with a biosecurity incursion.*
>
> *Given the importance of ryegrass to the livestock sector it amazes me that they don't take ryegrass pests and diseases more seriously and make sure that the necessary capability is available either within their own agency or at AgResearch. Animal health is always at the forefront of their mind … plant health tends to take a backseat.*

PHEL said that they did not know of a NZ pastoral pathologist they could contact in the event of a new pasture disease discovery. Biosecurity NZ were unaware of any serious emerging pasture threats but acknowledged that this could be because no one is looking:

> *A properly designed biosecurity surveillance approach would consider what to look for, how to look, where to look, and when to look, with estimates of the population sizes we're aiming to detect, survey detection efficacies, and plans for responding when something is found: Though achievable, I'm pretty sure this concept is still agricultural science fiction in NZ!*

Not only is there weak plant biosecurity capability in the pastoral sector, but there there was also concern expressed that there may be significant risk pathways that are not adequately monitored. For example, NZ imports approximately 2 million kg of ryegrass seed annually, and some interviewed were of the opinion that there was insufficient inspection at the border for potential ryegrass pathogens (more on this later in the report).

Industry representatives interviewed for this review were generally aware of the lack of focus on pasture biosecurity science, but their general response was that other things take higher priority. Some expressed surprise at the current state of pasture biosecurity science, while others suggested that it is MPI's responsibility. That said, the dairy industry has recently teamed up with biosecurity consultants to develop D-BRiEF[19].

> *The Dairy Biosecurity Risk Evaluation Framework (D-BRiEF) enables the dairy industry to tap into the knowledge and experience of New Zealand and international experts to assess exotic risk organisms.*
>
> *This means that we can better understand:*
> - *the probability of an organism to enter New Zealand*
> - *its potential to spread to a large number of farms*
> - *the potential impact of each organism on affected farms.*
>
> *This information will allow Dairy NZ to make better decisions about how to invest dairy farmers levy in a more effective and targeted way and support the wider dairy sector in understanding and preparing for these risks.*

Key points

- **Pastoral plant biosecurity science capability is very weak, with few (often late-career) entomologists and nematologists and no plant pathologists specialising in this research area. There appears to be little opportunity for successional planning.**
- **There is a lack of experienced generalists who can address, or even appreciate, the bigger picture of biosecurity at the level of pasture systems.**
- **There is very limited funding available from pastoral plant biosecurity science from either government or industry.**
- **Risks to NZ from emerging pasture pathogens do not appear to have been adequately assessed. This was of concern to some respondents, who felt there could be gaps in NZ's biosecurity system that put our pastures at risk of pathogen incursions (e.g. gaps in the seed import pathway).**

Case study
Biocontrol of clover root weevil

Clover root weevil (*Sitona lepidus*) originates from Europe but has been present in NZ since at least 1994. Natural dispersal occurs by flight, but the weevil is also a proficient hitchhiker in hay and on vehicles. By 2006 weevil populations had spread throughout the North Island, and by 2015 throughout the South Island. Given its high reproductive potential and lack of natural enemies and competitors in NZ, clover root weevil has become one of our most damaging pests of clover[20].

The weevil is difficult to control with insecticides, so in 2006 AgReseach introduced a small parasitic wasp (*Microctonus aethiopoides*), as a biocontrol agent. This introduction was very successful, with the wasp now widespread and able to effectively control the weevil in many areas in most years. Biocontrol programmes of this kind are challenging to implement, however, because of the international work required to locate potentially suitable biocontrol agents, and the extensive non-target host testing required before release of an exotic control agent can be approved. Moreover, biocontrol agents are not capable of fully eradicating the target pest, so there is potential over time for the weevil to begin evolving strategies to elude the parasitic wasps' impact. This highlights the importance of ongoing monitoring and research to support programmes of this kind.

AgResearch

Adult clover root weevil and its parasitic wasp biocontrol agent.

Natural estate plant biosecurity science

NZ has a long history of research effort focused on biodiversity and ecosystem function on our natural estate. Nevertheless, even today approximately 10–20% of our native plants have not been formally described, and our knowledge of native insect ecology remains limited. Knowledge of endemic fungi and micro-organisms is comparatively poor, with estimates that there are probably three times the number of species in NZ than have been identified.

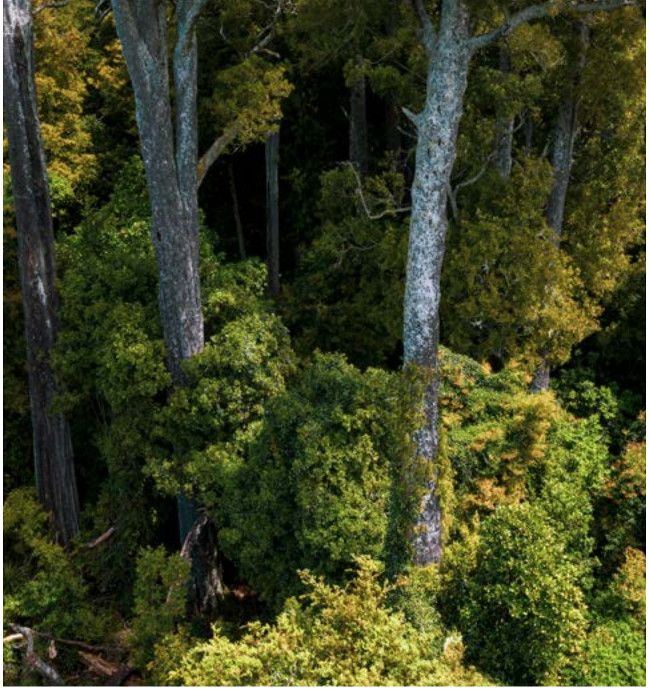
The implication of these gaps could be future uncertainty as to whether a 'new' biosecurity threat is an exotic incursion or the emergence of a previously undescribed native species. A related issue is that the Official New Zealand Pest Register (https://pierpestregister.mpi.govt.nz/) lacks accuracy, sometimes leading to the use of incorrect species names. A new version was released in December 2020[21] but a comment received was that the new version 'should have been vetted or advised by qualified taxonomists and cross-checked against the National Databases'. Nevertheless, MPI is to be congratulated for getting this database online.

There is very little active biosecurity surveillance of our natural estate, so we rely on general surveillance to provide alerts to new problems. (By contrast, NZ's commercial forestry sector has been conducting targeted surveillance for approximately 70 years to provide for an early warning should an incursion occur.) DOC does not have trained mycologists on staff, and hence fungi are not currently covered from a biosecurity or conservation perspective.

Twenty years ago, there was a belief that NZ's native forests were relatively immune to exotic pathogen attack[22], particularly from pathogens that did not evolve in Gondwana forests. That thinking changed with the discovery of new *Phytophthora* species that are indiscriminate in their use of, and their negative impacts on, a wide range of host plants (see box).

Kauri dieback disease and myrtle rust (see boxes) are two other high-profile examples in recent years that illustrate how poorly prepared we are to deal with incursions in our natural estate.

Despite the efforts of dedicated scientists, natural estate plant biosecurity science is currently very much under-resourced in NZ. We have little idea of what endemic pathogens we have in our natural estate at present (including fungi, bacteria, viruses and *Phytophthora*), and the extent to which pathogens may be contributing to declining forest health is also uncertain. There, is however, anecdotal evidence of poor forest health in some areas, and at last count there were 11 *Phytophthora species* causing disease symptoms in NZ's natural forests.[23] Given our limited knowledge of these species and disease processes on our natural estate, we cannot be confident of recognising a new incursion.



Biosecurity surveillance of the natural estate is needed.

While our ability to identify native fungi and micro-organisms is very limited, our ability to predict how exotic pathogens might interact with our native plants is an even larger gap. Sentinel plant research, looking at what pests and pathogens are attacking NZ plants growing overseas, can help in this regard, but we have little capacity for research in this area.

Similar capacity gaps are evident – although somewhat less pronounced – for insect pests on the native estate. The biodiversity of several groups of native insects is not well described, and our ability to predict how exotic insects might affect our natural estate is poor. The impact of the hadda beetle (*Epilachna vigintioctopunctata*) 10 years ago on our native Solanaceae species is an example of a recent exotic invasion that posed a threat to both production crops and native plants.

Somewhat ironically, it was efforts by DOC to protect native brassica species that led to the eradication of the great white butterfly (*Pieris brassicae*), which MPI had given up on despite concerns about the potential impact of the insect on production brassicas.

> *Input from the local community was critical to success in eradicating the Great White Butterfly. DOC because of their local presence was viewed in a better light than MPI. Of course, it helped that it was a big butterfly that could be easily recognized by school kids.*

Key points

- **There is inadequate funding for the scientific capability and capacity needed to understand endemic pathogen–host interactions in our natural estate. We currently have limited information on the endemic fungi, bacteria, viruses. and *Phytophthora* in natural areas, which weakens our capability to recognise new incursions.**

- There is very limited capability and capacity to predict the impact of exotic pathogens (and, to a lesser extent, exotic insects) on our natural estate. *Phytophthora* spp., the bacterium *Xyella fastidosa*, and the fungi *Ceratocystis lukuohia* and *C. huliohia* are examples that pose unknown, but potentially serious, threats to our natural ecosystems as well as to our productive sectors. There are almost certainly other threats that are currently 'unknown unknowns'.
- NZ lacks the capacity to assess the social and cultural impacts of a serious natural ecosystem incursion.
- Scientific contributions to plant biosecurity surveillance across our natural estate are currently relatively weak, although NZ does benefit from trans-Tasman collaboration through the Centre of Excellence for Biosecurity Risk Analysis (CEBRA) in Australia.
- DOC and MPI have limited capability and capacity in terrestrial plant science biosecurity in the natural estate and are currently very occupied with kauri dieback and myrtle rust disease.

Case study
Spread of kauri dieback disease

Kauri dieback is a forest dieback disease of kauri trees (*Agathis australis*) caused by the oomycete pathogen *Phytophthora agathidicida*, which is most likely exotic. Kauri dieback was first recognised in the early 1970s on Great Barrier Island, and was initially identified using traditional taxonomic techniques as *P. heveae*. In 2006, kauri dieback in the Waitakere ranges was recognised as having distinctive symptoms, and the disease agent was eventually fully discriminated in 2015 as new to science and named *P. agathidicida*.

In 2008 the causal agent was declared an 'unwanted organism' under the Biosecurity Act, but in practice little was done to contain or monitor its spread. Between 2011 and 2016 the infection rate in trees in the Waitakere ranges doubled. As the main pathway of spread is thought to be human activity, local iwi placed an unofficial rāhui over large areas of kauri forest in 2017, and by 2018 Auckland Council had closed all forested areas of the Waitakere Ranges to the public. The Council began disease surveys in 2006, a joint management group was initiated in 2008, and the National Kauri Dieback Management Programme began in 2019.

NZ's kauri forests are now in serious decline[24]. Kauri dieback is an unfortunate example of how incorrect assumptions about the virulence of a pathogen, difficulties in discriminating native and introduced pathogens, uncertainties about host range and transmission dynamics, lack of systematic surveillance, and lack of control tools can result in a delayed and ineffective response to pathogen incursion and subsequent large-scale spread over a 40-year period. Given gaps in current biosecurity science in the natural estate, NZ remains at risk that this history could repeat with other iconic plant species and ecosystems.

www.kauridieback.co.nz/

Mature kauri killed by kauri dieback disease.

Freshwater plant biosecurity science

The review team was unable to identify scientists working on biosecurity risks posed by pests and pathogens on native freshwater plants. Research in this space is focused on invasive aquatic macrophytes and problem algae such as cyanobacteria (blue-green algae), didymo (*Didymosphenia geminata*) and 'lake snow' (*Lindavia intermedia*). These organisms were considered out of scope for this review, although their considerable ecological and economic impacts are acknowledged.

Key points

- **NZ appears to have minimal plant biosecurity capability in the freshwater plant area, other than for invasive aquatic macrophytes and algae.**
- **The significance of this gap is unclear, as the risk that exotic pests and pathogens pose to our freshwater aquatic plants may be relatively low.**

Resistance and resilience for plant production systems and natural ecosystems

There are ways to defend against incursions other than to detect and destroy the invading organisms. Several interviewees noted that enhancing the resistance and resilience of plants and plant systems is a key approach, as incursions of some problem species may be inevitable in the medium to long term.

> *There will always be incursions – we need to be less naïve about that and start putting more effort into post-border solutions. And we also must accept that there is not going to be a magic bullet or magic solution for some of these incursions – or at least, not one that is cost-effective. The ultimate solution is going to be development of resilient plant stocks, which will be especially important in some of the productive sectors where the plants have a very narrow genetic base.*

This review was focused on the capability to be prepared for and respond to a specific, serious incursion, so we did not attempt to look in depth at NZ's capabilities in ecosystem resilience science. The kiwifruit industry's amazing success in dealing with Psa is an example where disease tolerance in the G3 clone provided a rapid means to mitigate the impact of a devastating pathogen incursion.[25] The fact that the industry was fortunate to have G3 already available as an alternative to their more susceptible Hort16A plantings is a striking example of resilience that allowed the industry to rapidly recover from the incursion event. That this recovery was due in part to good luck does not detract from this success story, but does highlight the need to be more proactive in identifying commercial clones that are tolerant of pathogens not yet in NZ. Other methods of introducing resistance and resilience also need to be explored.

Other industries that are not as well endowed with scientific capability as the kiwifruit industry are unlikely to recover as rapidly from a serious pathogen incursion. This ability comes from scale, with larger and more valuable industries having a greater ability to invest, but it also comes from awareness and strategic thinking on the part of industry leaders. Breeding for disease resistance against key pathogens and insects is occurring overseas for several horticultural and arable crops grown in NZ, but NZ needs to evaluate what the key threats are and prioritise effort in this research area.

As well as plant selection and breeding, this research area aims to better understand and then potentially manipulate the microbiome, a scientific field that is in its relative infancy.[26] It also implies developing ways to manage our productive systems differently so that they are more resilient to disturbance. For example, research to enhance organic matter storage in soils could help crops to be more resistant to drought, which will in turn help protect against insect and pathogen attack. Interviewees felt it would be easier to make a productive system more resilient to stressors than a natural system, such as a kauri forest.

There is some NZ research on the application of endophytes on seed coatings (particularly in grasses for production purposes and insect resistance), and also on seed storage methods. More could be done to investigate the application of beneficial endophytes across all productive sectors, and the natural estate. Considerable effort has gone into the science of *Epichloë* endophytes on grass production and resistance to insects, and the industry is reaping the benefits.

Horticultural crops can recover much more rapidly than most forestry crops from a devastating disease, primarily because of the physiology of the different crop plants and the ability (and the need) to reproduce horticultural plants from more mature tissue vs young tissue (mainly seeds) in forestry. Most forest species, like pines, have rejuvenation challenges, and to select and breed a disease-resistant family can take decades, and even then may not be very successful.

Outside of genetic engineering, the science of beneficial organisms (including endophytes) appears to be the only way that scientists can reasonably rapidly (years rather than decades) make radiata pine more resistant to pathogens, and potentially insects. Although this science is in its infancy in forestry, it is reassuring to see a substantial MBIE-funded research programme recently starting on this topic, and also research by private companies to explore this option. While endophyte science offers substantial promise to improve resistance to pests and pathogens, there are significant cost barriers to making progress. There are also fundamental knowledge gaps that need to be filled.

Genetic modification and genetic engineering technologies also offer opportunities to enhance resilience, but currently these technologies are not being investigated in NZ on any significant scale, as they are in other countries such as Australia. While there is a gap in capability in NZ, this reflects the political and social hurdles that would need to be addressed before such work could begin. Unfortunately, with the rate of pathogen spread increasing and the level of stressors (drought and temperature in particular) also increasing, there is a compelling need to at least research the application of advanced molecular technologies. Deployment is another matter, but it would be wise to have some effective weapons in the arsenal in case they are needed.

As was pointed out, and emphasised by a number of those we spoke to, 'research into plant and ecosystem resilience needs to operate on a very different (50 year?) timeframe from widget-chasing'.

Key points

- **Future pest and pathogen incursions are inevitable, and it is unrealistic to expect to find a magic bullet solution for every problem species. More scientific capacity is needed to develop plant and ecosystem resilience to incursions, especially for commercial crops that have a narrow genetic base.**
- **There is an increasing need to screen plant varieties for resistance against biosecurity threats not currently in NZ. Some of this research and capability sits offshore, depending on the sector and where the relevant germplasm resources are located.**
- **NZ researchers face barriers to importing resistant cultivars and germplasm (e.g. EPA restrictions and quarantine facility bottlenecks).**
- **This research area will require long-term funding if it is to succeed.**

Predictive spread modelling

Predictive modelling of pest and pathogen spread is needed to develop surveillance systems for the early detection of unwanted organisms, and also to predict the spread and potential impacts in the event of an incursion. NZ has only a few skilled experts in this area, but benefits from trans-Tasman collaboration through CEBRA. CEBRA is an MPI-DAWR jointly funded collaboration hosted by the University of Melbourne to provide risk assessment expertise that helps strengthen various parts of our biosecurity system.

Those we spoke to do not believe that we need to recreate CEBRA in NZ, but felt that risk modelling in NZ does need a boost. It is important that modellers understand biological systems, and ideally biosecurity and how risk organisms spread. This is not always the case, however, as some modellers are apparently overconfident and make predictions outside of their expertise. It would be useful for modellers to better understand how MPI and the biosecurity system works.

Industry agrees that much more could be done in risk modelling, and that we could learn from Australian experience with spotted wing Drosophila, and also from NZ animal epidemiologists. Some skilled modellers have recently retired and others are about to. This is an area that needs more capacity.

Climate change will have an impact on biosecurity risk and how new organisms will spread and affect NZ plant systems. Skills are relatively low in this area.

There are also many data gaps for biosecurity organisms already established in NZ that, if filled, would help to model outbreaks and opportunities for control.

Depending on the question being asked, incorporating economic, environmental and social/cultural impacts into predictive models may be important. Capability to include economics is adequate whereas capability to include environmental and social/cultural components of risk and impact appears underdeveloped.

Key points

- **NZ animal biosecurity is well supplied with outbreak modellers, whereas the plant sector apparently relies on a smaller number of key individuals.**
- **Plant sector modellers utilise a smaller range of epidemiological approaches than their animal sector counterparts.**
- **NZ needs more risk modellers to help develop surveillance systems and to model outbreaks in the event of an incursion.**
- **There is a need to better understand and predict the impacts of climate change on biosecurity risk.**
- **Capability to incorporate social/cultural components of risk and impact into predictive models is underdeveloped.**

Northland pasture.

Risk assessment and prioritisation

There are many unwanted organisms that are known to be a threat to NZ's productive systems, and also some that are thought to be a threat to natural ecosystems. It is recognised that we cannot work on everything, and that international collaboration is needed. Many of the sectors we interviewed have undertaken prioritisation exercises or are in the process of doing so.

MPI has an Emerging Risks team, and a relatively new Intelligence Unit. It was suggested to the review team that the Emerging Risks team needs more resources because it is difficult for the team to properly investigate all emerging risks. For example, the ryegrass import health standard (IHS) has not been updated for years because no new emerging risks have been identified, but if there are no ryegrass pathologists in NZ then who would identify emerging risks?

The HSNO Act is a significant barrier to rapidly responding to major plant biosecurity incursions, as without MPI intervention to use the powers of the Biosecurity Act it is illegal for scientists to move plants or live insects infected with the incursion anywhere – into containment or anywhere else. And 'Obtaining permits to move and reproduce new pests can take 4–8 weeks.'

There was a suggestion that we do not have a good understanding of what pests and pathogens transfer between our productive estate and our natural estate. Native insects have crossed over and caused damage to productive estates, and there are examples of pathogens doing the same. Weeds (which were out of scope for this review) could act as reservoirs of dispersal routes for pests and pathogens. But we do not know the extent of these problems, or if unwanted organisms are going in the other direction as well. The extent to which conservation plantings lead to pathogen transfer from nurseries into the natural estate is also unclear.

There is currently a project being funded by the New Zealand's Biological Heritage National Science Challenge (NSC) investigating the development of a more comprehensive risk assessment framework that includes social, cultural, and environmental considerations as well as economic ones. Such a framework would have been very useful for assessing the emerging risk posed by myrtle rust disease – before it arrived.

Risk assessment, and indeed incursion responses, would be enhanced if the existing informal networks among experts were formalised and made more available to others. During the review we heard comments from many people, including those in industry and government departments, that they often did not know where the experts were to ask: 'The networks across MPI, the CRIs, DOC and potentially universities and museums should be formalised and made more transparent.'

Brown marmorated stink bug damage.

Key points

- **Inadequate risk assessment capacity in MPI may have limited the investigation of emerging risks and the development of import health standards in the past. However there has recently been a significant uplift in additional technical capacity in risk assessment (including emerging risk assessment) and Import Health Standards development. A Biosecurity Intelligence Team was also established to monitor drivers of biosecurity threats and provide early warning of changes in threats and threat forecasts.**
- **The HSNO Act, as currently implemented, is a significant barrier to scientists rapidly responding to major plant biosecurity incursions.**
- **In contrast to the productive sectors, there does not appear to be funding to support tracking the emergence overseas of exotic organisms that could pose new risks to our natural estate.**
- **Biosecurity risk assessment requires assessment of the social, cultural and environmental significance of a threat, as well as the potential economic impacts. Current capability appears to be weak in all three areas.**
- **More formalised networks of national and international collaboration would be useful to industry for better understanding high-risk biosecurity organisms.**
- **There are specific gaps in the science on particular groups of insects and pathogens, which need to be addressed. To some extent these can be covered by international collaboration, but ideally NZ should have its own capability in key areas.**
- **NZ lacks capacity in biosecurity surveillance science. However, there is recognition that we have a strong involvement with CEBRA that helps to address this gap.**

Biosecurity detection technology and control tool development

NZ tertiary education has moved away from traditional programmes in plant science, ecology, entomology and pathology, but we are rapidly gaining skills in engineering, computing, machine learning, robotics and sensor technologies that can be applied to plant biosecurity science. As with modelling, this is an area that needs to include generalists and people with skills at bringing teams together to really have an impact. The Science for Technological Innovation NSC, together with the New Zealand's Biological Heritage NSC, are currently working together towards this goal.

There do not appear to be significant gaps in technical capability limiting development, but there are gaps in the skills needed to bring understanding of biological systems and biology together with engineering.

There are capability gaps in finding cost-effective tools that can help specific biosecurity problems. *Phytophthora* pathogens is one area where problems are increasing as new *Phytophthora* species are either discovered or become established in NZ. More are knocking on the door as world trade and travel patterns bring pathogens and insects closer to home. It is generally accepted that solutions to *Phytophthora* incursions are very difficult to develop, other than breeding for resistance. However, for long-lived plants that are not amenable to rejuvenation and cloning, breeding is probably not a viable option. Kauri is a good example.

Chemical sprays will work to some extent against most pathogens, even *Phytophthora*, if applied correctly. However, many chemicals are being banned because trading partners will not accept their residues on exported products, others are prohibited for NZ public health reasons, and even benign biologicals cannot be used because of public concerns over aerial spraying. This topic is covered below under 'Social science'.

Key points

- **There are capability gaps in bridging our (incomplete) biological knowledge of unwanted organisms and the emerging capabilities of engineering/computing technology.**
- **In the context of control tools, there are significant biological knowledge gaps for species not yet in NZ but considered high risk for incursion. There is a need for greater scientific capability to address these gaps.**
- **There are capability gaps in the research extension pathways needed to facilitate the adoption of new technologies by end users.**
- **Alternative pest control methods are needed as regulations tighten and some existing tools are phased out. NZ, being a tiny market for such tools, needs to choose its research targets very carefully.**
- **NZ's pesticide science capabilities lie primarily in the private sector, so access to a 'neutral voice' on pesticide application is an emerging gap.**

Case study

Suppression of exotic fruit fly incursions

NZ has been highly successful in responding to exotic fruit fly incursions, with several such incursions effectively suppressed over the past two decades. The National Fruit Fly Surveillance programme[27] is built on strong science, as is the response process that is initiated when an invasive fruit fly is detected.[28] Key reasons for our success in detecting and responding to this pest include (a) the realisation by both industry and government that failure to detect and respond to a fruit fly incursion could be extremely costly to the horticultural industry and the NZ economy; (b) the availability of surveillance and response systems based on long-standing science undertaken in NZ, Australia and internationally; and (c) ongoing scientific capability and research effort that underpins our readiness and response system, ensuring effective preparation for future incursions. In addition to providing early detection capability, the national surveillance programme provides assurance to trading partners that NZ is free from economically significant fruit flies.

www.mpi.govt.nz/biosecurity/

Queensland fruit fly – a serious pest in Australia that has been detected in NZ surveillance traps on multiple occasions.

Social science

There are gaps in effective biosecurity social science, but it is not clear if these are capability gaps or a need to adjust focus. There are certainly social scientists available who can and do work on biosecurity topics, but several interviewees felt that there are significant gaps in our understanding of how to incentivise industry members and the public to better acknowledge and address biosecurity risks. Several commented that many Endeavour bids would benefit from a social science (and also a Māori) perspective.

Decades of experience have made NZ 'very good at detecting and eradicating unwanted fruit flies'. We have also been very successful at detecting and eradicating various moth species. Even so, there are ongoing challenges in this area associated with the use of aerial technologies for chemical pesticide or even biocontrol deployment in urban areas. These need to be addressed with the help of social science, but it is unclear whether we currently have the capability to enable this to happen, and it is an area that needs to be further developed.

It was also identified that there are social licence needs in areas such as the aerial spraying of chemicals in urban areas, although there were comments from interviewees that 'this might fall into the realm of psychology'. More broadly, there is an emerging body of work on social acceptance and behavioural change that deserves more attention. MPI has benefited from social science input in several areas, including urban pest insect incursions and *M. bovis*. A specific capability gap identified is the need for social scientists with relevant primary industry experience.

Key points

- **There are gaps in the range of social science currently being undertaken, but it is not clear if there are gaps in capability or a lack of focus (and funding).**

RNC media

Fungal disease turns pine trees red after heavy rain.

University training and the need for 'system-level' generalists

A common comment from interviewees was that plant biosecurity science has become the domain of experts in specific disciplines, particularly in molecular biology, and that NZ is now lacking scientists with a strong understanding of fundamental science and generalists who can see the bigger picture and where the components fit. We also heard complaints from several people that MPI has become 'focused on the development of widgets' they hope can solve biosecurity problems, but these widgets and other tools (such as chemical sprays) are being worked on in isolation of important underpinning science on the biology of the unwanted organisms and/or the systems that need to be treated.

MBIE funding was seen as a key barrier to CRIs employing generalists, meaning there is no demand for training generalists. MBIE funding favours 'science excellence', and the interpretation appears to be that a generalist cannot produce excellent science – at least not excellent enough to attract MBIE Endeavour funding. There is also little incentive for universities to train generalists, 'because the Performance-Based Research Fund system doesn't value them'.

Some CRIs, such as Scion, struggle to recruit from within NZ as we do not produce many PhDs in forest pathology and entomology. COVID-19 has exacerbated the problem because it is now difficult to recruit from other countries. PHEL primarily recruits from offshore at present because of the lack of suitable graduates from NZ universities.

NZ plant biosecurity science used to have many generalists who were trained in classical plant biology, and in subjects such as general plant pathology, before they went on to more specialised degrees. Most of these people are now retired, and those still working are about to retire. As well as conducting science, many generalists were engaged in extension work transferring their knowledge to land managers. They were also the people who could be relied on in the event of an incursion to understand the bigger picture and how a new organism might affect a productive system, and potential ways to deal with it.

It seems that many of today's young PhDs are very specialised but not very practical. It takes years to develop practical skills and the field experience to understand productive and natural ecosystems. Experienced scientists are better equipped to apply knowledge to problems and are extremely useful in the event of a new incursion. They are apparently becoming scarce in CRIs, universities, and government departments.

While there is a need for generalists, there is also a shortage of specialised skills in some areas. Epidemiologists, who are trained to understand how disease organisms spread, are in short supply. This is especially the case in plant biosecurity science, rather than in animal biosecurity where NZ has a traditional focus. Part of the problem in plant biosecurity is the lack of data for epidemiologists to utilise in model predictions. The plant biosecurity world is a great deal more complicated than the animal world, but skills are transferrable provided the data are available.

Industry and MPI have employed significant numbers of biosecurity experts in recent years but have struggled to fill positions. Industry and MPI both require graduates with more general knowledge of how systems work, as well as some more specialised knowledge in core biosecurity subjects such as entomology, pathology, and molecular sciences. There have been discussions, mainly among members of B3, to establish a Master's degree in plant biosecurity. This suggestion has considerable merit because biosecurity problems will most likely be an increasing concern in coming decades. Respondents were generally supportive of the Master's programme suggestion, although one took the view that assembling teams of PhD-level specialists when specific biosecurity problems arise is a more effective strategy.

University training in traditional plant biosecurity skills is declining, although it is reassuring to note that the Bio-Protection CoRE has recently had its funding extended another 8 years, rebranded as Bioprotection Aotearoa. The comment was made that despite the increasing importance of *Phytophthora* to NZ biosecurity across all sectors, and the ongoing lack of solutions to *Phytophthora* disease problems, NZ still does not have a *Phytophthora* expert in a university. We also learnt that the Department of Botany at Otago is the only university department in NZ specialising in the science of plants, and one of only a few in Australasia. A solid understanding of botany is clearly a prerequisite for many aspects of plant biosecurity, including identifying plant species in any plant biosecurity surveillance and/or investigation role. Botanical skills are obviously critically important in the case of the natural estate, where a vast number of plant species are present.

Discussions with Australian biosecurity experts suggest there is less of a problem in Australia, where relevant PhDs and post-docs continue to emerge from the university system. The AgriBio initiative between the Victorian government

Cane dieback caused by Psa.

and Latrobe University (www.agribio.com.au) is a particularly interesting model to consider, as is the Forestry and Agricultural Biotechnology Institute (FABI; www.fabinet.up.ac.za/) in South Africa.

Key points

- **Despite a demand for biosecurity generalists in industry and government, there is a lack of biosecurity generalist training in universities. It has been suggested, and supported by most interviewees, that a Master's degree in plant biosecurity would be very useful.**
- **There are systemic reasons why biosecurity generalists are not being produced by universities. For example, MBIE science funding policy and selection criteria have made it difficult for CRIs to offer career paths in biosecurity science.**
- **There is a shortage of specialised skill training in some specific areas, including epidemiology and pasture pathology.**
- **There is a need for a *Phytophthora* expert at a NZ university.**
- **Two promising international models for university training are the AgriBio university department in Australia and the Forestry and Agricultural Biotechnology Institute (FABI) in South Africa.**

Biosecurity coordinators and leaders

The COVID-19 pandemic has taught NZ a great deal about the importance of interchanging skills across domains and organisations during a serious biological incursion – whether for early detection, tracking, or social acceptance. It has also shown the importance of strong leadership and interagency coordination, which is an important message for those who would be charged with responding to a serious plant biosecurity incursion.

Biosecurity responses require science coordinators and leaders to be effective. These are not so much skill gaps in plant biosecurity science as skill gaps in organisations that need to be filled, ideally, with people who understand biosecurity science. Some interviewees commented that plant biosecurity science in NZ is 'all over the place' and that there is a need for greater coordination. B3 is helping to meet that need, but much more could be done to improve networking, collaboration, and skill sharing.

Comments we received on this topic included:

> *In the future there will be big problems when a TAG [technical advisory group] is pulled together and there are no people that understand systems and even the biology of organisms.*
>
> *There is a real lack in people who can bring teams together; who see the bigger picture. They need to understand science and systems.*

Dying radiata in the Basque country, Spain.

> *It's the interpersonal skills that are just as important as the science skills. Many scientists suck at communication. We need better two-way interaction.*

Science coordinators are needed who can pull teams together and ensure that TAGs have the correct skill sets. Biosecurity response leaders need to be able to work with teams and communicate effectively with external stakeholders (some interviewees identified 'effective communication' as being a capability gap).

Science leaders are also needed in CRIs, universities and government departments. Such skills seem to be in short supply. In addition, there are gaps in the implementation skills needed to make new scientific findings operational. Government departments, in particular, but also industry need practical skills in plant biosecurity to pull things together and respond effectively. One particularly telling comment in the pastoral domain was, 'The group does have the capability to respond to a disease issue or incursion but it might take months to build an appropriate team'.

Under the Government Industry Agreement (GIA), sectors should be partnering with MPI and Biosecurity NZ in readiness and response, and plans should be in place that can be implemented in the event of an incursion. There appears to be a capacity gap in the system to prepare such a plan for pasture protection.

> *An important capability gap is the bridge between scientific expertise and the regulators who need to access it for making operational and policy decisions. For example, relatively few researchers understand MPI, and MPI and others don't always understand how to properly use the 'tools' developed by scientists. There's a need for people who can translate the particular challenges faced by MPI and other operational biosecurity agencies into science projects, and then communicate the results of the science back to MPI. Those people could be scientists or regulators or knowledge brokers, but wherever they sit they need to know about both camps.*

Key points

- **Biosecurity science leaders and coordinators are in short supply. Such skills are especially important in the event of a serious incursion, as teams capable of a 'surge' response will need to be assembled rapidly.**
- **Science leaders are needed in some research fields to build and lead biosecurity-focused science teams.**
- **Biosecurity NZ is currently short-staffed in plant science capacity and requires experienced scientists who can work with industry to develop response plans and identify research needs.**

Case study

Forest biosecurity surveillance

The NZ forest industry's successful biosecurity surveillance and diagnostic system was first introduced approximately 60 years ago and has been under constant improvement ever since. The latest iteration of the system[29] models the risk of biosecurity incursion across seven import pathways (sea vessels, used vehicles, used machinery, sea containers, wood packaging, wooden furniture, and live plants) and the movement of people. The surveillance system, funded from a log levy and based on the best science available in NZ and internationally, focuses on early detection of pest and pathogen incursions via these risk pathways. The plantation forest industry and MPI can be confident that biosecurity surveillance staff from SPS Biota, matched by world-class diagnostics at Scion and MPI's PHEL, have detailed knowledge of what pests and pathogens are already present in NZ and so will notice anything new. As well as providing an early-warning system, the scheme is used to provide assurances to trading partners that NZ plantation forests remain free of unwanted organisms.

W. Dyck

Forestry staff at Tairua monitoring forest health.

Funding – research and infrastructure

This section briefly considers funding issues that affect NZ's capability to prepare for and respond to significant biosecurity incursions. Funding issues need to be examined in the context of the larger drivers of biosecurity awareness and strategic thinking. What are these key drivers and how can science address them? How much investment should go into biosecurity science, given other priorities? These are difficult questions to answer, but without strategic thinking the default answer is always 'not much'.

Given the vast range of possible pest and pathogen threats across numerous sectors, funding of biosecurity science obviously needs to be based on strategic priorities. But priority-setting needs to be based on scientific estimates of risk, creating something of a Catch-22. Clearly, biosecurity risk is increasing, and science funding is having a difficult time keeping pace.

Australia has recently released a report, *Australia's Biosecurity Future*, which warns that Australia needs an overhaul of its biosecurity system to better respond to increasing threats:[30]

> *Even a tripling of investment over the next 10 years would result in an increased biosecurity risk, a report released by the CSIRO on Wednesday warned. CSIRO's director of health and biosecurity Rob Grenfell said the coronavirus pandemic was a stark reminder of why biosecurity was so important.*

Our review findings indicate that in some sectors NZ's biosecurity scientific capability and capacity have decreased in recent decades, whereas in other sectors capability has increased. In some cases, such as the kiwifruit industry, increased scientific effort has been in reaction to a major biosecurity scare. Current capability in Plant & Food

Research to address kiwifruit biosecurity issues is impressive [although there are concerns about future capacity as older, experienced scientists near retirement].

In contrast, there has been declining biosecurity capability in the pastoral plant biosecurity science area in recent years. Major pasture insect impacts decades ago led to large investments in entomology capability and the subsequent development of effective biocontrol agents. There has also been very impressive investment into the application of *Epichloë* endophytes to enhance ryegrass resistance to insects. However, as noted previously, there is now rather fragile capability in pasture entomology, with many experienced staff nearing retirement and very little capability in pastoral plant pathology.

If there was a significant scare in pasture disease in NZ, such as the pasture dieback that is occurring in Queensland and New South Wales, NZ would struggle to respond. It is impossible to instantly rebuild biosecurity science capability, and while some skills could be brought in from other sectors and other countries, this seems to be a dangerous strategy for protecting the most valuable plant crop in NZ.

Every year KPMG reports in its annual Agribusiness Agenda that agribusinesses rank biosecurity as their number one priority:

> *It is no surprise in the midst of the most significant pandemic the world has faced in a century, that biosecurity retained the top ranking in the 2020 priorities survey.* [KPMG Agribusiness Agenda 2020[31]]

Biosecurity may be ranked as the number one priority, but clearly the level of industry investment in biosecurity varies considerably across sectors. This review did not attempt to quantify the variation by sector. However, based on responses from numerous interviewees, the review team concluded that the level of investment in biosecurity science by some sectors is too low, which is contributing to the capability gaps described in this report.

Government shares a major responsibility for funding biosecurity science. Indeed some respondents suggested that government has *all* the responsibility, and that industry should not be funding biosecurity science at all. MBIE's science policy statements over recent years have, however, made clear that government is not interested in fully funding applied science – co-funding partnerships with relevant industries are the expectation.

Several respondents commented that the SSIF [Strategic Science Investment Fund] seems to be an increasingly important mechanism that CRIs are using to support their biosecurity capabilities. A contrary argument we heard, however, was that SSIF contracts have wording emphasising 'transformational research' and 'changing end-user paradigms':

> *MPI and DOC priorities are usually a fair way down the list [of what CRIs can spend SSIF funds on], especially as the work gets towards the operational end of things, unless the government departments are willing to substantially co-invest.*

Respondents had concerns about NZ's current approach to funding biosecurity science and were critical of both government and industry. Many highlighted funding uncertainties that have led to insecurity among staff, an inability of CRIs to offer clear career pathways in biosecurity, and difficulties planning staff succession. The current science/education funding systems also discourage the training of generalists, because both the PBRF and MBIE science funding criteria emphasise 'science excellence' over 'impact'. A representative comment received from a scientist was:

> *MBIE funding drivers certainly seem to be against usefulness. Although there's a 'pathway to implementation' category, it seems secondary to 'excellence'. While I'd argue that good applied science should rate highly in the excellence stakes, in reality, unless you arbitrarily put in some 'sexy' techniques, you'll be rated poorly. This leaves a huge gap between the ultra-applied research that industry might fund, and stretchy blue-sky stuff that MBIE might consider. This is where I see the major gap in NZ science, and it seems to be getting wider.*

Several interviewees commented that current funding patterns make it problematic to maintain a 'standing army' of scientists and technicians prepared to rapidly respond to an incursion that will come at some unknown time in the future: 'We have to have them doing something substantial meanwhile to maintain credibility'. CRIs struggle to source ongoing and stable funding to grow and maintain the kinds of applied research skills that are most valuable in an incursion response [for example, chemical control skills such as spray technology, formulation, application uptake, bio-availability, and dose response]. It was suggested that NZ cannot afford to retain 'excessive' skilled scientists in fields such as nematology if there appear to be no major problems that need addressing. A counterargument that we heard, however, is that we currently do not have an adequate understanding of what nematodes do and how they affect crop production, so there is useful research that could be done.

There were numerous comments that the funding system often leaves the research process incomplete, because the steps needed to ensure knowledge transfer and adoption by stakeholders are not funded. Pest and pathogen impact studies are straightforward to justify, whereas it appears to be much more difficult to get funding to develop biocontrol or biopesticide solutions through to a point where they are useable by producers.

We heard that it is difficult to get MBIE to fund collaborative projects that bring sectors together. One scientist suggested that Scion's 'Healthy Trees Healthy Future' programme was the last of these: this programme brought pathology skills together with 'omic' skills. There has also been reducing funding over the years for traditional ecology (i.e. understanding functional interactions among communities of organisms) in favour of advanced molecular science. Consequently, NZ is training a generation of scientists with specific skills, but who lack field experience, practical training, and plant systems-level knowledge.

The B3 science collaboration has been a successful effort to support a wide range of biosecurity programmes involving multiple partners. 'Science capability has seldom been limiting factor for B3 because collaboration enables us to look for capability across the range of partners. But funding any new area for investment means something else needs to stop and there is a general feeling that there is underinvestment in everything we do. B3 has made significant investments in engineering capability (i.e. specialists) and social science but this has come at the detriment to so-called generalists because of the finite financial envelope.'

Plant & Food Research and Scion receive funding from commodity levies that support biosecurity science, and Plant & Food Research receives substantial royalties from kiwifruit producers that benefit kiwifruit biosecurity. To those in arable science, the shift in Plant & Food Research's focus towards valuable fruit crops has meant less emphasis on crops of interest to them. Scion's biosecurity science funding has suffered in recent years from unsuccessful MBIE bidding, and also the recent reduction in commodity levies as a consequence of the impact of COVID-19 on the log trade. AgResearch receives relatively little funding from industry for biosecurity science and has been unsuccessful with recent MBIE bidding (although none of the bids requested funding for ryegrass research).

CRIs clearly tend to 'follow the money': if there is no industry or regulator investment in a plant biosecurity topic, it is highly unlikely a CRI will invest on their own. Various comments received were along the lines of 'The funding for ryegrass disease work dried up. MBIE didn't consider it "new" enough to fund and AgResearch stopped supporting the work. Industry hasn't done much to support it either.'

There was also considerable criticism of what is perceived to be MBIE's enthusiasm for a 'start-up widget company' approach:

> *The gap between widget invention and widget adoption is partly the fault of the researchers who don't build in milestones for the full development chain. But it is also the fault of the funders, who don't insist on seeing implementation milestones included in funding proposals.*

The review team heard repeatedly that there needs to be greater emphasis on funding longer-term programmes with milestones, rather than discrete, short-term projects: there is a 'gap in good leadership for those kinds of milestone programmes'.

There were comments that technician capacity has greatly reduced in recent years, at least within AgResearch. A counterargument was that it is much easier to train and recruit technicians than specialised scientists. The adequacy, or otherwise, of technician capacity was beyond the scope of this review, but it could be addressed by a plant biosecurity skills compendium (see 'Recommendations').

Key points

- **Plant biosecurity science funding is at reasonable levels in horticulture, forestry, and arable crops, but is low to very low in pastoral agriculture and in the natural estate. There is concern about recent declines in funding support for forestry biosecurity science.**
- **Given the diversity of horticulture species that are vulnerable to biosecurity incursions, the available investment needs to be stretched in many different directions and whether or not the investment available is reasonable is yet to be determined. Meanwhile, agility and flexibility of scientists able to work across multiple crops and pest/disease systems helps to maintain science capacity.**
- **There is a need for a national plant biosecurity strategy with clear priorities for the country and identified mechanisms to secure funding from the industry sectors that would benefit. The Government Industry Agreement (GIA) mechanism is meant to do this, but GIA partnerships have been uneven in the extent to which they have funded proactive 'readiness' research.**
- **Some industries are much less willing than others to fund plant biosecurity science through commodity levies or a Biosecurity Act levy.**
- **CRIs struggle to secure MBIE funding for applied biosecurity science, despite (in some cases) submitting bids that receive excellent ratings.**
- **Funding for biosecurity research on the natural estate is in a more precarious situation than in the production sectors, in part because no GIA-type mechanism is available to help leverage government funding. As shown by recent serious pathogen incursions, there is relatively little science funding and readiness to protect even the country's most iconic plant species.**

Specific organisms of concern

Given the broad range of exotic pests and pathogens that could threaten NZ plants, the review team did not attempt to review our capability to respond to specific organisms. At that level of detail the distinction between capacity gaps and knowledge gaps begins to blur. Nevertheless, some organism-specific comments made by interviewees were relevant to the review, and these are summarised below.

- Some high-profile species, such as the brown marmorated stink bug (BMSB; *Halyomorpha halys*) are regularly intercepted at the border. BMSM is considered highly likely to cause serious damage and disruption should it establish, so industry has worked proactively with MPI to avoid incursion of this pest.
- In contrast, myrtle rust disease was regarded as a serious threat to NZ's myrtle species 7 years before it was detected in NZ. Little was done to prepare for its arrival, despite science bids to MBIE. Possibly MPI regarded its arrival as inevitable, and it being a rust assumed that little could be done to combat its spread. Industry's relatively low interest in the pathogen may have been a contributing factor.
- Two *Ceratocystis* fungi from Hawaii (*C. lukuohia* and *C. huliohia*) now threaten to deliver even greater impact than myrtle rust disease on NZ *Metrosideros* species. The kiwifruit industry is also concerned that these pathogens might affect their vines. Science is needed to understand the pathogen's potential impact, and also to improve understanding of the environmental component of the disease triangle. As one interviewee commented, 'The thing that keeps me awake at night are the air-borne pathogens that could arrive from Australia – at present all we can do is monitor for their arrival.'

Nicola Robertson

Brown marmorated stink bug damage to apples in Italy

- Work by Eric McKenzie prior to his retirement has meant that NZ has a reasonable knowledge base on rust fungi (which covers several genera). However, apparently that is not the case for several other groups of pathogens. For example, NZ's key Ascomycete specialist is close to retirement. We know relatively little about the potential impact of the bacterial pathogen *Xylella fastidiosa*, which could threaten our natural estate as well as our productive sectors.
- There is concern that fall army worm (*Spodoptera frugiperda*) could be dispersed by wind to NZ from Australia. It is one of many *Lepidoptera* species that could damage NZ plants, and both industry and DOC have indicated the need for scientific effort to develop proactive plans for the control or eradication of these species.
- It was suggested by several interviewees working in the natural estate that entomology skills are 'pretty thin' and in some areas overly reliant on experts who are retired and donating their time. NZ appears to have better capability across some insect orders than others, but the review team did not investigate at that level of details given the time available for the review.
- There are thousands of nematode species, many of which can cause serious plant diseases. NZ has several nematologists, including one taxonomist, but only one is working in pasture environments. Two years ago the forest industry was experiencing a potentially new and serious nematode incursion and had to wait several days for NZ's only nematode taxonomist to return from leave. (Fortunately the nematode proved to be a relatively benign species that had probably been present in NZ for some time.) Australia has additional nematologists, whose expertise NZ can tap into, but the network appears to be an informal one based on personal contacts.
- NZ has virologists and virus diagnostic capability, but new viruses are continually being discovered. While we do have diagnostic expertise, we have limited capacity to gather the information needed to assess whether the viruses are native or an incursion.

Case study

Spread of myrtle rust

Blossoms of an 'Ōhi' a tree.

www.islandconservation.org/rapid-'ohi'a-death/

- The invasive airborne myrtle rust (*Austropuccinia psidii*), which originates from South America, has a wide host range within the family Myrtaceae and has been spreading globally in the past decade. Myrtle rust was first recorded in Australia in mid-2010, in New South Wales[32]. By the end of that year it had been found in Queensland, and by 2015 it was widespread in Queensland, New South Wales and Victoria, where it has had severe impacts on *Eucalyptus*-dominated ecosystems. By 2017 the rust had been detected on the NZ mainland, where it is now spreading and infecting valued native species.[33]
- Due to its airborne mode of transmission, the arrival of myrtle rust in New Zealand became inevitable once the pathogen had spread widely in Australia. Nevertheless, relatively little local research was undertaken in anticipation of its arrival. The rust currently threatens many valued NZ myrtle species, including pōhutukawa (*Metrosideros excelsa*), northern rātā *(M. robusta*), and the NZ endemic *Lophomyrtus* genus. Its presence in NZ also portends the potential arrival of even more serious pathogens of myrtle, such as the South American strain of myrtle rust and the Hawaiian species of *Ceratocystis*, which causes rapid 'ōhi'a death in Hawaii.[34]

Useful comments that were outside of scope

The review team captured some additional comments that we considered important but that were outside the scope of the review. These are summarised below.

- Many respondents commented that there is insufficient involvement of Māori in biosecurity science. The comment was especially noted when the subject of social and cultural constraints on the adoption of biosecurity technologies was discussed.
- Ideally, NZ's biosecurity system would prevent pests from ever breaching our border. However, Several interviewees commented that there are opportunities to be more proactive in biosecurity surveillance (including the use of sentinel plantings) in China, the South Pacific, and Australia.
- Issues were raised about NZ's seed import system and the risk it presents to the productive sectors (and potentially the natural estate). For example, NZ imports in the order of 2 million kg of ryegrass seed per year as well as large volumes of seed for northern hemisphere out-of-season multiplication. There was concern expressed that not enough testing is done for the presence of pathogens in the seed, although samples are examined for the presence of weed seed and disease symptoms, and some phytosanitary requirements must be met for import approval. This is an example of how New Zealand at times places considerable reliance on international linkages for pre-border scans for emerging risks and issues overseas.
- One particularly concerning example of the possible contamination of NZ pasture from seed imports was from a paper published in 2016[35].

> *The DNA-based assay indicated that* Aphanomyces trifolii*, a root pathogen of subterranean clover, may be present in the dairy-pasture soils. As this pathogen is currently not recognized as present in New Zealand, a definitive determination of its presence is required.*

This paper, presented at a conference in 2016, raises concerns that a new oomycete may have been introduced into NZ pasture systems. *Aphanomyces* is a genus associated with pasture dieback in Australia[36]. No action has been taken on this NZ finding, as only DNA, rather than the organism itself, has so far been detected.

- A further concern we heard about seed imports is that some *Lolium perenne* material being introduced to NZ is potentially herbicide-resistant. If herbicide-resistant ryegrass were to become widespread, this could present a serious threat to the use of conservation tillage to reduce greenhouse gas emissions.
- There is an expectation at MPI that 'if there were emerging pastoral pathogen risks that MPI would be notified'. However, if there are no pastoral pathologists in NZ and no system of pastoral surveillance for emerging pathogens, this could be a risky approach. The rye grass Import Health Standards have not been worked on for years because no new emerging pathogens have been notified to MPI. A Catch-22 scenario?
- We heard concerns about processes; for example, that it 'can take six months to get a DOC permit to monitor myrtle rust disease'. Another comment was that 'DOC doesn't agitate MPI enough' to get surveillance done in the natural estate.
- The Environmental Protection Authority (EPA) was also perceived by some respondents as a barrier to an effective biosecurity response:

  > *Scientists are banned from undertaking any research on new organisms without HSNO approval. This has been an issue with harlequin ladybird, a self-introduced parasitoid of guava moth, giant willow aphid, and others. Just when we need to be urgently doing science on these organisms, we are prevented from doing so until they are 'de-newed'.*

- We also heard, however, that updated processes now allow the EPA to approve work on new organisms without going through the de-newing process. The Biosecurity Act sets out some requirements that must be met before conducting research on 'unwanted organisms' e.g. a CTO approval may be required. Access to specialist advice to navigate regulatory requirements for biosecurity research is clearly a critical consideration within the system.
- Scientists need to be working proactively in advance of an incursion, particularly if we know that incursion is inevitable (as was the case with myrtle rust disease). The myrtle rust disease incursion response struggled with scientific issues (e.g. how to store seed) and cultural issues arising from Māori concerns. These could have been anticipated and work begun sooner.
- The problem of seed-banking expertise and infrastructure capacity is significant, and one that probably needs to be looked at by government in consultation with Māori. This should probably be part of the collections and databases review that is currently underway by MBIE.
- Several interviewees expressed concern over the lost opportunity to establish a biopesticide industry in NZ. Products such as Aureole Gold are in demand by kiwifruit growers as a replacement for copper, but this product needs to be imported from Germany – despite having been invented in NZ.
- Several respondents mentioned the virtues of a biosecurity institute in place of the current distributed biosecurity network. Others felt a virtual network might be better. Everyone agreed that B3 is a good model and has been very important in helping bring scientists together, both with each other and with industry and government.
- Weeds were out of scope for this review, but many pointed out that they are a huge issue for terrestrial and freshwater systems. For terrestrial weeds, unwanted incursions across the border are less of a problem than naturalisation of some of the 40,000 exotic plant species already present in NZ. We cannot predict which introduced plants will naturalise because not enough work has been done on the biological characteristics that favour naturalisation. Understanding this 'would help EPA be less risk averse'. Meanwhile, weed experts are ageing out of the research community.

Key points

- **There is a shortage of Māori scientists working in plant biosecurity.**
- **There are concerns about the lack of pathogen testing for rye grass seed and other seeds imported into NZ in large quantities.**
- **MPI's emerging risks notification system appears weak in the area of pasture pathogens.**
- **EPA and DOC permitting processes for enabling biosecurity science can be very slow.**
- **Seed-banking science and systems are gaps.**
- **NZ may be missing out on an opportunity to establish a biopesticide industry.**
- **Weed biosecurity science capability is declining and should be reviewed.**

Conclusions

While NZ's biosecurity system has been well served by the legacy of the Department of Scientific and Industrial Research, MAF, and the Forest Service, many of the original cohort of scientists and technicians that transferred into CRIs in 1992 have since retired, or are about to. The CRIs have been required to operate under the NZ Companies' Act, and over the last three decades have been responding to changing governments and science policy. These and other drivers have resulted in the plant biosecurity scientific capability and capacity that NZ has today. NZ can rightfully claim to have one of the best plant-focused biosecurity systems in the world. It is by no means perfect, however, and this review has identified gaps in capability and capacity.

The purpose of this review was not to explore reasons for the current state of plant biosecurity science. Nevertheless, the review team does feel that an understanding of reasons for the gaps identified in this report will be important for any future efforts to fill those gaps. Five key reasons for the current state of plant biosecurity science in NZ were proposed by interviewees:

1. lack of strong strategic signals from some industry sectors and government science agencies that plant biosecurity science is important

leading to:

2. inadequate government funding to support the applied science needed to underpin NZ biosecurity strategies
3. inadequate science funding from some industry sectors to support applied plant biosecurity science
4. inadequate government funding to adequately support fundamental science to better understand our natural ecosystems
5. lack of tertiary training in plant biosecurity science areas, resulting in part from an inability of CRIs to offer clear science career pathways in biosecurity research.

The lack of support from some industry sectors would be a useful topic for future review, as the rationales suggested to the review team were, at least in some cases, complex. For example, there is speculation that NZ pastures are 'bullet proof' and resilient to pathogens, and if they did get diseased 'they can simply be replanted'. The forestry sector, by comparison, became aware of the potentially devastating effects of insects and pathogens to the resource in the middle of the last century and has been on high alert ever since: 'Forest pathologists are helping to preserve a huge, long-lived standing crop. We have to protect it – we can't just pull it up and resow.'

Some – but not all – horticultural and crop sectors have recently experienced the devastating impacts of insects and pathogens, which has altered their view of the importance of biosecurity, and they are now much more proactive in protecting their resource; however, for others 'Because we've had no major incursions in our industry, there's some complacency.'

NZ has had several notable successes dealing with biosecurity incursions thanks to the biosecurity science capability in the country combined with the effectiveness of MPI and other agencies: 'We are now very good at detecting and eradicating fruit flies. We have had significant success eradicating moths, although perhaps our methods need to change for next time.'

The recent eradication of the pea weevil is a good example of an incursion that was eradicated through excellent leadership and cooperation – all based on science. Nevertheless, there are many examples of incursions that have not been eradicated, such as the clover root weevil (*Sitona obsoletus*), the granulate ambrosia beetle (*Xylosandrus crassiusculus*), and red needle cast (RNC; caused by *Phytophthora pluvialis*) in radiata pine. Could better plant biosecurity science (for example, in surveillance, diagnostics and eradication methodology) have made a difference? Undoubtedly yes, but at what cost and what benefit?

In the case of clover root weevil, earlier detection could have made a difference, but a biocontrol agent was successfully developed and deployed, avoiding a loss of between $200 million and $1 billion per annum.[37]

> *The combination of a favourable environment, lack of competition for an abundant food resource, high reproductive capability of the weevil and a lack of natural enemies inevitably meant clover root weevil was going to become one of New Zealand's most damaging pests of clover.*[37]

The granulate ambrosia beetle (*Xylosandrus crassiusculus*) is a serious horticultural tree pest. It was discovered in Auckland in early 2019 through MPI's High Risk Surveillance System (HRSS), but it was thought to have established possibly 3 years earlier.[38] The biggest risk is if the fungus it carries, and feeds on, is pathogenic to the trees it infects. To date that has not proved to be the case in NZ. MPI has decided not to attempt eradication and instead is monitoring the situation.

RNC is caused by a new-to-science foliar *Phytophthora*, probably originating from Oregon and spread by wind and rain. Although detected relatively early (in 2008) by the forest industry's Forest Biosecurity Surveillance programme, RNC was soon found to have spread throughout the North Island. Detection was complicated by the fact the disease symptoms look very similar to those of another disease common in radiata pine, also caused by a foliar *Phytophthora*. *Phytophthora* scientists were recruited to Scion from Australia to work on the problem, and research continues to assess its impact, and to understand the biology of the pathogen and its interaction with the host species: radiata pine and Douglas fir. Control methods are also being researched. At the time of the incursion NZ's skills in *Phytophthora* were very limited, and extremely limited for foliar *Phytophthora*.

NZ's plant biosecurity science and the application of this science over decades has greatly reduced the cost of these kinds of incursions. Nevertheless, incursions that have not been eradicated are still causing losses to primary production in the order of billions of dollars per year. Costs to the natural estate and the public good are more difficult to estimate; if iconic species such as kauri were lost, the cost would be immeasurable. The challenge we face is to maintain an optimal level of day-to-day biosecurity protection (i.e. weighing up the costs and benefits of being prepared for relatively foreseeable risks) while maintaining sufficient capability and capacity to respond to less frequent but more serious incursions.

Recommendations

This review concludes that there are gaps in NZ's capabilities in plant biosecurity science that create weaknesses in our overall biosecurity system. Some of these gaps, such as the science needed to protect the natural estate, are large and will be difficult and expensive to fill. Other gaps, such as in pastoral agriculture, are also large but the fix is perhaps more obvious and more feasible to achieve. Solutions will take time to develop and implement, and will cost money, so this will only happen if stakeholders want it to happen.

The review team supports the recommendation of the Biosecurity 2025 SD5 Working Group[39] that a compendium of existing biosecurity science skills, by discipline, be compiled for all relevant organisations, and that it include recognition of the important skills provided by generalists – those who understand natural and production systems and how unwanted organisms can affect them. Such a compendium should include a table of existing risk modellers and bioeconomists, who could be engaged in the event of an incursion or in research projects to model how a particular organism might spread in NZ and affect our economy.

It is generally accepted that scientists skilled in a particular discipline, such as entomology or pathology, can apply their skills across sectors, and there are many examples of this happening. But it is also accepted that effective response to a new incursion requires more than just specialised skills, and there is a need for people with a broad understanding of how productive and natural ecosystems function. Together, specialists and generalists can be most effective responding to and dealing with an incursion. MPI has considerable capability and experience in pulling teams together, but concerns have been expressed that there are not enough biosecurity generalists available to work in TAGS if needed.

NZ's skills in biosecurity surveillance are limited, and we benefit from our support of CEBRA for assistance in risk modelling. We also contract in expert help from other countries. Few sectors are employing scientifically designed biosecurity surveillance programmes, and there is virtually no such biosecurity surveillance of the natural estate. This is clearly a science gap.

Some respondents said that NZ should not try to cover everything, but should rely on international networks of scientists. COVID-19 has made that more difficult, but not impossible, but there is obviously a perception among some respondents that there are skills overseas just waiting to be utilised. Other respondents were unsure about this: '[International] researchers often make these positive noises but I wonder how many are keen to donate their time and resources?'

Several respondents expressed concerns about the availability and complementarity of biosecurity-oriented university courses. A survey of foundational teaching in general plant biology at university level, and of core subjects available for biosecurity-oriented Master's/PhD programmes, would be helpful in identifying teaching gaps and opportunities for course expansion.

Our impression is that the relevant networks are currently mostly at the personal level, and that it would be worthwhile to document what interconnections exist more formally, particularly in areas where capability and capacity in NZ are thin. Development of an international network capability map was recommended to us by some industry respondents:

> *International collaboration is important to more rapidly understand the science of risk organisms. We see this now with many organisms, such as BMSB and Xylella. Euphresco[40] is a good example of international collaboration.*

Key points

- **As a next step, the reviewers recommend that a compendium of existing biosecurity-relevant science skills, by discipline, be compiled for all relevant science providers. The compendium should include identification of plant-systems-level generalists.**
- **There is also a need for an infrastructure database to identify current strengths and gaps in NZ's key biosecurity science equipment and facilities.**
- **These two compendiums would assist with proactive planning for future serious incursions, including better clarification of the role each science organisation would be expected to play in such an event.**
- **The reviewers recommend a survey of foundational teaching in general plant biology at university level, and of core subjects available for biosecurity-oriented Master's/PhD students, with a view to identifying teaching gaps and opportunities for subject expansion.**
- **While recognising that Better Border Biosecurity (B3) is an excellent model, there is a need for improved biosecurity science networks, including international collaborators, that are accessible by industry as well as by government and scientists.**

Appendices

Appendix 1. New Zealand's biosecurity system

New Zealand's biosecurity system is based on risk management activities undertaken across a range of inter-related areas – internationally, at the border, and within New Zealand. This graphic, sourced from *New Zealand's Biosecurity 2025 Direction Statement*, summarises the system's main layers, activities and outcomes.

	Layer of the system	Outcomes
International	**International Plant and Animal Health Standards** Developing international standards and rules under the World Trade Organization Sanitary and Phytosanitary Agreements.	Science and risk-based standards lead to an easier environment to trade in while protecting our biosecurity.
	Trade Agreements and Bilateral Arrangements Negotiation, agreements and processes for future biosecurity cooperation and trade.	Biosecurity requirements for New Zealand businesses are reasonable and create commercial certainty when trading overseas.
	Risk Assessment and Import Health Standards Identification of risk and specification of requirements for people and goods coming into the country, including assessment of applications to import organisms new to New Zealand.	The majority of biosecurity risks are managed offshore so that compliant passengers and cargo arrive at our border. Biosecurity risks that arrive onshore are managed effectively.
Border	**Border Intervention** Educating and auditing to encourage compliance. Inspecting to verify compliance and taking action to manage non-compliance.	Trade and travel are facilitated for people and goods complying with New Zealand regulation. The accidental or illegal import of pests is prevented from creating biosecurity risk.
Within New Zealand	**Surveillance** General and targeted programmes to detect harmful pests and diseases.	Harmful pests and diseases are detected promptly. New Zealand's pest freedom status is known. The spread of established pests into new areas, or changes in a pest's risk profile, are detected promptly.
	Readiness and Response Regular testing of the biosecurity system's capability to respond. Responding to detected harmful pests and diseases.	The biosecurity system is ready to respond to new organism incursions. Harm from detected new pests and diseases is minimised.
	Long-term Pest and Disease Management **National scale management** – eradication, containment or management of a pest across New Zealand. **Regional management** – primarily led by regional councils through regional pest management plans and pathway plans. **Local scale management** – to protect values in places. Pests within a site are managed to the extent necessary to protect the place's values.	Harm caused by established pests and diseases is reduced or contained, through exclusion, eradication, progressive containment, or sustained control at the most appropriate scale (national, regional or local).

Appendix 2. List of interviewees

Respondent	Position[a]	Organisation[a]
Sophie Badland	Biosecurity Manager	NZ Wine
Nigel Bell	Science Team Leader, Soil Biology/Nematology	AgResearch
Peter Bellingham	Senior Researcher	Manaaki Whenua – Landcare Research (MWLR)
Paul Bradbury	Director	SPS Biota
Rosie Bradshaw	Professor in Genetics	Massey University
Angela Brownie	Acting Director, Readiness and Response	MPI
Peter Buchanan	Pathologist	MWLR
Mark Bullians	Biosecurity Business Manager	Plant & Food Research
Lindsay Bulman	Science Leader, Forest Pathology	Scion
David Burger	General Manager	DairyNZ
Libby Burgess	Science Group Leader, Applied Entomology	Plant & Food Research
John Caradus	CEO	Grasslanz
Paul Champion	Programme Leader – Freshwater Biosecurity	NIWA
Tony Conner	Science Group Leader Forage Science	AgResearch
Will Cuddy	Plant Pathologist	NSW Dept Primary Industries
Bill Dyck	Biosecurity Consultant (self-interview)	BDL
Matt Dyck	Biosecurity Manager	KVH
Tom Etherington	Spatial Modeller, Ecology	MWLR
Erik van Eyndhoven	Biosecurity Manager, Natural Forests	MPI
Colin Ferguson	Agricultural Entomologist	AgResearch
Verity Forbes	Technical Advisor	DOC
Karyn Froud	Biosecurity Consultant	Biosecurity Research Ltd
Beccy Ganley	Biosecurity Science Manager	Plant & Food Research
Hoda Ghazalibiglar	Molecular Plant Pathologist	MPI
Travis Glare	Director	Bio-Protection CORE
Stephen Goldson	Principal Scientist, Biosecurity	AgResearch
Lynley Hayes	Science Team Leader, Biocontrol and Molecular Ecology	MWLR
Veronica Herrera	Director	MPI
Rod Hitchmough	Science Advisor Threats	DOC
Dave Hodges	Biosecurity Senior Advisor	DairyNZ

[a] When interviewed in mid-2020.

Ian Horner	Team Leader, Pathogen Biology	Plant & Food Research
Gary Houliston	Portfolio Leader, Plant Biodiversity and Biosecurity	MWLR
Chris Houston	Senior Manager, Technical Policy	Beef + Lamb NZ
Mark Johnson	Seed Phytosanitary	NZGSTA
John Kean	Risk Modeller	AgResearch
Lalith Kumurasinghe	PHEL Manager	MPI/PHEL
Ivan Lawrie	GM Business Operations	FAR
Jo Luck	Director	PBRI Australia
Robin MacDiarmid	Senior Scientist, Virology	Plant & Food Research
Calum MacNeil	Senior Scientist, Freshwater Ecology	Cawthron Institute
James McCarthy	Ecosystems Modeller	MWLR
Rebecca McDougal	Programme Leader – Pathology	Scion
Marie McEntee	Lecturer, Social Scientist	University of Auckland
Mark McNeill	Scientist, Biosecurity	AgResearch
Petra Muellner	Risk Consultant	Epi-Interactive Ltd
Wim Nijhof	Group Leader, Human and Ecological Health	ESR
Maureen O'Callaghan	Principal Scientist, Microbiology	AgResearch
Michael Ormsby	Manager, Biosecurity Science and Risk Assessment	MPI
Sofia Orre-Gordon	Science Team Leader, Biocontrol and Biosecurity	AgResearch
Steve Pawson	Senior Lecturer, Forestry	University of Canterbury
Enrico Perotti	Risk and Science Director	MPI
Craig Phillips	Senior Scientist, Biosecurity	AgResearch
Anna Rathe	Biosecurity Manager	Horticulture NZ
Christine Reed	Manager, Biosecurity Risk Analysis	MPI
Mark Ross	CEO	Agcarm Inc.
Brad Siebert	Biosecurity Manager	NZ Avocado
German Spangenberg	Director, AgriBio	La Trobe / Agriculture Victoria Research
Nick Spencer	Science Team Leader, Informatics	MWLR
Margaret Stanley	Associate Professor, Ecology	University of Auckland
Alison Stewart	CEO	FAR
Alan Stewart	Chief Scientist	PGG Wrightson
Tasha Tassell-Matamua	Senior Lecturer, Social Scientist	Massey University

David Teulon	Director / Principal Scientist	B3/PFR
Fiona Thomson	Technical Advisor Threats	DOC
Peter Thomson	Director	MPI
Nick Waipara	Senior Scientist, Biosecurity	Plant & Food Research
Steven A Wakelin	Microbial Ecologist	Scion
Prue Williams	GM Science	MBIE
Toni Withers	Senior Entomologist	Scion
Susie Wood	Senior Scientist, Biosecurity Freshwater and Marine	Cawthron Institute
Ian Yule	R&D Manager	PlantTech

Appendix 3. Other acknowledgements

The authors acknowledge the following additional individuals who assisted in preparation of the report by providing helpful information, clarifications or responses to specific queries.

Respondent	Position[b]	Organisation[b]
Matthew Brady	Freshwater Technical Advisor	DOC
John Brightwell	Response Manager	MPI
Andrea Byrom	Director	NZ Biological Heritage NSC
Bev Clarkson	Capability Leader, Plant Ecology	MWLR
Mark Fitzpatrick	Director, Terrestrial Science	DOC
Luis Gea	Team Leader, Geneticist	Plant & Food Research
Wellcome Ho	Principal Scientist	MPI
Keith Iken	Technical Advisor Freshwater	DOC
Suzanne Keeling	Science Strategy Manager	Beef and Lamb
Peter Kemp	Professor, Pasture Science	Massey University
Clement Lagrue	Science Advisor Ecosystems	DOC
Janice Lord	Associate Professor, Plant Ecology and Evolution	University of Otago
Duane Peltzer	Principal Scientist, Ecosystem Ecology	MWLR
Charlotte Pushparajan	Senior Adviser – Germplasm Imports	MPI
Tom Richardson	Past CEO	AgResearch
Andrew Sander	Response Manager	MPI
Jacqueline Rowarth	Professor, Plant and Soil Science	Lincoln University
Marc Shallenberg	Associate Professor, Freshwater Ecosystems	University of Otago
Katrin Webb	Principal Advisor, Science Investments - Threats	DOC

[b] Position and organisation when contacted.

Footnotes

1 Investment to enable this report was gratefully received from Manaaki Whenua's MBIE Strategic Science Investment Fund biodiversity platform, Plant & Food Research, MPI, AgResearch, Scion, NZ Biological Heritage National Science Challenge and the Bio-Protection CoRE at Lincoln University.
2 For example, the Ngā Rākau Taketake (myrtle rust disease) Strategic Science Investment Fund platform
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39 www.biosecurity2025.nz/assets/Resources/8f83c1a57b/Work-plan-Strategic-Direction-5.pdf
40 Euphresco (euphresco.net) is a network of European organisations funding and coordinating research in the phytosanitary area.