Stocktake of Biosecurity Research, Science and Technology Priorities

March 2021

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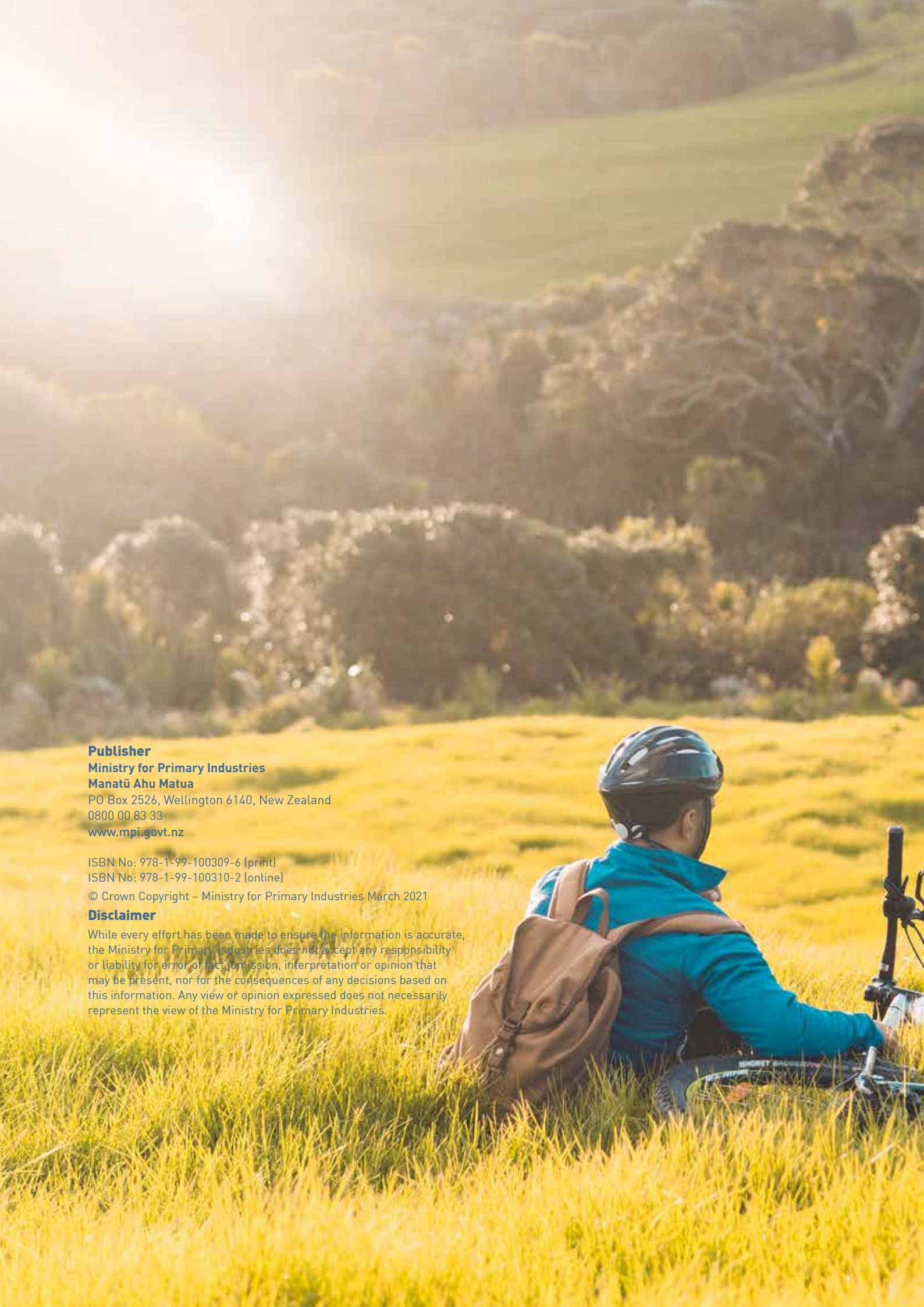
BIOSECURITY 2025



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Foreword

Launched in 2016, *Biosecurity 2025* set out future directions for strengthening Aotearoa New Zealand's biosecurity system and is intended to be an enduring guide for New Zealand's biosecurity system until at least 2025.

Research, science and technology play a critical and foundational role in New Zealand's biosecurity system. The research needed to protect our marine, freshwater, and land-based environments; our primary production, trade and tourism; and the health and wellbeing of our people and culture, is currently identified in numerous published documents and processes. The purpose of this Stocktake is to bring together the many existing priority signals into one document, and to provide some overarching high-level priorities for immediate action.

The Stocktake aligns biosecurity research, science and technology with *Biosecurity 2025* and the needs of the biosecurity system. It is designed to support investment choices in research programmes, inform science capability and capacity planning, and support development of partnerships with local and international research collaborators. Priorities are targeted to an initial five-year horizon, with short-term and long-term outcomes. The priorities are aimed at driving investment toward addressing New Zealand biosecurity's biggest challenges.

The assessment and identification of priorities outlined in this Stocktake was led by a Biosecurity Science Working Group (Working Group) with support from the Ministry for Primary Industries Manatū Ahu Matua (MPI). Priorities were collated from a system-wide assessment of more than 30 relevant existing published documents (and associated planning processes) from industry, Non-Government Organisations (NGOs), regional and national government agencies, and hapū and iwi environmental plans and priorities, as well as focused discussions with New Zealand experts in biosecurity science and management.

The list of priorities in this Stocktake is long; reflecting the complexity of the biosecurity system. To provide greater focus the working group identified six top priority areas where immediate attention could result in some big wins for the biosecurity system.

The Working Group thanks the many contributors who provided input to help develop this Stocktake. The Working Group also acknowledges and commends the work of many people to establish *Biosecurity 2025* and subsequent work plans. In building on their work, we gratefully accept the challenge of ensuring that the biosecurity system is supported by forward-looking research and innovation, aligned to system needs.

The Biosecurity 2025 Science Working Group:

- Dr Ian Ferguson, MPI (Working Group Chair)
- Dr Andrea Byrom, Director of the Biological Heritage National Science Challenge
- Dr Oliver Floerl, Cawthron Institute
- Dr Nick Waipara, Te Tira Whakamātaki (The Māori Biosecurity Network)
- Dr John Roche, Departmental Science Adviser for MPI, replaced Dr Ian Ferguson as the Working Group Chair in September 2018

The role of science and innovation in New Zealand biosecurity system

Aotearoa New Zealand context

New Zealanders value the natural, urban, and production environments in which they live and work. Natural landscapes underpin our sense of national identity. Our economic, environmental and cultural prosperity are inextricably linked to, and strongly dependent on, our natural environment.

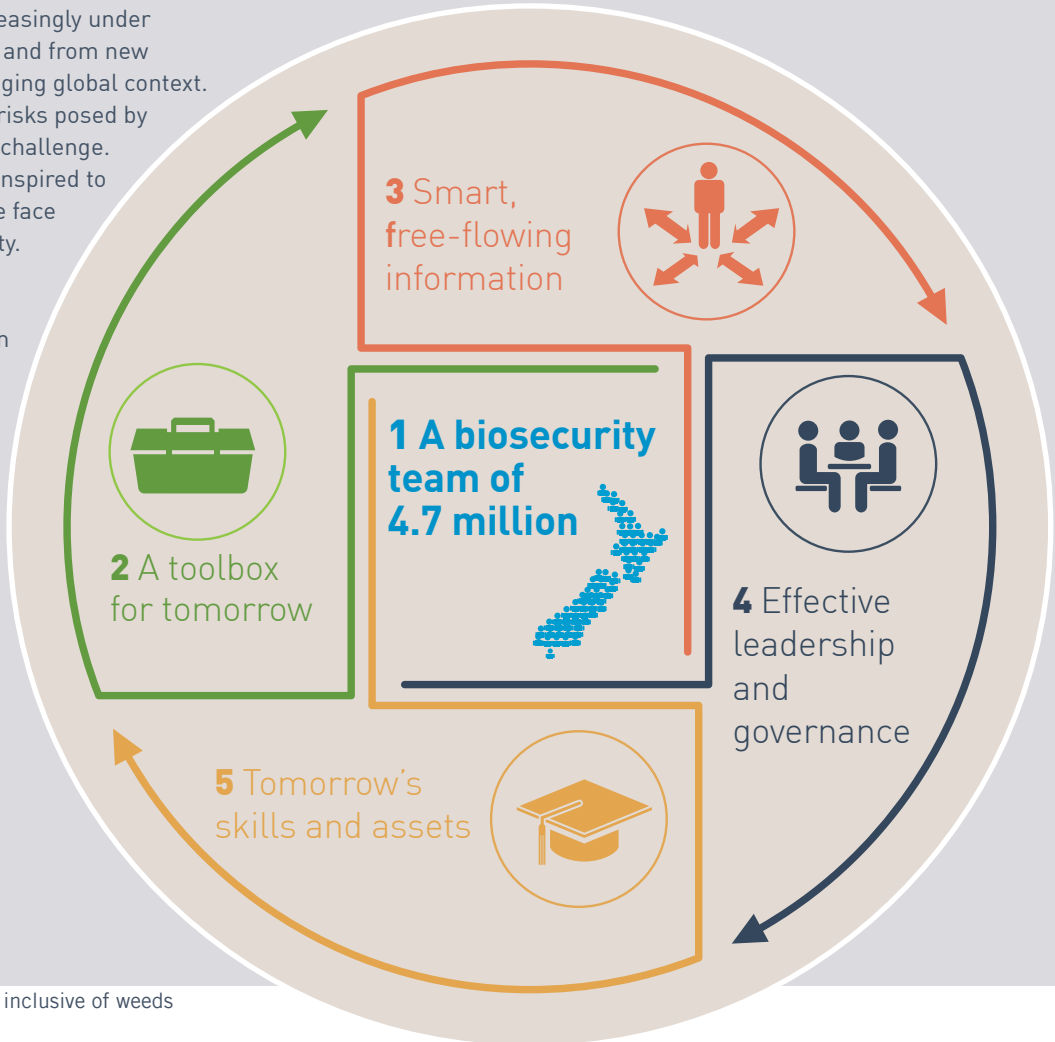
People all over New Zealand are practising biosecurity every day – working in our communities, in business, in government and in our own backyards. And in a uniquely New Zealand context, Māori are now recognised as having a distinct and important role in the biosecurity system. There is growing recognition of what's at stake; our lifestyles, livelihoods and environments depend on a state-of-the-art, effective biosecurity system, and on having the social licence to act.

Our unique environments are increasingly under threat from introduced organisms and from new threats emerging in a rapidly changing global context. Protecting New Zealand from the risks posed by pests[1] and diseases is a continual challenge. More New Zealanders need to be inspired to take action because the threats we face are growing in scale and complexity. Growth and diversity in trade and tourism, changing risk pathways, climate change, and pressure from established pests are just some of the examples of the pressures New Zealand faces.

Science and innovation have a major role to play in future-proofing our biosecurity system – a role that was outlined in *Biosecurity 2025*, which identified five interconnected strategic directions, each with a critical science component:

> Biosecurity is the exclusion, eradication or management of pests and diseases that pose a risk to the economy, environment, and cultural and social values, including human health. The biosecurity system spans activities offshore (pre-border), at the border, and within New Zealand (post-border).

Figure 1: Five key strategic directions in Biosecurity 2025



1 Throughout this stocktake "pests" is inclusive of weeds

The role of science and innovation in New Zealand biosecurity system

Global context

New Zealand's biosecurity science has a clear global context and needs to remain strongly connected to international research and innovation. Many countries around the world are facing similar challenges associated with pests and diseases, and strong international cooperation can maximise progress and prevent duplication of effort. Pest and disease threats originating offshore usually have an associated body of knowledge that we need to access, including potential management tools and techniques. While our unique environment can make it difficult to predict the likely impacts of an organism should it enter our country, having a good understanding of what is known about potential threats still has considerable value. Continually scanning for new approaches and technologies and being open to a robust, objective review of New Zealand science, programmes and strategies, is vital for a healthy biosecurity system.

There are many opportunities to strengthen New Zealand's biosecurity system through international collaborations. Collaborative global research consortia need to be part of New Zealand's biosecurity research portfolio. Such collaborations afford essential access to research skills and resources and open New Zealand researchers and biosecurity practitioners to novel approaches and ideas.

We also need to ensure excellence and objectivity in our biosecurity science. Increased use of international peer review; involvement of international expertise in research teams and science advisory groups; collaboration with indigenous knowledge holders; secondments; and reciprocally, placement of New Zealand scientists with offshore research institutes and biosecurity regulatory and advisory bodies, are all potential mechanisms to increase connectivity, collaboration, and excellence.

Globally, biosecurity science and innovation trends and drivers include the rapid emergence of step-changing technologies, e.g. genomics; artificial intelligence; real-time surveillance systems; the threat of bioterrorism; big data, modelling, and free-flowing data systems; characterisation of changing global trade routes and risks; regional- and national-scale eradication of invasive species; and the impacts of climate change on biosecurity risks and threats.

Other indigenous peoples, like Māori, have developed customary practices and knowledge to respond to biosecurity incursions as well as manage invasive species that threaten their land and resources. Indigenous peoples also hold traditional ecological knowledge and provenance of many species that are now present in New Zealand. Recognising this indigenous global network, and their relationships with Māori, will enable international collaboration and connections with indigenous led approaches, ideas and learnings.

Why a Stocktake?

This Stocktake is one of the major outputs arising from Biosecurity 2025. It addresses the needs identified by Biosecurity 2025 to:

- set research and innovation priorities strategically, so that investment is aligned with, and delivers to, whole-of-system needs;
- incorporate a breadth of disciplines, knowledge systems (especially mātauranga Māori), and research fields; and
- ensure science and knowledge outputs are relevant and outcome-focused, practical and accessible, and that timely and effective use is made of them to benefit the biosecurity system.

Priorities for biosecurity science exist in numerous published documents and processes. The purpose of this Stocktake was not to undertake a full prioritisation process from the ground up but to capture those existing priorities and bring them together into one place, and to identify some key areas for immediate attention where focused research effort is required.

Priorities identified in section 3 and 4 of this Stocktake were collated from a system-wide assessment of existing priority signals. Common priorities were aggregated. Priorities were drawn from a variety of sources, including:

- more than 30 relevant published documents from industry, NGOs, regional and national government agencies, (including the Primary Sector Science Roadmap and the Conservation and Environment Science Roadmap), and hapū and iwi environmental plans and priorities (Appendix 1);
- cross agency interactions related to biosecurity science planning processes; and
- focused discussions with New Zealand experts in biosecurity science and management.

It is intended that this Stocktake will provide a consolidated and future-focused view of research and innovation needs for the New Zealand biosecurity system. It will influence investment choices in research programmes to 2025; inform science capability and capacity planning; and support development of partnerships with local and international research collaborators. The shared view of science and technology needs that this Stocktake supports will help science funders, providers, educators and industry to work collaboratively, identify common opportunities, and focus research effort to areas of importance to the biosecurity system.

Relationship with other government science initiatives

The Stocktake, by bringing together biosecurity research priorities drawn from a raft of various other strategies, plans and published documents, provides a cohesive summary of biosecurity research needs across the whole biosecurity system. The Stocktake will not replace other strategies and plans, which provide direction in their respective parts of the system, but rather provides an overarching view of needs.

These priorities can inform and align with biosecurity science and research investment priorities across industry groups, the Government Industry Agreement process, local and regional government, national government agencies (especially MPI, Department of Conservation and Ministry for the Environment), research organisations and the education sector. The Stocktake, as part of Government's overall strategy for the science system, will help inform investment and be an important document for the strategic directions of key New Zealand science programmes and funds including the National Science Challenges, Tertiary Education Commission Funds, Strategic Science Investment Fund, and contestable science funding.

How this Stocktake is structured

This document can be viewed through two lenses. Section 3 focuses on **nine long-term outcomes** needed to future-proof an "end to end" biosecurity system (Figure 2). Priority areas for research are listed under each outcome. Section 4 presents a view of the biosecurity system stratified by **three domains** (the biophysical environment, social/cultural and economic domains) that our biosecurity system protects. Priorities for domains are cross-referenced to the nine outcomes. **Science and research priorities in sections 3 and 4 are not listed in priority order**.

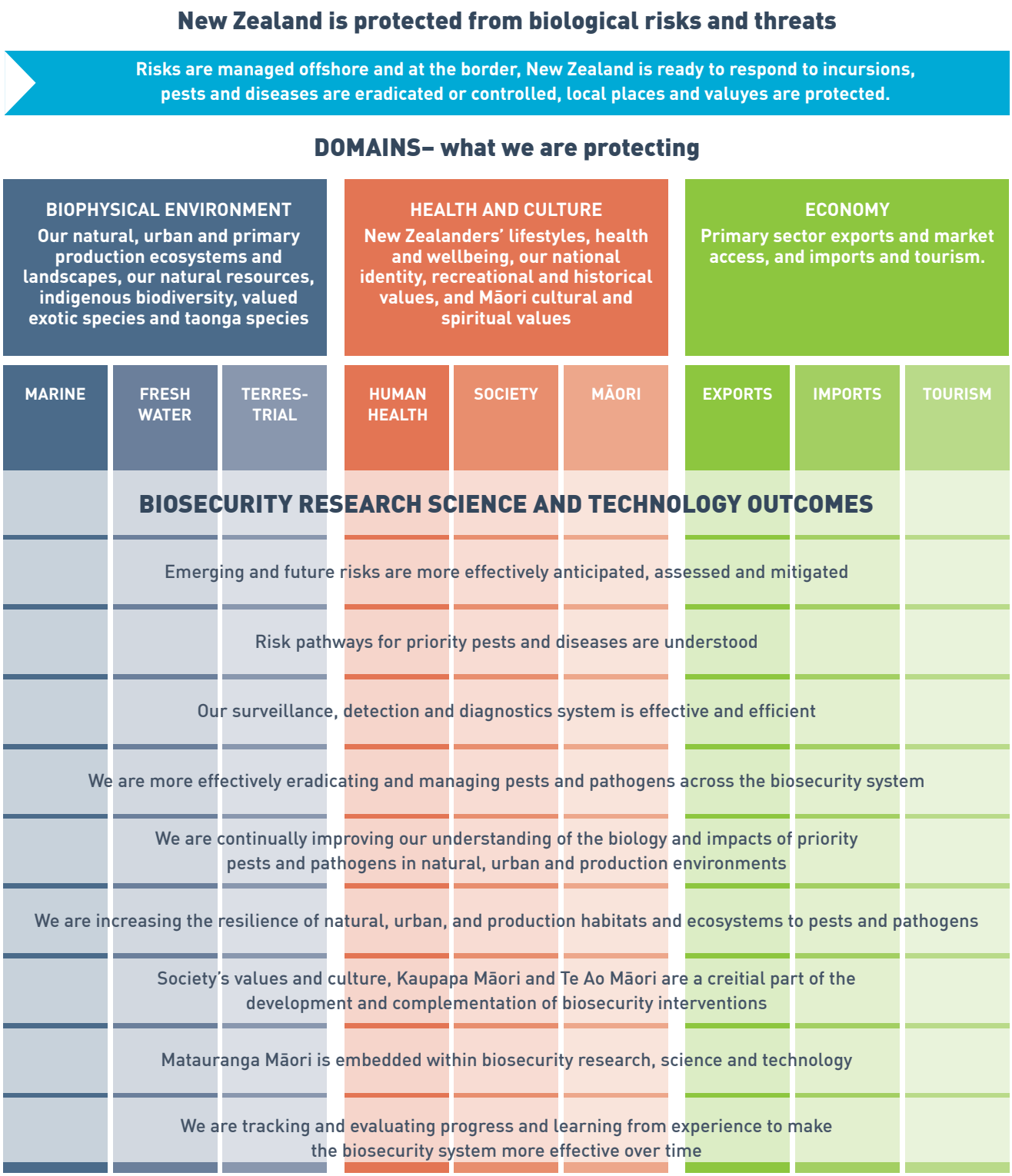
Priorities listed in the outcomes and domains overlap at times as they are designed to stand alone, catering to people with different interests working within different parts of the biosecurity system. Investors, researchers and funders with an interest in strategic, longer-term impact in a particular part of the biosecurity system, e.g. surveillance and diagnostics, can refer to section 3 (Outcomes) of this Stocktake. Those with a particular interest in cross-cutting domain-specific priorities such as freshwater should consult section 4 (Domains). A brief introduction to existing effort and/or progress to date is provided in each section.

The aggregated view of science and innovation priorities – cross-referenced between sections 3 and 4 – is intended to help science funders, providers, educators, and industry to act collectively and collaboratively; to identify common opportunities; and to co-design directed effort toward outcomes of importance for end to end biosecurity.

Figure 2 illustrates how the domains and outcomes fit together, with the biosecurity system outcomes cutting across all the domains.

Recognising that the list of collated existing biosecurity science priorities is long and it is not possible to achieve all priorities at once, the Stocktake also identifies six overarching priority areas (section 2) where immediate focused effort would see significant gains for our biosecurity system.

Figure 2. Biosecurity research, science and innovation priorities framework.



Beyond the Stocktake

This Stocktake has been compiled from a range of key sources. It is a foundation document that provides a comprehensive view of research needs across the biosecurity system. The priorities set out in sections 3 and 4, are all important, but cannot all be progressed at once. In developing the Stocktake, the Working Group identified areas that are critical across multiple outcomes and domains where collective effort and greater focus could lead to significant strengthening and futureproofing of New Zealand's biosecurity system. These 'system-wide priorities for biosecurity research' all meet the following principles. They:

- are consistent with te ao Māori;
- have a sense of timeliness and urgency including addressing emergent risks;
- cut across domains and/or outcomes, and therefore have a greater need for focus and alignment and likely require a multidisciplinary and/or collaborative response; and
- will drive significant systemic improvements, agility and impact for the biosecurity system.

Science plans have already been developed for a range of biosecurity issues, including *Mycoplasma bovis*, kauri die back and myrtle rust. Similar science plans with clear success criteria could be developed for each of the following system priorities.

This will require ongoing involvement and leadership from the biosecurity science community and stakeholders. For biosecurity research to be effective, it needs to be prioritised and undertaken within the context of all biosecurity system participants, including (as defined in Biosecurity 2025) Māori/iwi; industry and businesses; scientists and research organisations; landowners and occupiers; community groups and NGOs; regional councils; MPI and other government agencies; and individuals, including in their capacity as travellers, educators and consumers.

Top biosecurity system-wide research priorities

1. **Maximising the value of mātauranga Māori and te ao Māori for biosecurity research – acknowledging and supporting the significant value that partnership with Māori, including Māori-led research, can provide** Currently, partnership with Māori knowledge holders and biosecurity practitioners in science and research needs development. Embedding mātauranga Māori in biosecurity research will ensure we are drawing on all critical knowledge available to help address critical biosecurity issues. Addressing this priority will also be important internationally as an example of effective partnership with indigenous peoples in biosecurity.

2. **Streamlined data integration, sharing, and re-use for better biosecurity outcomes – taking advantage of new approaches to data management, use and integration to increase the efficiency and effectiveness of the biosecurity system.** – taking advantage of new approaches to data management, use and integration to increase the efficiency and effectiveness of the biosecurity system. Innovative data use is critical to increase the efficiency and effectiveness of the biosecurity system and will require effective management of sensitive information, data sovereignty and privacy considerations.

3. **Integrating social, psychological, behavioural and biophysical research for creative biosecurity solutions – creating strong biosecurity and a strong biosecurity culture through understanding how we incentivise active participation in biosecurity.** The biosecurity system relies on people. People's values and behaviours drive system change, and human decision-making shapes policy and legislation. Better understanding the people elements alongside the biophysical will strengthen biosecurity.

4. **Integrating step-changing technologies into the biosecurity system – understanding the potential of new technologies for improved biosecurity, including whether the acceptability or social licence to support them exists.** New technologies have the potential to deliver transformational change for the biosecurity system in New Zealand, but we need to determine their acceptability in the New Zealand landscape and where appropriate capitalise on these advances. This could include consideration of the potential of genomics, gene editing, robotics, artificial intelligence, nanotechnology, and sensor technologies. .

5. **New approaches for supporting science for readiness and response for high risk organisms – prioritising and addressing critical science needs to aid prevention, accelerate eradication or rapidly improve management of high risk organisms.** When significant new biosecurity issues arise we need to take a strategic and aligned approach to map out, prioritise and address critical science needs. This priority will support careful consideration of which areas require additional focus.

6. **Driving science to fill the critical gaps in biosecurity risk pathways – ensuring that risk pathways (both international and domestic) are as well managed as possible by addressing the most fundamental science gaps.** Pathways for biosecurity risks are constantly changing with global trade, travel and tourism patterns. Science and research needs to be focused to help us ensure that international and domestic risk pathways are as well managed as possible, and to address the most fundamental risks both in a prevention and response context.

Innovating through kaupapa Māori and embedding mātauranga Māori – a new way of working with Māori

Māori/iwi have a critical role in the biosecurity science system as partners with the Crown through te Tiriti o Waitangi. Māori are also kaitiaki of New Zealand's taonga, have increasing statutory roles in the sustainable management of natural resources, and hold a nationally significant stake in the management of land and water in New Zealand.

Māori possess a unique knowledge and perspective which has a distinctive contribution to make to New Zealand's biosecurity science system. Better connectivity, co-innovation and integration between kaupapa Māori (research defined and led by Māori) approaches and other biosecurity science will help address the many challenges we face in the biosecurity system and greatly improve biosecurity outcomes. Kaupapa Māori research approaches are often interdisciplinary, and therefore draw on a range of interconnected values and practices, informed by a holistic worldview.

A key component of kaupapa Māori research approach is mātauranga Māori. Mātauranga Māori is a dynamic and constantly evolving Māori knowledge system that encompasses traditional knowledge, worldview and values along with local and contemporary knowledge.

The Stocktake supports the integration of mātauranga and Māori priorities across the development of all research, science and innovation to provide system-wide solutions to biosecurity, as well as supporting mātauranga Māori in its own right.

A key part of implementing the Stocktake will be identifying how mātauranga Māori is recognised, developed and used in new ways, both distinct from and (where appropriate) integrated with other science approaches. This may include making use of indigenous knowledge systems to inform early detection and modelling of risks to New Zealand; developing best practice protocols for research that uses or impacts all taonga; co-developing and/or testing emerging and novel biosecurity technologies with hapū and iwi; and developing kaitiakitanga-led initiatives to prevent and manage biosecurity threats.

Developing kaupapa Māori and mātauranga Māori approaches within the biosecurity system will require Māori engagement to be strengthened, and ensuring Māori are represented in all decision-making processes in biosecurity incursion responses. It will require kaupapa Māori and mātauranga Māori to be better understood and supported, and support researchers to develop expertise in these areas.

A new way of working with people and communities

Biosecurity 2025 stresses the importance of all New Zealanders in the biosecurity system and that everyone has a role to play. In a similar way, biosecurity science cannot be undertaken in isolation of our people. How the research is undertaken is as important as the research itself. Engagement with all end-users needs to be undertaken from the start. This will help ensure that biosecurity tools and technologies can be used as the social licence to do so exists; that research outputs are relevant, practical and accessible; and that investment is prioritised, aligned and delivering to the whole-of-system needs.

A culture of community, collaboration and interdisciplinary research partnerships is key to success in biosecurity and the science which contributes to it.

On a national scale, we must more effectively engage the public, communities and other stakeholders in the undertaking of science. Building social networks to help engage effectively with stakeholders, especially in relation to risk management interventions, prevention and mitigation will be key to success.

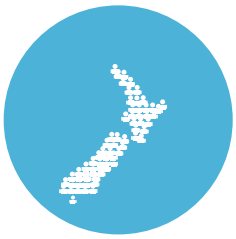
Better sharing of data and information is also an area where significant gains can be made. For example, developing readiness and response plans for different scenarios will be of value if shared widely amongst all those with a responsibility in a particular response scenario.

Zoe Lyle

Priorities through the lens of **outcomes:** *science to support our long-term goals for New Zealand's biosecurity system*

The task of protecting New Zealand from biological risks and threats addresses end-to-end biosecurity, including: managing risks offshore (pre-border); our activities at the border; post-border activities to reduce the likelihood of harmful pests or diseases establishing in New Zealand; and eradicating or managing established pests. Nine outcomes focus research, science and technology to support end to end biosecurity. Priorities for research, science and technology are organised under each outcome.

Integration across outcomes is also desirable because research and innovation needs are often parallel or complementary. System-wide communication, cross-pollination of ideas, and sharing of developments is critical.



Outcome Statement 1: Emerging and future risks

Outcome stocktake: Emerging and future risks are more effectively anticipated, assessed and mitigated.

This outcome is about improving methods and the evidential basis for identifying, prioritising and managing biosecurity risks at the earliest intervention points, ideally before risk organisms reach New Zealand. This includes improving New Zealand's ability to forecast emerging biosecurity risks within a changing climate and international environment and with growing trade and tourism; address systemic risks; and ensure that citizens and businesses have confidence in the biosecurity system and can participate as needed.

Priorities within this outcome particularly support strategic directions 1 and 2.

Priorities

- Identify priority emerging pests and pathogens nationally and internationally
- Develop robust tools to predict the potential associated biosecurity risks (direct and indirect) of priority pests and diseases across New Zealand's natural, urban, and production environments
- Develop methods to better predict, monitor and analyse potential biosecurity risks and opportunities resulting from changes in:
  - resource use and availability, such as energy or food resources;
  - geopolitical dynamics and international dynamics;
  - transport technologies;
  - domestic industry practices, such as intensification of primary production systems;
  - climate; and
  - tourism (diversification and intensification of).
- Assess the efficacy of existing tools and strategies for managing risks to New Zealand offshore
- Develop and validate new, cost-effective, safe and environmentally sound tools and strategies for managing risks, which optimise the use of data and analytics and integrate information on human, economic and environment behaviour with biological science, anomaly detection and predictive modelling
- Identify priority biosecurity risk taxa for which taxonomic information is lacking and address critical gaps in information
- Improve our ability to identify latent risks from pests and diseases already present in New Zealand, including lag times from establishment to impact, and why some exotic species establish and spread and others do not

Outcome Statement 2: Risk pathways

Outcome stocktake: Risk pathways for priority threats are understood.

This outcome is focused on understanding the pathways through which pests and pathogens can enter New Zealand and spread. This includes understanding pest and pathogen vector/host/commodity relationships and pathway analysis and modelling to better target risk goods and understand the magnitude of risk associated with the pathway.

Priorities within this outcome particularly support strategic direction 2.

Priorities

- Improve our ability to forecast, anticipate and manage new pathways before they present a risk
- Increase understanding of pathways through which high-risk pests and diseases enter New Zealand by developing better methods to trace incursions to and from the source
- Improve understanding and characterisation of natural and human-mediated pathways through which damaging pests and diseases can spread within New Zealand, and identify the most effective points of intervention
- Improve understanding of the potential for taxa in New Zealand to act as hosts, vectors or facilitators for exotic pests and diseases
- Improve treatments for risk goods and vectors at pre-border, at the border and in transitional facilities, including evidence-based information for target organisms and effective application
- Develop methods to better monitor, analyse and predict how climate change, and its impacts (such as other environmental stresses), will potentially change domestic and international pathway risks
- Improve our ability to anticipate and manage the risks from rapidly growing pathways such as eCommerce
- Understand the new biosecurity risks from changes in tourism, with increased tourist numbers, new source countries, and an increasing desire to have experiences in the natural environment
- Improve our ability to verify that compliance measures have been undertaken

Outcome Statement 3: Surveillance, detection and diagnostics

Outcome stocktake: Our surveillance, detection and diagnostics system is effective and efficient.

Detecting and accurately identifying pests and pathogens before, or as soon as possible after their introduction, knowing whether they are part of an established population or not, and accurate surveillance of their distribution and spread, is vital for the success of management or eradication campaigns.

Better knowledge of where pests and diseases are also opens the door to more targeted control strategies and reduced non-target impacts. Cost-effective large-scale surveillance is a critical need here.

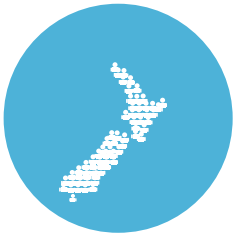
Taxonomy and biosystematics are in the midst of a profound technological revolution, with advances in technologies including three-dimensional imaging, big data and molecular tools. It is important that we keep up-to-date with international progress in technologies for identification and detection of pests and pathogens to ensure readiness to respond if and when the social context is right.

This outcome includes information technology and data science along with development and application of targeted, cost-effective screening, surveillance and early detection tools, including pathway surveillance.

Priorities within this outcome particularly support strategic directions 2, 3 and 5.

Priorities

- Develop new and improved detection and diagnostic tools for cost-effective surveillance of priority environments, risk pathways or vectors pre-border, border and post-border, including:
  - sensors capable of detecting incursions that we are currently unable to detect; and
  - new algorithms that are capable of identifying incursions using existing and aggregated data that is currently available, including community surveillance information.
- Develop integrated surveillance systems and the means to capture and interpret surveillance data from multiple sources so that data is widely accessible, inter-operable, can be queried, is integrated across domains and sectors, and can be analysed and modelled to support timely action
- Develop improved survey designs and sample methods for surveillance, particularly for the deployment of new technologies
- Undertake mātauranga Māori research to establish historical relationships and provenance of invasive species
- Establish the effectiveness of community (including iwi) based crowd-sourced surveillance systems
- Improve understanding of how indigenous knowledge systems can inform early detection and modelling of risks to New Zealand
- Build and maintain species/taxonomic/provenance inventories across the biosecurity system
- Identify priority biosecurity risk taxa for which taxonomic information is lacking and address those gaps, including biosystematics research
- Develop genetic sequence databases to enable effective molecular detection of pest and disease organisms, and develop real-time genetic field sequencing devices that can identify pest and disease organisms within hours of testing
- Develop predictive modelling for detection probabilities in New Zealand environments



Outcome Statement 4: Eradicating or managing pests and pathogens

Outcome stocktake: We are more effective at eradicating and managing pests and pathogens across the biosecurity system.

New Zealand continues to face new incursions, in addition to needing to combat pests and pathogens that are already here. Tools and technologies are needed for both. This outcome focuses on eradicating or managing pests and pathogens that pose a risk across all domains, recognising the need for public participation and for the approaches to be socially acceptable.

Priorities within this outcome particularly support strategic directions 1 and 2.

Priorities

- Develop generic best practice readiness and response plans, including validated operational protocols for different scenarios
- Develop models of cultural, environmental, social and economic costs and benefits in eradication that enable effective, real time decision making
- Develop new and improve existing tools and techniques that are more cost-effective, socially and culturally acceptable, and humane, to improve pest and pathogen management and eradication at landscape and seascape scale
- Improve monitoring methodologies for effects (from management actions) on non-target species and the environment
- Quantify pest density-impact thresholds for managing pests and pathogens across interconnected landscapes and seascapes where eradication is not feasible
- Appropriately use mātauranga Māori (knowledge, practices and tools) to eliminate or eradicate pests and diseases

Outcome Statement 5: Biology and impacts of priority pests and pathogens

Outcome stocktake: We are continually improving our understanding of the biology and impacts of priority pests and pathogens in natural, urban and production environments.

This outcome is focused on growing the biological knowledge platform for biosecurity. We need to understand the biology of pests and pathogens, along with the ecosystems (see section 3.6) to assess their relative biosecurity risks and find the most effective points of intervention to prevent and mitigate their impact.

There is a particularly pronounced knowledge gap with respect to predicting the impact of threats to natural environments and biodiversity, because in most cases there is no body of evidence on prior associations between our native species and new incursions. This contrasts with pests and diseases of crops and livestock, where we can draw on the experiences of other countries with the same organisms.

Priorities within this outcome particularly support strategic direction 2.

Priorities

- Establish consistent and transparent parameters for establishing which invasive organisms should be considered priority pests and pathogens
- Increase understanding of the likely distribution, ecology, behaviour and direct and indirect impacts of priority pests and diseases, their relative biosecurity risks, and the most effective points of intervention in production and natural ecosystems
- Increase understanding of the population dynamics of multiple interacting pests and pathogens, including the role of the host/vector and/or environment on these dynamics
- Increase understanding of the exacerbating factors which may influence how successful a pest or pathogen is at establishing within New Zealand, including virulence, specific New Zealand conditions, climate change or disturbance, e.g. fire or earthquake
- Improve understanding of the behaviour of invasive pests around control and surveillance devices, and their interaction and encounter rates, to increase detection probabilities
- Prioritise and conduct studies of New Zealand's biodiversity targeted at data deficient areas or taxa to understand our baseline so change can be detected

Outcome Statement 6: Increasing resilience

Outcome stocktake: We are increasing the resilience of natural, urban and production habitats and ecosystems to pests and pathogens.

Resilience is defined as the capacity to absorb disturbance and maintain function. Landscapes and species interact dynamically, competing or co-evolving over time as an ecosystem shifts from one state to another. This outcome is focused on the richly interconnected relationships of flora, fauna, people and place, and how biosecurity actions can help maintain characteristics New Zealanders value, restore degraded ecosystems, and determine how human decision-making influences ecosystem resilience.

Priorities within this outcome particularly support strategic directions 2 and 5.

Priorities

- Develop methods to predict, monitor and assess the susceptibility of natural, urban and primary production environments to pests and pathogens
- Improve our understanding of cultural, social and ecological interdependencies, including pest or pathogen impact threshold levels and the degree of reversibility of impacts on ecosystems
- Improve understanding of how climate change could impact on potential future incursions; established pests and pathogens; and our natural and production environments, and change the resilience of our ecosystems to future incursions
- Characterise ecosystem responses over time and space to multiple stressors on complex systems, including pests and pathogens, land use change, and climate change
- Develop appropriate indicators of change in social-ecological systems that are suitable for use by biosecurity decision-makers and communities
- Develop and design tools and methods to enhance resilience to pests and pathogens of urban and production environments, including enhancing native biodiversity in these systems to reduce the establishment and proliferation of invasive organisms
- Identify situations in which landscape-scale and site-based biosecurity management approaches could be integrated and understand the opportunities, methodologies and constraints to scaling from site to landscape
- Investigate how policy, legal and institutional biosecurity arrangements can help improve ecosystem resilience outcomes

Outcome Statement 7: Society's values and culture, kaupapa Māori and te ao Māori

Outcome stocktake: Society's values and culture including kaupapa Māori and te ao Māori, are a critical part of developing and implementing biosecurity interventions.

Everyone has a role to play in biosecurity. The enormity of the biosecurity task means that we need all New Zealanders to play a part. If we are successful, every New Zealander will know the importance of biosecurity and be motivated to act, with synergistic benefits for society and the environment. For those directly involved in the biosecurity system, this means better understanding the complexity of society and incorporating that understanding into the system so that the system better reflects the values, needs and aspirations of New Zealanders.

Current biosecurity initiatives and programmes, for example Predator Free 2025 and response programmes such as for *Mycoplasma bovis*, offer significant opportunities to engage with communities. This engagement can lead to the programmes being shaped by societal views in relation to potential new interventions and initiatives. There is much to be learned from these existing programmes.

Priorities within this outcome particularly support strategic directions 1, 2, 4 and 5.

Priorities

- Develop comprehensive models for New Zealanders' values, beliefs, and motivations regarding biosecurity and how these are changing over time
- Determine how factors such as increased urbanisation and changing demographics shape and inform biosecurity values
- Understand barriers to, and opportunities/drivers to enhance, participation in the biosecurity system
- Improve understanding of social acceptance of, and underlying drivers for, the acceptability or otherwise of new biosecurity tools and technologies
- Increase understanding of the effectiveness of compliance approaches for modifying behaviour, and compliance with relevant legislations
- Investigate power and trust in institutional arrangements and regulatory bodies to help build social licence to manage biosecurity risks and threats more effectively, and to improve the services provided
- Quantify the linkages between the social, cultural and biophysical dimensions of the biosecurity system
- Understand how the tools and techniques used to drive social innovation and behaviour changes can be an enabler of science uptake and policy change
- Increase understanding of how and when mātauranga Māori

and Kaupapa Māori approaches can be used to develop kaitiakitanga-led initiatives to prevent and manage biosecurity threats and support related decision-making
- Understand, through partnership with Māori, how tikanga (customary practices and procedure) can be better included in policy and approaches to manage biosecurity risks and threats
- Increase understanding of how and when mātauranga Māori and Kaupapa Māori approaches can be used to develop kaitiakitanga-led initiatives to prevent and manage biosecurity threats and support related decision-making
- Understand, through partnership with Māori, how kawa (customs and protocols) and tikanga (customary approaches and guidelines) can be better included in policy and approaches to manage biosecurity risks and threats

Outcome Statement 8: Mātauranga Māori is embedded

Outcome stocktake: Mātauranga Māori is embedded within biosecurity research, science and technology.

Mātauranga Māori (the Māori knowledge system) and tikanga whakahaere (Māori management practices) inform Māori biosecurity priorities and can make an important contribution to the management of pests in, and eradication of pests from, New Zealand.

Embedding mātauranga Māori is a strategic priority for science in New Zealand and engaging Māori in research is a priority for both the Crown and Māori. This is reflected in the Ministry of Business, Innovation and Employment's policy framework Vision Mātauranga, which aims to unlock the science and innovation potential of Māori knowledge, resources and people for the benefit of New Zealand.

Priorities within this outcome particularly support strategic directions 1, 4 and 5.

Priorities

- Understand the role of Māori in the biosecurity science system, and how to partner with Māori to enhance biosecurity outcomes
- Understand the values Māori consider when assessing risks across whole of system biosecurity decision-making and policies, e.g. risk to community safety, identity, food source, etc.
- Develop tools and risk assessments that provide appropriate consideration of impacts of pest species on all Māori values, as defined by Māori, and what types of impacts pest species could have in the future relevant to te ao Māori
- Develop biosecurity tools to support iwi, hapū and whānau in their role as kaitiaki and decision makers
- Develop hapū and iwi data sovereignty systems that underpin and explore critical knowledge relating to indigenous data governance, ownership and access, and potential solutions for benefit and innovation across the whole biosecurity system
- Develop culturally-informed standards with tangata whenua for use by people undertaking research, generating data from indigenous and taonga species included in biosecurity-based research programmes

Outcome Statement 9: Tracking and evaluating progress

Outcome stocktake: We are tracking and evaluating progress and learning from experience to make the biosecurity system more effective over time.

This outcome is focused on enabling New Zealand's biosecurity system to continually learn, improve and adapt over time by collecting and making effective use of large amounts of data to inform decision-making. This should include information collected specifically for biosecurity purposes as well as making use of related environmental data.

Priorities within this outcome particularly support strategic directions 1, 2, 3 and 5.

Priorities

- Develop new or improved tools for more cost-effective and standardised collection of critical environmental data, including in situ, automated and real-time monitoring technologies
- Develop methods, inclusive of indigenous protocols, to manage large volumes of data collected across the biosecurity system (and data collected for other purposes but of relevance to the biosecurity system) and better tools/processes/analytics to deliver maximum impact and use by decision-makers and communities
- Increase understanding of the barriers, opportunities and potential mechanisms to enable data sharing (of data both directly and indirectly relevant to biosecurity and recognising data provenance and the protection of indigenous data)
- Develop improved and robust methods for evaluating the cost-effectiveness of biosecurity management and interventions (from prevention to response) and their delivery of the desired outcome(s)

Priorities through the lens of domains: protecting our biophysical environment, health, culture and economy

The biosecurity system contributes to the protection of environmental, cultural, social, and economic values (domains). These values are inextricably linked. Each domain presents a snapshot of current state, including the big biosecurity challenges, current initiatives and progress, and domain-specific research and innovation priorities.

- The Biophysical Environment domain encompasses our natural, urban and primary production environments. It includes our natural resources, including primary production systems, indigenous authority systems and networks, indigenous biodiversity, ecosystems, landscapes, taonga species and valued exotic species. It spans marine, freshwater (including estuarine and wetland) and terrestrial landscapes, and covers both plant and animal health.
- The Health and Culture domain is about how biosecurity relates to health and wellbeing, our national identity, indigenous distinction, Māori cultural and spiritual values, recreational and historical components of our society, and New Zealanders' lifestyles.
- The Trade and Tourism domain covers biosecurity priorities for critical components of our economy, including market access and primary sector exports, imports, tourism and indigenous jurisdictions.

Domain 1: Our biophysical environment: natural, urban and primary production environments

This domain encompasses our unique biophysical environments, natural, urban and primary production, terrestrial, marine, freshwater, estuarine and wetland ecosystems and landscapes, natural resources, indigenous biodiversity, taonga species and valued exotic species.

Protecting our marine environment

New Zealand has an expansive and complex marine estate and the fourth-largest Exclusive Economic Zone in the world. Due to its geographic isolation, New Zealand has a high proportion of endemic marine species unique to New Zealand, including key taonga species. As an island nation, shipping is an integral part of our international and domestic trade. Hundreds of international and thousands of domestic recreational vessels explore our coasts annually. Our association with an international transport network and our increasingly complex domestic network provide effective pathways for the spread of marine pests and diseases. Our aquaculture industry is growing and diversifying, with multiple farming regions located from the top of the North Island to the bottom of the South Island. Wild fisheries and other maritime industries are also susceptible to introduced pests and diseases. Our approach to managing marine biosecurity threats into the future requires effective governance, recognition of indigenous territorial boundaries, clarity surrounding national and regional roles, buy-in and uptake of biosecurity culture and appropriate long-term investment.

Biosecurity challenges in the marine environment

New Zealand's marine industries, including aquaculture, are expected to grow. A changing global climate will affect the susceptibility of our waters to the establishment of non-indigenous species. Together, economic and environmental change will likely alter existing, or open up new risk pathways for marine pests and pathogens. We need to strengthen understanding and awareness of marine biosecurity risks and impacts to develop the best possible management tools. New Zealand is taking a pathway-based approach to mitigate international and domestic marine biosecurity risks. Effective technologies and strategies based on science and mātauranga are required to support our growing regulatory tool-box and enable risk management and mitigation with minimal impact on trade and tourism.

Current research progress in the marine environment

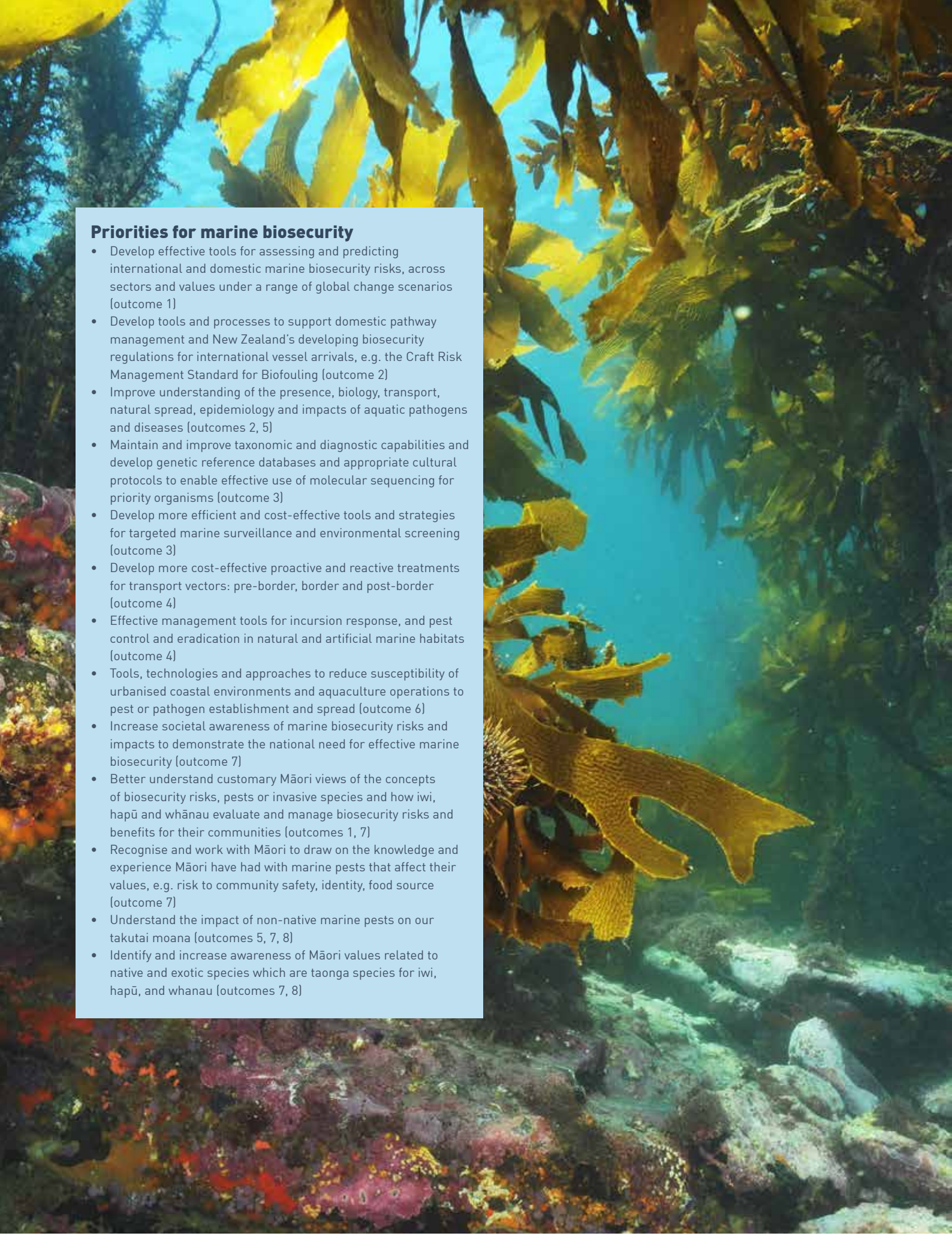
We have made significant progress over the past two decades. Today, we have a reasonable understanding of which marine pests are established around New Zealand, how they got here, and how they are spreading. Present research continues to make progress on the development of improved surveillance tools, ways to identify high-risk transport vectors and decision tools for intervention. We have developed strategic international collaborations to address shared challenges.

While proactive approaches to prevent the uptake of pests and pathogens by transport vectors (particularly biofouling, but also others) have been developed to some extent, the regulatory framework that allows or requires their use and effective application is largely lacking. There is a lack of cost-effective, fit-for-purpose treatment tools for high-risk international and domestic vectors and pathways, and a lack of cost-effective tools and strategies for control or eradication of established populations. We also require a better understanding of the longer-term value of effective marine biosecurity to all New Zealanders in order to justify sustained support.

Ārai Koiora ā-Moana – marine biosecurity is a research priority for Māori

Enabling and implementing te ao Māori perspectives within New Zealand's current marine biosecurity system has been consistently highlighted as a priority for Māori. For this to occur we need to: recognise the values held by Māori; understand how those values are impacted by biosecurity (which are not always quantifiable); and understand how they can be appropriately considered in decision making for New Zealand's marine biosecurity (both the spread of existing or arrival of new marine pests). We need to increase knowledge around how marine pest incursions have impacted on Māori values in the marine environment and how they might in the future. We need to also recognise Māori knowledge and experience of biosecurity issues within our coasts and oceans.

Research to include the value of marine environments to Māori and how Māori evaluate the threats from pest species to their marine environments is lacking. An example of an incursion that has led to considerable concern around impacts on native species and cultural activities (traditional harvesting) is the Mediterranean fanworm (Sabella spallanzanii), which has invaded a wide range of coastal habitats in both the North and South Islands. In contrast some non-native species, like the Pacific oyster (Crassostrea gigas) cause changes to natural habitats, but are now an important source of kaimoana and, for some, a source of employment and income.



Priorities for marine biosecurity

- Develop effective tools for assessing and predicting international and domestic marine biosecurity risks, across sectors and values under a range of global change scenarios (outcome 1)
- Develop tools and processes to support domestic pathway management and New Zealand's developing biosecurity regulations for international vessel arrivals, e.g. the Craft Risk Management Standard for Biofouling (outcome 2)
- Improve understanding of the presence, biology, transport, natural spread, epidemiology and impacts of aquatic pathogens and diseases (outcomes 2, 5)
- Maintain and improve taxonomic and diagnostic capabilities and develop genetic reference databases and appropriate cultural protocols to enable effective use of molecular sequencing for priority organisms (outcome 3)
- Develop more efficient and cost-effective tools and strategies for targeted marine surveillance and environmental screening (outcome 3)
- Develop more cost-effective proactive and reactive treatments for transport vectors: pre-border, border and post-border (outcome 4)
- Effective management tools for incursion response, and pest control and eradication in natural and artificial marine habitats (outcome 4)
- Tools, technologies and approaches to reduce susceptibility of urbanised coastal environments and aquaculture operations to pest or pathogen establishment and spread (outcome 6)
- Increase societal awareness of marine biosecurity risks and impacts to demonstrate the national need for effective marine biosecurity (outcome 7)
- Better understand customary Māori views of the concepts of biosecurity risks, pests or invasive species and how iwi, hapū and whānau evaluate and manage biosecurity risks and benefits for their communities (outcomes 1, 7)
- Recognise and work with Māori to draw on the knowledge and experience Māori have had with marine pests that affect their values, e.g. risk to community safety, identity, food source (outcome 7)
- Understand the impact of non-native marine pests on our takutai moana (outcomes 5, 7, 8)
- Identify and increase awareness of Māori values related to native and exotic species which are taonga species for iwi, hapū, and whanau (outcomes 7, 8)

Protecting our freshwater environment

A wide range of existing and potential freshwater pests pose a significant threat to New Zealand's environment and economy. Between catchments, people are the primary vectors for invasion and spread of non-indigenous organisms, providing challenges and opportunities for biosecurity management. While there are numerous examples of successful interventions and eradications, more new pests are becoming established than are being eradicated.

Aquatic invasive species such as didymo in the South Island and koi carp in the North Island continue to compromise the integrity of freshwater systems. Terrestrial exotic species such as Canada geese (Branta canadensis) also impact on water quality and indigenous species habitat, along with being damaging to crops.

Pests and diseases, water abstraction, over harvesting, climate change, increasing sediment and nutrients, pollution, and habitat loss and modification are driving the decline in indigenous freshwater biodiversity and ecosystem health. These threats often occur in combination and their interactive effects can be more damaging than any one threat in isolation.

Biosecurity challenges in the freshwater environment

Many of New Zealand's lakes, streams and rivers have declined in quality and health, increasing the sensitivity of our freshwater bodies to the impact of pests and diseases. Specific biosecurity challenges include:

- illegal importation for the aquarium trade and the unintentional or deliberate spread of pests;
- increasing cultural diversity and value systems that have the potential to escalate introduction and movement of new pests;
- limited tools and capacity to control and/or eradicate new and existing pests; and
- knowing what pests are present in an area and detecting new organisms at low densities.

Current research progress in the freshwater environment

Numerous freshwater pests have been eradicated either nationally, for example marron, or regionally within New Zealand, for example hornwort from the South Island and Lagarosiphon major from Lake Ngakapua. Some progress has been made on risk assessment modelling for freshwater restoration, and research identifying high-value water bodies has been undertaken, allowing for prioritisation of protection and restoration efforts.

Research and innovation can help prevent or minimise the impact of freshwater pests and diseases. Progress in this area requires a focus on investment in early detection, eradication and management of biotic threats, along with a need for tools and strategies to restore degraded freshwater ecosystems. Restoring ecosystems requires better knowledge of species interactions and ecosystem dynamics to understand and build ecosystem resilience and predict thresholds for 'state-shifts'. There is also a need to better understand how to scale restoration efforts appropriately.

Priorities for freshwater biosecurity

- Identify and prioritise high-risk species before they enter New Zealand (or naturalise in the case of risk species kept in captivity) (outcome 1)
- Develop and implement pathway management tools and strategies, focusing in particular on high-value water bodies (outcomes 1 and 3)
- Develop cost effective detection and surveillance tools and strategies for freshwater pests and diseases (outcomes 3 and 4)
- Develop cost-effective eradication tools and methods to enable application at scale: optimise pest control technologies ranging from species-focused solutions to whole-of-waterbody interventions (outcome 4)
- Understand the effects of and ecological services provided by pest species in invaded environments, including natural, urban and degraded environments (outcome 5)
- Undertake economic evaluation of intervention management and predict the impact of freshwater pests with and without intervention (outcomes 5 and 9)
- Better understand values, behaviours and drivers related to native freshwater biota and freshwater systems to strengthen biosecurity interventions and behaviour change (outcome 7)
- Te ārai koiora wai māori (freshwater biosecurity). Identify and understand the range of freshwater pests and other non-indigenous species that are already present and impacting wai māori, as well as understand the novel interactions between these pests and taonga species (outcomes 7 and 8)
- Identify and increase awareness of Māori values related to native and exotic species which are taonga species for iwi, hapū, and whanau, (e.g. trout – an invasive species but still highly valued by some Māori interests and iwi) (outcomes 7 and 8)
- Understand the roles of, and how to empower, kaitiaki and all New Zealanders in preventing invasions (outcomes 7 and 8)
- Understand how climate change, under different scenarios, will alter pest and pathogen distribution and impacts in freshwater ecosystems (outcome 9)
- Understand the effects of freshwater pests and pathogens as environmental stressors, and their interactions with other environmental stressors (outcome 5)
- Understand the role of terrestrial pests and pathogens on water quality, quantity and habitat (outcomes 5 and 6)

Terrestrial Environments

Protecting our valued plants

Protecting our native flora and primary production landscapes against invasive weeds, diseases and pests is an ongoing battle. Invasive plants can outcompete natives in the absence of natural enemies, transforming habitat and driving large scale biodiversity loss. They can cost our farming and forestry sectors billions of dollars each year in management costs and production and export losses. New Zealand's plant-based industries are growing and changing rapidly, with novel uses for plant components providing a wealth of new opportunities for the primary sector. The future of these growing industries is dependent on a robust biosecurity system.

Plant biosecurity challenges

New Zealand has been battling plant pathogens such as *Phytophthora agathidicida* (causing Kauri dieback); *Austropuccinia psidii* (commonly referred to as myrtle rust – a threat to iconic species such as rātā, pōhutukawa and mānuka); *Pseudomonas syringae pv actinidiae* (Psa-V, causing bacterial canker of kiwifruit); and other pathogens causing impacts on forestry and pastoral-based production.

Pests such as Argentine ants, fruit flies and brown marmorated stink bugs, and mammals such as possums, wallabies and tahr, are further substantial threats to New Zealand's primary industries and native flora.

As plant industries grow, there are increased challenges to ensure that plant material imports are pathogen and pest free, and that nurseries are not hubs for the spread of pests and pathogens. Some plant biosecurity threats enter New Zealand via pathways which are harder to manage, such as weather systems. The myrtle rust incursion highlighted the need to be able to quickly respond to a new biosecurity threat using cost-effective, large-scale surveillance and treatments.

Classical biological controls are likely to be insufficient going into the future, and novel technologies need to be tested for societal and environmental efficacy. To maintain or gain social licence for tools to combat plant pests, weeds and pathogens, agencies need to work with hapū and iwi, communities and industry.

Interest in ecosystem restoration is flourishing, with kaitiaki and Māori environmental resource units and voluntary groups undertaking local ecological protection and restoration projects. These initiatives provide opportunities for central and local government to support the growth and interconnection of hapū and iwi with community-led efforts toward restoration at a landscape scale.

Current research progress in plant biosecurity

The Better Border Biosecurity (B3) consortium of research providers, which has a specific focus on plant biosecurity and has been in existence for more than 13 years, is an example of how a collaborative, cross-institutional approach can deliver greater benefit from research and innovation and provide strategic linkages to international research teams. In addition, development of Government Industry Agreements has significantly increased industry investment and engagement in preparedness activities for plant-based biosecurity risks. A formal emerging risk system now actively screens for new weeds, pests and diseases that may be a threat to New Zealand. Biosecurity research to reduce risk on germplasm import pathways and on plant movement pathways remains a priority to maintain New Zealand's access to elite germplasm.

Significant issues remain with access to and management of information and risk data. Issues with provenance and data sovereignty, the safe storage, retrieval, quality and completeness of such data significantly hinders New Zealand's ability to respond to biosecurity threats in a timely, comprehensive and cost-effective manner.

Tools to detect the presence of pathogens before disease is manifest can mitigate spread and increase the chance of successful eradication. The range of tools available to manage biosecurity risks has declined significantly in recent years as a result of societal concerns. This decline has significantly increased the risk that New Zealand will not be able to effectively prevent or respond to future plant biosecurity threats.

Priorities for Plant Biosecurity

- Understand the role of environmental factors and stressors in pest or pathogen occurrence and symptom expression (outcome 1)
- Identify major classes of potential new pests and pathogens, and ensure there is appropriate research to underpin mitigation of risk establishment and spread (outcomes 1, 2 and 5)
- Investigate novel and emerging technologies for risk assessment, pathway management, diagnostics, surveillance, and pest and disease eradication and control (outcomes 3 and 4)
- Understand societal values in relation to new and existing tools for pest and pathogen management and eradication, and drivers of uptake of biosecurity measures (outcomes 4 and 7)
- Support pathway and impact assessment, and response strategies for new and high-risk pests and pathogens and their vectors (outcome 5)
- Protect the ecological function of avian and insect pollinators in natural and primary production ecosystems (outcome 6)
- Build resilience to future biotic threats and to climate and land use change by improving plant and ecosystem health in natural and primary production ecosystems (outcome 6)
- Support and enable mātauranga Māori, kaupapa Māori responsiveness, and Māori values and priorities to understand risks, measure and monitor plant health as well as manage and or eradicate pests and diseases that impact taonga plants (outcome 8)
- Improve tools for data access, collection, storage, integration, analysis, and quality assurances (outcome 9)

Protecting our valued animals

This domain focuses on biosecurity threats to domestic animals, indigenous terrestrial fauna, and marine and freshwater fauna. Pests and pathogens pose a great risk to our valued indigenous and non-indigenous fauna, through direct impacts such as predation and disease, and indirect impacts such as competition and altering of landscapes and habitats.

The health of animals, people and the environment is connected, e.g. overuse of antibiotics in both humans and animals lead to antimicrobial resistance in the environmental microbiota, potentially leading to more resistant strains of microbially-mediated human disease. A One Health approach must involve the collaborative effort of the cultural health, human health, veterinary health, and environmental health communities to achieve optimal health outcomes for both animals and people.

New Zealand's livestock sectors are responsible for approximately 70 percent of domestic exports. Farm animals are vulnerable to diseases not currently present in New Zealand, but which exist in many other countries. Although foot and mouth disease poses the greatest threat of economic devastation to the primary industries and New Zealand Inc., avian and swine influenza could be equally devastating to their respective industries, not to mention the risk to human health and the challenges they could pose the New Zealand health sector. The recent outbreak of *Mycoplasma bovis* revealed that even a disease with no human or direct export impacts can impose significant financial and social costs upon New Zealand. Companion animals and other animal–based industries, such as horse racing, are equally vulnerable.

New Zealand's unique indigenous fauna are also susceptible to mammalian pests. For example, rats, stoats and possums kill approximately 25 million native birds every year and have caused the decline or extinction of many native insects and lizards. Exotic parasitic insects, insect predators and competitors such as exotic predatory snails, and a wide range of viral, bacterial and fungal pathogens, all impact on our valued animals. Some of these cause diseases that can threaten species on the brink of extinction. For example, cloacitis (crusty bum) is a major threat to the survival of kākāpō; and New Zealand's amphibian populations are vulnerable to chytridiomycosis, the disease caused by chytrid fungus. Similarly, our marine mammals and birds are at risk from pests and diseases. Harmful algal blooms and diseases can be significant causes of mortality of New Zealand fur seals, sea lions and hectors dolphins, while avian diptheria is a major issue for our endangered penguins.

Disease threats, invasive pests and climate change often interact to compound the effects and create a "perfect storm" for vulnerable indigenous fauna.

Animal biosecurity challenges

Border control is an ongoing challenge, with the need to balance risks from imports against the benefits of trade. Sophisticated risk assessment based on the collation and analysis of large volumes of international data and strong scientific evidence is a necessity. The growing threat of antimicrobial resistance is an extension of our biosecurity challenges, with increased pressure to reduce the use of antimicrobials in animal production systems. Although New Zealand is a relatively small user of antibiotics in production animals on a global scale, much of densely populated south-east Asia's swine and poultry production systems are heavily dependent on antibiotics. Antimicrobial resistance is, therefore, a risk to food security and human health, factors that can directly influence New Zealand's biosecurity system.

There is an on-going risk of animal diseases entering New Zealand via air-borne vectors such as insects and migratory birds, e.g. avian influenza. While these risks cannot be eliminated, appropriate surveillance and biosecurity measures can be adopted to reduce the risk of incursions and/or to increase preparedness for their arrival. Detailed understanding of the presence of pests and diseases internationally, animal population demographics and movement, disease epidemiology, pathway connectedness, epidemiological modelling of disease spread, and control measures, are key to preparedness and response. This will require a better system for integrating international and national animal health data sources to support research and surveillance efforts (for animal industries and native fauna alike).

Climate change will create new biosecurity challenges by allowing for existing pests and pathogens to spread, and new pests and pathogens such as subtropical pests and other taxa that are already recognised as high risk, to potentially establish. Climate change may also create new biosecurity challenges less directly, for example by allowing for new industries with associated new risks. Climate is just one of several factors that affect invasion potential. Other factors such as import pathways, border management, host suitability and land use intensification or change will also operate synergistically to change future risk.

Current research progress in animal biosecurity

For diseases of our valued non-indigenous fauna, there is a large volume of international science to draw upon,

however this is not the case for our valued indigenous fauna. Most of the New Zealand specific research efforts to date have focused on the data science aspects of biosecurity preparedness and response, including analysing trends in passively-collected animal health data streams, characterising patterns of animal movements and contacts among livestock farms, and developing computer simulation models to explore outbreak scenarios. These studies have highlighted significant issues with the quality and completeness of national animal health data, which stem from the lack of incentives for farmers to enter quality data. There is also a general lack of understanding as to why farmers have, or have not, adopted particular biosecurity practices and what can be done to motivate positive behavioural changes, which represents a whole new social science approach to disease epidemiology.

For management of mammalian and invertebrate pests, the scope of current research is broad and includes research into trapping, developing pest specific toxins, risk assessment, and surveillance strategies, along with research into new technologies and social licence. New technologies in the area of pest management are progressing rapidly.

Understanding trade trends is an ongoing need, as risk can be proportional to the volume of commodity imported, with an increase in volumes imported leading to increase in potential risk. The analysis of surveillance and intelligence data is an increasing area of development, with real-time data circulating in social channels more quickly than through official channels. Although diagnoses may be less accurate, an ability to collate and investigate data from various social channels offers an opportunity to strengthen biosecurity. Similarly, data integration through improved inter-agency cooperation, improvements in facial recognition technology, and interconnectedness traceability frameworks such as blockchains, will likely increase our ability to track passengers and shipments through their full itinerary. The realisation of this surveillance will require significant investment in bioinformatics algorithm development.

Priorities for animal biosecurity

- Develop new and improved tools for managing animal pests
- Improve understanding of mammalian pest behaviours at low densities to enhance the success of eradication efforts and increase the success of early detection
- Use risk mapping and gap analysis to determine which pests and diseases and which questions should be prioritised for future research (outcomes 1 and 9)
- Understand and quantify pathogen exchange between farmed and wild animals to inform animal health strategies at industry and farm levels (outcome 2)
- Increase understanding of trade volume variations for commodities, including short and long term trade trends, with more accurate data recording at the border at the point of entry (outcome 2)
- Improve understanding of how climatic factors and distribution pathways within New Zealand, (including unintended or illegal pathways) influence pest and disease establishment and spread (outcome 2)
- Apply genetic analysis tools, with appropriate validation, to understand the origin, relatedness, and spread of diseases (outcome 2)
- Integrate demographic, surveillance, and diagnostics databases with appropriate data management protocols, to ensure a comprehensive and integrated research approach to animal disease incursions and spread (outcome 3)
- Develop methods for earlier detection of new pests, diseases or disease risks (outcome 3)
- Improve understanding of disease reservoir and vector species to enhance success of eradication efforts and increase the success rate of early detection and prevention programmes. This should include wildlife reservoirs in addition to other livestock herds (outcomes 3 and 4)
- Investigate effective, practical and acceptable alternatives to mass slaughter of production animals in response to incursions of serious livestock diseases (outcome 4)
- Develop and test vaccines for potentially significant diseases for use on zoo animals and rare or endangered indigenous species (outcome 4)
- Strengthen the knowledge and evidence base about antimicrobial resistance (outcome 5)
- Support and enable mātauranga Māori, kaupapa Māori responsiveness, and Māori values and priorities to protect, manage and eradicate pests and diseases that impact taonga animals (outcome 8)
- Increase understanding of appropriate data standards and data management, which data to collect in terms of value, and how to store it (outcome 9)
- Understand Māori values related to species which are not native but are highly valued and taonga species for iwi, hapū, and whanau, e.g. pig, deer, tahr, chamois and goat. (outcomes 7 and 8)

Domain 2: Our health and culture: including Māori perspectives

New Zealanders' lifestyles, health and wellbeing, national identity, recreational and historical values, and Māori cultural and spiritual values, are all a function of a successful biosecurity system.

Protecting human health

As the movement of people and goods globally is increasing, the threat of diseases and vectors of disease, including new and emerging threats, being introduced into New Zealand grows. Visitor numbers into New Zealand increased by 50 percent from 200,000 people a month to 300,000 people a month during the last decade. Cruise ships, a large growth industry, visit New Zealand with passengers from around the globe.

Risks to human health may result from incursions of insects that can carry and transmit human diseases (such as species of mosquito capable of carrying Zika virus and Ross River virus), zoonotic diseases (diseases capable of infecting both humans and animals) such as Ebola and Salmonellosis, or new strains of organisms harmful to human health that can be carried in food and animal products. The human health impact may be physical illness or mental health and wellbeing impacts, as evidenced in the impact of *Mycoplasma bovis* on farmers, their families and communities. Climate change is also likely to put greater pressure on biosecurity by increasing the availability of suitable habitats for disease vectors, particularly insects.

Add to this, the growing threat of antimicrobial resistance, and the importance of biosecurity to our health wellbeing is obvious. Furthermore, recent incursions have threatened taonga species such as Kauri and Myrtaceae unique to Aotearoa, directly impacting on plants of cultural and spiritual significance.

Biosecurity challenges in human health

Our biosecurity system must continue to consider and manage the increased risk from the growing number of offshore visitors, vessels and products entering New Zealand each year to ensure that human, plant and animal health is maintained. Health and biosecurity must work closely to strengthen the One Health approach to identify and address the animal and health risks and to ensure we maintain the expertise required to respond to emerging disease threats. Understanding those threats and ensuring international collaboration is of paramount importance.

Distinctive biosecurity challenges and impacts to hauora (health and social wellbeing) continue to arise within Māori communities. A kaupapa Māori research approach that inherently embeds cultural authority is needed to identify and understand these on-going needs and challenges.

Effective prevention, detection and response are critical to reduce biosecurity risks. Biosecurity systems must evolve to take advantage of additional modern surveillance activities (e.g. social media monitoring), to alert authorities to known threats. Epidemiological and pathway connectedness modelling of diseases should be state-of-the-art.

The Ministry of Health, New Zealand Food Safety and Biosecurity New Zealand are committed to ensuring the International Health Regulations 2005 are being effectively implemented in New Zealand. Closer collaboration of these agencies with hapū and iwi is required to ensure a holistic and comprehensive approach to animal and human health, commonly referred to as One Health.

Current research progress in biosecurity and human health

A key focus of current research is on antimicrobial resistance (AMR), specifically benchmarking and surveillance programmes to establish the extent of AMR in New Zealand and the future risk. The Ministry of Health continues to investigate mechanisms to strengthen human health surveillance systems, including early detection of emerging disease threats. Furthermore, the Government has commissioned the building of a state-of-the-art physical containment-3 facility at Wallaceville. This high containment facility should enable preparedness for the majority of disease risks for New Zealand. Collaboration with the Australian Animal Health Laboratory in Geelong also provides access to a physical containment-4 facility.

Priorities for protecting human health

- Monitor the impacts of climate variations on vector establishment and accurately map current and potential distribution, to better target surveillance (outcomes 1 and 3)
- Increase identification of potential threats, including emerging diseases, and understanding of the epidemiology of zoonoses (outcomes 1 and 5)
- Work in collaboration with relevant overseas partners to develop alternative processes for the approval of new aircraft disinfection products (outcome 2)
- Use genetic tools and modern DNA-based modelling to understand the origin, relatedness and spread of incursions of organisms (outcomes 2 and 5)
- Strengthen the knowledge and evidence base about antimicrobial resistance through research and surveillance (outcome 4)
- Continue, as appropriate, the adoption of a One Health approach to current and emerging biosecurity risks, covering human, animal and environmental aspects of these risks (outcome 5)
- Increase understanding of new foodborne pathogens that could enter New Zealand and become established, and of already present pathogens that could increase in prevalence (outcome 5)
- Undertake social research to support more effective engagement, especially in relation to general surveillance and risk management interventions (outcome 7)
- Undertake kaupapa Māori research to identify distinct impacts to hauora that arise within Māori communities (outcomes 7 and 8)
- Establish cultural protection mechanisms in the development of responses to emergent and established biosecurity risks (outcome 7)

Society: protecting our way of life and what we value

All New Zealanders depend upon our biosecurity system. It is critical to our way of life as it underlies our livelihoods, our values and our lifestyle. The biosecurity system also depends on the understanding, buy-in and participation of people. Strengthening biosecurity in Aotearoa requires all New Zealanders – a team of 4.7 million willing participants – to be empowered to take action.

Biosecurity challenges for society

Societies are complex and multidimensional. They comprise a vast range of people with interconnected, and sometimes conflicting, priorities, practices and values. Understanding the complexities of society is a critical component in maintaining an adaptable and sustainable biosecurity system.

Recent high profile biosecurity incursions have highlighted the interconnectedness of biosecurity with our daily lives and how disruptive incursions such as kauri dieback and *Mycoplasma bovis* can be. Debates about the use of toxins for vertebrate pest control such as aerial 1080 are becoming increasingly polarised, with social and mainstream media rife with an array of opinions and assertions that vary greatly in their basis in evidence, but many of which are presented as factual. Such debates can be volatile and unpredictable.

New Zealanders are an integral part of the biosecurity system and need to be empowered and inspired to take action within their communities and nationally to build an inclusive, responsive and open biosecurity system that rapidly adapts to new and emerging evidence and feedback. The system also needs to recognise the uniqueness of our cultural landscape and recognise the distinction between mana whenua and tangata whenua.

Current research progress – society and biosecurity

Research on social science is growing, with increased emphasis on it in a number of areas including through the work being done by Better Border Biosecurity (B3).

Over the last two decades, New Zealand has made considerable progress in understanding how society perceives biosecurity risks, and our perception of the tools and strategies required to combat biosecurity threats. Longitudinal studies such as the University of Auckland's survey of attitudes and values, and Lincoln University's biennial survey of public perceptions of the New Zealand environment have amassed nearly two decades of data, with insights for the biosecurity system. Several other studies have focused on specific sectors, such as Manaaki Whenua's Survey of Rural Decision Makers.

More recent efforts have shifted focus to better understand the underlying values held in society towards biosecurity, and factors that inspire communities to take action. These include: more in-depth focus on Māori values; understanding behaviours and decision-making on current initiatives such as Predator-Free 2050; biosecurity risks in urban areas; and community action on kauri dieback and myrtle rust. The field of environmental psychology holds considerable promise in further progressing these research initiatives, and further work is needed to ensure that Māori values and actions are investigated with the appropriate tikanga and kaupapa Māori research methods in place.

Priorities for society and biosecurity

- Understand the biosecurity implications of increased urbanisation and lifestyle and demographic changes of New Zealanders (outcomes 1 and 9)
- Develop or adapt surveillance methods so they can be used by industry, agencies, and communities, and by Māori in developing hapū-based surveillance methods (outcomes 3 and 8)
- Address social licence and acceptance issues to enable multiple control technologies and data collection and sharing (outcome 7)
- Appropriate design of citizen science projects – quantifying bias in data, providing best practice guidelines, capturing negative results, and developing appropriate protocols for analysing, interpreting and relating data to support robust monitoring and surveillance methods (outcome 7)
- Develop a programme of staged engagement with the general public to test the acceptability of tools and techniques to control pests, diseases and weeds, including new genetic techniques (outcome 7)
- Develop templates to ensure communication of scientific uncertainties and management alternatives is done more clearly and consistently (outcome 7)
- Understand how groups can cooperate effectively to fight pests for as long as it takes to win (which can transcend funding, political cycles, and tenure of key individuals) (outcome 7)
- Develop and implement tools to measure change in societal engagement in biosecurity (outcome 7)
- Identify current behaviours and practices affecting border and post-border biosecurity risk management for different sectors, the reasons for these behaviours and practices, and the motivators, barriers and drivers related to achieving desired outcomes and behaviours (outcome 7)
- Increase understanding of social, organisational and cultural perceptions of biosecurity risks and their management (outcomes 7 and 8)

Māori and biosecurity

This section is about protecting taonga species, within the context of mauri and taiao, and embedding a te ao Māori perspective in the biosecurity system (also see outcomes 7 and 8). Māori have an integral role in Aotearoa's biosecurity system through the partnership of Māori and the Crown under te Tiriti o Waitangi. As tangata whenua and kaitiaki, Māori have a special relationship with their ancestral lands, waters, sites, wāhi tapu (sacred sites) and taonga.

Māori have a distinct knowledge base, mātauranga and tikanga whakahaere. Mātauranga Māori me o rātou tikanga are recognised as important sources of knowledge which inform mana whenua biosecurity priorities and contribute to the management of pests within Aotearoa.

Kaitiaki responsibilities are embedded in kaupapa Māori approaches and informed by mātauranga Māori, the combined knowledge of Māori systems, inter-generational environmental information, values, and philosophies. Mātauranga Māori continues to grow and evolve so that the cumulative body of knowledge is drawn from traditional understandings and enhanced through contemporary experience and practical use.

Māori and biosecurity challenges

The partnership of Māori and the Crown under te Tiriti o Waitangi forms the basis for working together on joint biosecurity outcomes. The challenge in any partnership is to resolve different perspectives to achieve equitable value. Te ao Māori (the Māori world) emphasises both the tangible and intangible and is based on intimate experience and exposure with the natural environments, over many generations. Cultural axioms such as wairuatanga (spirituality) and relationship and belonging, for instance through the interconnection of whakapapa (genealogy, lineage and descent) and whenua are expressions of the Māori world view.

Māori have strong economic interest in primary industries, including biological resources. The recognition of this interest has led to increased economic influence and enabled greater cultural influence. Māori are the largest landowners in Aotearoa and their efforts and involvement in biosecurity are vital for building a sustainable future for New Zealand's primary production economy.

In the traditional Māori view everything is interconnected and related, setting up a different relationship between people and their environment. This leads to different perspectives and approaches as expressed in concepts such as tangata whenua (indigenous people of the land), kaitiakitanga (stewardship) and mauri (life force). All living things, including humans, are seen as originating from the earth mother Papatūānuku and the sky father Ranginui.

While approaches and perspectives differ, there is strong alignment on objectives and great potential to enhance the biosecurity system. As kaitiaki, Māori rely on a robust biosecurity system to protect the biodiversity with which they have a whakapapa connection, as well as the protection of hauora of Māori communities.

Current research progress: Māori and biosecurity

Previous strategy documents, including the Biosecurity Strategy (2003) and the Biosecurity Science Strategy for New Zealand – Mahere Rautaki Putaiao Whakamaru (2007), noted a lack of understanding or valuing of Māori customs and knowledge. Such strategies, along with the 2010 Mātauranga Māori and Biosecurity Research paper, have provided the basis for improved Māori participation in biosecurity research. The kaupapa of Biosecurity 2025 has provided a vehicle to further strengthen Māori influence on science strategies, including participation in the Māori strategic advisory group for Biosecurity 2025 across all its five strategic directions.

Iwi and hapū have a fundamental role in New Zealand's biosecurity system including its science. At present there is a lack of recognition of Māori infrastructure, expertise and needs. This Stocktake of Priorities recognises the need to specifically consider and provide for partnering with Māori to deliver New Zealand's biosecurity outcomes. This will be achieved through targeted capability and capacity building at whānau, hapū and iwi levels to actively lead, co-innovate, contribute to, and participate in all aspects of biosecurity research, science and technology priorities.

Priorities for Māori and biosecurity

- Develop the ability to predict biosecurity risks to taonga and other culturally significant resources, and to determine the likely significance of the risk to tangata whenua and Māori organisations (outcome 8)
- Kaupapa Māori research – increase innovation through kaupapa Māori and Māori-led research that delivers co-design and co-innovation within all biosecurity research, science and technology priorities (outcome 8)
- Increase the benefits of biosecurity research and innovation by bringing together mātauranga Māori and contemporary research methods (outcome 8)
- Build capacity and capability amongst non-Māori researchers and end users to enable and empower them to work confidently in partnership with tāngata whenua (outcome 8)

Domain 3: Trade and tourism

Our economy is dominated by our primary and tourism sectors. The quality of our natural environment is the basis for attracting international visitors and producing and marketing high-quality, high-value goods around the world. This domain encompasses market access, primary sector exports, imports, and tourism.

An overarching opportunity for these sectors is to adopt and practise the concept of kaitiakitanga, both for the future of their industries, and for the future generations of New Zealand.

Protecting market access and export trade

Aotearoa is free of many of the pests and diseases found in other countries. This gives us a comparative advantage as other countries become increasingly concerned about the biosecurity risks to their own production systems. However, the size of New Zealand's biosecurity challenge is increasing with growing changes in the movement of goods, people and vessels and climate. It is essential that our biosecurity system protects both production and market access. Along with serious implications for our market access, the inadvertent export of our biodiversity could impact on ecosystems elsewhere in the world, and undermine our unique endemicity. As a biosecurity-conscious nation we should take measures to prevent this.

Biosecurity challenges for market access and export trade

A changing climate increases the complexity of the biosecurity risks we face as pest and pathogen distribution changes. Meanwhile the increased inward movement of goods and people, as vectors for the entry of pests and pathogens, escalates the probability of incursion and the biosecurity challenge. New Zealand's international obligations under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) requires that "any sanitary or phytosanitary measure is applied only to the extent necessary to protect human, animal or plant life or health, is based on scientific principles and is not maintained without sufficient scientific evidence..." The SPS Agreement is the binding international agreement that provides the legal basis on which the 164 World Trade Organization members can establish legitimate biosecurity measures. New Zealand, building on the SPS Agreement, has also established additional rules under the sanitary and phytosanitary chapters of our free trade agreements. New Zealand relies on trading partners' consistent implementation of these rules when we are negotiating access for our exports into foreign markets, and similarly trading partners expect New Zealand to consistently implement these rules to the import of their products into New Zealand.

Current research progress for market access and export trade

Science to support market access varies across different industries. In some industries there has been considerable investment in science to support improved access to our overseas markets, in others much less. Regardless, research for market access and export trade is an ongoing need as preferences and expectations of consumers change and we trade with new and increasingly diverse partners with different requirements and concerns. This is an area where industry funding and engagement is particularly critical. Science and technology to support comprehensive full supply chain traceability and provenance is also a current and growing area.

Priorities for market access and export trade

- Develop effective systems to ensure traceability of primary products from the field or production site to the market, including understanding all inputs into the production system (outcome 3.2)
- Develop better inspection and detection tools to test the compliance of exports with the biosecurity requirements of our trading partners, including alternatives to visual inspection and systems to prove the absence of pests and pathogens on export crops and products (outcome 3.3)
- Develop and enhance non-chemical options for mitigation of pests and pathogens of concern to overseas markets, including developing systems approaches (outcome 3.4)
- Improve existing, and develop new, treatments for export commodities to increase cost-effectiveness and meet increasingly stringent environmental and human safety standards. This includes improving the use and application of existing treatments, seeking alternatives, ensuring that social licence of effective treatments is gained and maintained, and that there are methods for safe destruction or recycling of chemicals where appropriate (outcomes 3.4 and 3.7)
- Understand the potential market access implications of new or improved biosecurity treatments and tools and initiate pro-active science and technology to mitigate impact (outcomes 3.6 and 3.9)
- Understand the biosecurity implications to native biodiversity of change in trade and tourism patterns (outcomes 3.1)

Reducing the risk of pests and pathogens associated with trade

New Zealand is a trade dependent economy and a firm supporter of free and open trade. Our open economy has meant New Zealand importers and consumers enjoy access to a much wider and competitively priced range of goods and services. The top categories comprising nearly 50 percent of imports are vehicles (16 percent), machinery (16 percent), fuel (9 percent), and electrical equipment/goods (8 percent). We also import processed and unprocessed food products, such as meat and dairy products and grains and seeds. Imported goods arrive every day and unwanted organisms may be present in or on the goods, packaging, or the ship or plane carrying them. But it is impossible to inspect everything.

Biosecurity challenges for reducing the risk of pests and pathogens associated with trade

The value of imports has doubled since 2000 (from $30 billion) and continues to grow steadily at an average of 4 percent per year. As an indication of volume, around 250 vessels arrive each month at New Zealand's ports with 70,000 containers to unload. Keeping up with this growth is a significant challenge. There is a constant and increasing flow of goods, but limited space and resources for processing at ports and airports and mail centres.

Key challenges include:

- the number and diversity of management tools available and acceptable are not sufficient for increasing trade, and trade and risk data are fragmented and incomplete;
- trade pathways are becoming more complex, with new and unassessed risks;
- increasing trade with other 'Gondwana' environments, e.g. southern South America, may expose the New Zealand environment to greater, and less understood biosecurity risks;
- audit/assurance/verification systems/tools to ensure compliance with import requirements are limited/non-existent, e.g. sensor tech;
- intelligence systems to focus limited resources onto highest risk pathways are currently limited;
- iwi and hapū are not engaged at the point of incursions introduction.

Current research progress in reducing the risk of pests and pathogens associated with trade

Research in this area has focussed primarily on research to support pushing the risk offshore, setting high standards for people exporting goods to New Zealand and enforcing those standards. Online purchasing and New Zealand's changing demographics has led to increasing volumes of food and parcels coming from the Pacific Islands, India and China. Targeted social marketing research and data from border interceptions are enabling an 'audit approach', focusing mitigation and detection on high-risk areas while reducing time on low risk areas. New tools and methods are emerging to support this work, for example the combination of x-ray and machine learning algorithms to scan greater volumes of parcels faster, underwater cameras and drones to check the hulls of ships, and targeted online marketing.

Priorities for reducing the risk of pests and pathogens associated with trade

- Develop methods to better monitor and analyse trade patterns and the changing risk status of trading partners, and identify potential changes in the suite of pests, diseases and vectors that pose a risk to New Zealand (outcomes 1 and 9)
- Increase understanding of the pathways through which high-risk pests and diseases can enter New Zealand by developing better methods to trace incursions back to, and forward from, the source (outcome.2)
- Develop new and improved identification and diagnostic tools for the border, and post-entry quarantine and transitional facilities (for imports and exports), including alternatives to visual inspection (outcome.3)
- Continue to develop and validate (with increased international collaboration) measures, tools and strategies that are cost-effective, safe and socially acceptable for managing risk offshore, either before departure from the country of origin, while in transit, or at the border/transitional facility (outcome 4)
- Develop improved treatments for risk goods at the border and in transitional facilities, including clear, scientifically supported information on efficacy against the target organisms and details required for effective application, such as concentration/temperature/time data, and implementation (outcome 4)
- Increase understanding of behaviours and practices affecting border and post-border biosecurity risk management for different pathways, including the motivators, barriers and drivers relating to desired outcomes (outcome 7)
- Increase understanding of behaviours associated with passenger and importer non-compliance with biosecurity requirements (outcome 7)
- Increase understanding of the effectiveness of compliance tools and methods of modifying behaviours, such as sanctions and cultural management approaches (outcome 7)
- Improve New Zealand's border protection through enhanced connectivity and management of biosecurity data, an understanding of complex networks, and the ability to measure system performance and the impacts of changes to interventions on levels of managed risk (outcome 9)

Managing biosecurity risks from tourism

Tourism is a vital component of New Zealand's economic and social wellbeing, directly contributing approximately 5.9 percent of our GDP annually. However, it is also a significant risk from a biosecurity perspective. Tourism, indigenous flora and fauna and our primary industry are inextricably linked, and biosecurity protects the value and sustainability of all these. In peak months, up to half a million international visitors are arriving from an increasing diversity of places. For most, awareness of the importance of biosecurity is low and their encounter with our border biosecurity will be a novel experience. Once here, visitors can potentially facilitate the spread of pests and diseases domestically.

Tourism and biosecurity challenges

International visitor numbers have almost doubled in the last decade, and in the year to April 2019 international visitor arrivals reached a new record of 3.9 million. This increase, as well as the fact visitors are coming from more places and visiting more locations in Aotearoa (including remote areas), equates to more opportunities for more pests and diseases to get into and establish in New Zealand. Increased visitor numbers are increasing pressure at the border. For example, soil on the footwear of passengers arriving at New Zealand's international airports carries potential hazardous organisms, such as bacteria, fungi, nematodes and seeds. Not all footwear is declared nor are x-ray machines able to distinguish between clean and contaminated footwear.

From a visitor experience perspective, the tourism industry seeks faster processing time and minimal disruption. But with greater visitor numbers, time and space constraints for processing visitors presents a continuing challenge for our border biosecurity.

Meanwhile, biosecurity internally is dealing with many legacy pests and diseases that are threatening ecosystem function, production systems and amenity values- the very things that visitors come to see.

Current research progress – biosecurity and tourism

Better Border Biosecurity are undertaking a number of projects relating to biosecurity and tourism. Current tourism-related research includes visualising visitor flows within the first seven days of arrival in New Zealand, and research around understanding and increasing biosecurity awareness within the New Zealand tourism industry, including, for example, developing and accessing the value of a biosecurity trail to raise awareness.

Visitor flow information will be used to identify 'hotspots' of visitor aggregation and potential biosecurity risks, and to determine alignment with the high-risk surveillance network and pest and disease incursion data. The biosecurity trail is being developed with Auckland Botanic Gardens to increase biosecurity awareness amongst international and domestic visitors and will include a survey to capture information around what tourists know about biosecurity. Mapping of tourism industry biosecurity knowledge and risks from visitors will be used to develop a model framework for raising biosecurity awareness and compliance.

Other projects underway include social network analysis with tourist operators; research into popular press articles on tourism and biosecurity; statistical assessment of the strength of the relationship between incursions records, tourism data and population data; and a vision mātauranga project.

Identification of specific biosecurity risks for New Zealand Māori Tourism and the wider Māori tourism sector including iwi, hapū and whānau, was identified within their wider provision of protecting their kaupapa of compelling visitor experiences, robust commercial enterprises and cultural leadership.

Statistics New Zealand's commercial arm, Data Ventures, is leading work regarding mobile location estimates and is currently developing a suite of Population Density products capturing the number of people who work, live and play in a given geographical area at a given time. Future developments may extend to travel patterns, including population segmentation to tourists (international and domestic) and local residents.

Priorities for biosecurity and tourism

- Analyse the changing biosecurity risks from increasing international visitor numbers, changes in countries of origin of visitors, and changes in location and types of tourism activities (outcome 1)
- Better understand and quantify the potential for visitors to carry high risk pests and pathogens and the risk of establishment from visitor activities in our marine, freshwater, and terrestrial environments (outcome 1)
- Increase understanding of international and domestic visitor flows in New Zealand, and hence the pathways through which high-risk pests and diseases could be spread through their activities (outcome 2)
- Understand the role of tourism not only as a threat, but also in protecting natural landscapes (including urban parks) and primary industries (wine, demonstration farms) (outcomes 2 and 6)
- Increase understanding of the vulnerability of different environments to tourism activities and the biosecurity risks posed by tourism in iconic biodiversity spots and sensitive areas, including remote islands (outcome 6)
- Understand the social and cultural attitudes and behaviour of visitors affecting biosecurity risk management for different tourism sectors (outcome 7)
- Increase understanding of the effectiveness of compliance tools and methods of modifying behaviours, such as sanctions (outcome 7)
- Understand and identify key biosecurity pathways and risks to te ao Māori within the Māori tourism sector, including overlaps with the broader New Zealand tourism sector, and develop appropriate tools to mitigate those biosecurity risks (outcome 8)
- Develop systems to enhance connectivity, management and analysis of visitor biosecurity data to allow for early decisions and interventions (outcome 9)
- Develop tools to support hapū and iwi to monitor high-value sites and effectively manage visitor movements and associated risks to taonga (outcome 8)

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Glossary

Term	Definition
Big data	Very large data sets that can be analysed computationally to reveal patterns, trends, associations and interactions
Biodiversity	Diversity among and within plant and animal species in an environment
Biofouling	Organisms or assemblages of aquatic species that colonise submerged artificial surfaces such as vessel hulls (and internal spaces) or coastal infrastructure (e.g. pontoons, seawalls, piles)
Bioinformatics	Analysis and interpretation of biological data using computer science, statistics, mathematics and engineering
Biophysical	The branch of biology that applies the methods of physics to the study of biological structures and processes
Biota	The animal and plant life of a particular habitat or region
Blockchain	Distributed database that maintains a continuously growing list of ordered records or blocks, which are secured from tampering or revision
Ecosystem	Biological community of interacting organisms and their physical environment; a complex network or interconnected system
Endemic	Unique to a country
Genome	Complete set of genes or genetic material present in a cell or organism
Germplasm	Living genetic resources (for example, seeds, plant species, animal breeds) that are used for plant and animal breeding
Hapū	New Zealand indigenous nations, with genealogy to tribal territory
Hauora	Health and vigour; to be fit, well and healthy
Informatics	Systems and processes used to collect, curate, manage and interrogate information
Iwi	Collection of New Zealand indigenous tribe or people within a geographic region
Kaitiaki	Guardian or custodian
Kaitiakitanga	Guardianship or stewardship practices
Kaupapa Māori	Māori-led research approaches, a Māori way. A way of researching that is underpinned by te ao Māori and draws extensively from tikanga and mātauranga Māori
Kawa	Customs and protocols
Mana whenua	Cultural authority over land, water people and resources
Mātauranga Māori	Modern term for the combined knowledge of Polynesian ancestors and the experiences of Māori living in the environment of Aotearoa. The term takes many forms, such as language (te reo), education (acquired knowledge), intergenerational traditional environmental knowledge and shared treasures and values (taonga tuku iho, mātauranga o te taiao), traditional knowledge of cultural practice, such as healing and medicines (rongoā), fishing (hī ika) and cultivation (mahinga kai)
Mauri	Life force, the essential quality and vitality of a being or entity
Microbiome	The totality of microorganisms and their collective genetic material present in or on the human body or in another environment
Nanotechnology	A technology executed on the scale of less than 100 nanometres, the goal of which is to control individual atoms and molecules, especially to create computer chips and other microscopic devices

Term	Definition
Natural capital	Stocks of natural assets, including soil, air, water and all living things. A wide range of services (see ecosystem services) that make human life possible are derived from natural capital
One Health	A common description of a holistic and comprehensive approach to animal and human health
Primary sector	Industries and activities across the whole-of-the-value chain, including food, fibre products (wood and wool fibre), and the biomaterials and by-products from terrestrial-and aquatics-based production systems. Also encompasses the broader set of organisations and individuals that support the sector, such as through science and other knowledge-intensive or specialist services
Rangatiratanga	Sovereignty, self-management, chiefly authority to govern
Social license	Ability of and organisation or industry to undertake business in a socially and environmentally acceptable way with confidence from society
Taiao	The natural world and environment, nature
Takutai moana	Coast, foreshore and seabed
Tāngata whenua	Indigenous people of the land, Māori citizens
Taonga	Treasured item, resource, technique or idea. In the primary industries this includes land, water, flora and fauna
Te ao Māori	The Māori world, world views
Te ārai koiora wai māori	Freshwater biosecurity (management of freshwater pests)
Tikanga Māori	Customary system of values and practice that have developed over time and are deeply embedded in social context, code, practice and protocol
Tikanga whakahaere	Management practices
Tool	An electronic device, mechanical device, paper driven process, mathematical model, analysis software, decision making software, or policy, to effect an output
Transport vector	A mobile 'unit' that can facilitate the translocation of organisms or propagules between locations. Examples include ships, boats, airplanes, humans, animals or transported goods
Vector	Something (usually a living organism) that can transfer a disease-causing organism
Vision Mātauranga	Ministry of Business, Innovation and Employment policy that aims to unlock the science and innovation potential of Māori knowledge, resources and people through actions and investments through the public science and innovation system
Wai māori	Fresh water
Wairuatanga	Spirituality
Wāhi tapu	Sacred place, subject to long-term ritual restrictions of access or use
Whakapapa	Genealogy, lineage or descent
Whānau	Extended family linked through genealogy
Whenua	Land, ground or domain
Zoonotic disease	A disease capable of infecting both humans and animals

Appendix 1: Documents and resources accessed

The following documents and strategies were accessed for context, and to aggregate research, science and technology priorities across sectors and domains.

Government reports and strategies:

- Australian Academy of Science and Royal Society Te Apārangi. (2018). *Discovering Biodiversity – A decadal plan for taxonomy and biosystematics in Australia and New Zealand 2018-2027*. Retrieved from **https://www.science.org.au/files/userfiles/support/reports-and-plans/2018/taxonomy-decadal-plan-lo-res-v200618.pdf**
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