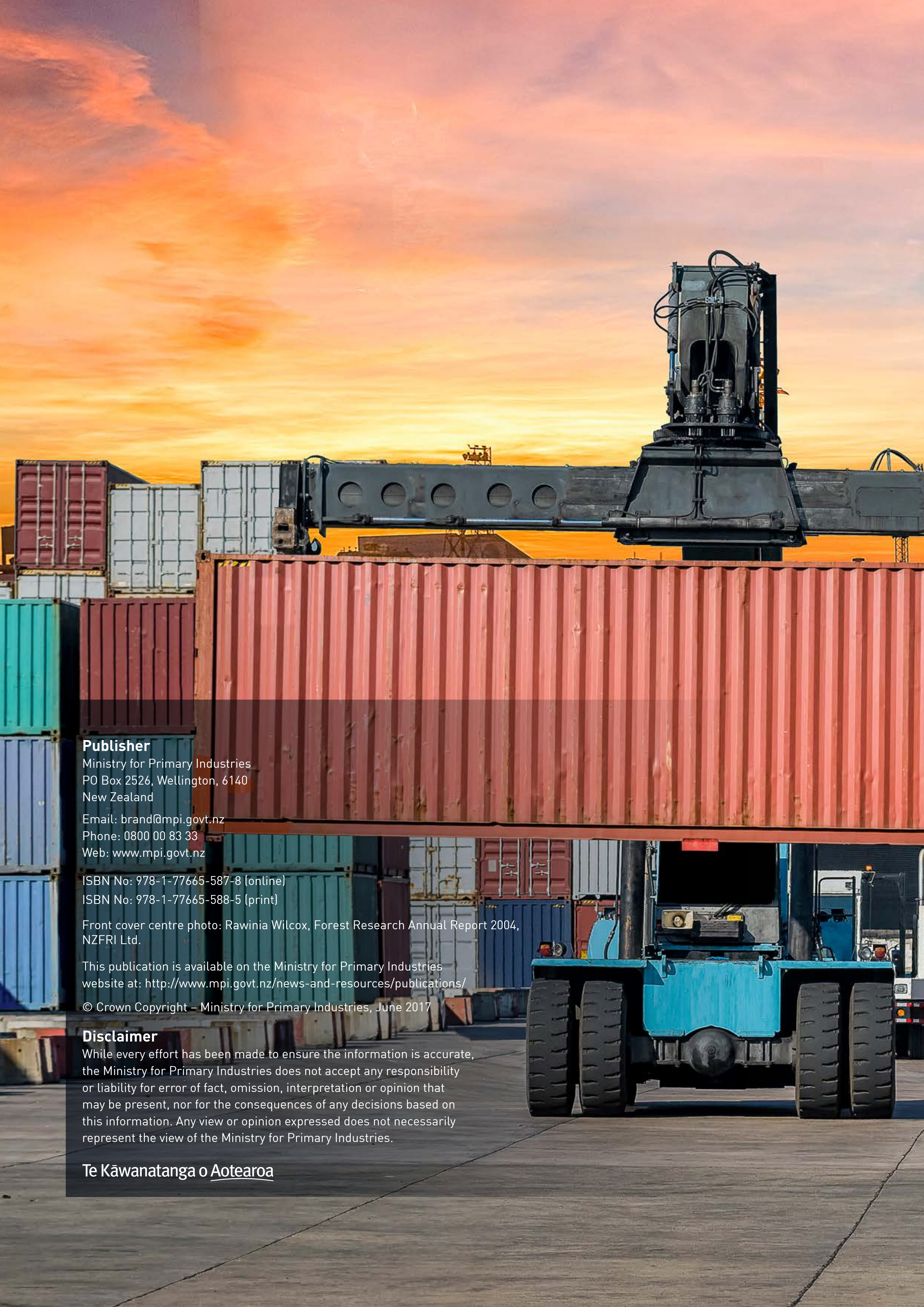
Primary Sector Science Roadmap

Te Ao Tūroa

Strengthening New Zealand's bioeconomy for future generations



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Te Kāwanatanga o Aotearoa

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**Ko te whainga o ā mātou mahi pūtaiao mai i te whenua
ki ngā rangitūhāhā
ko te āta tiaki i ā tātou tino taonga,
kia taea tonu ai te whakarato i ngā hua whai uarā ki te ao,
whai painga hoki mo te hauora me te wairua o ngā iwi
o Aotearoa.**

**Our science covers everything between the earth to the heavens
– the length, the breadth, the width, the depth,
we commit to the careful and sustainable use of our
precious resources,
to provide products of value to the world
and bring benefit and wellbeing to the people and spirit
of New Zealand.**

Ministerial foreword
from Primary Industries and Science and Innovation Ministers

New Zealand is known worldwide for its primary sector – a country where land and seascapes, farming, forestry, and food production are an integral part of our culture and our economy. Our reputation for producing high-quality, innovative, and safe products has been with us through some remarkable change over the decades – such as the opening up of new markets in Asia – and is likely to be a critical advantage for our prosperity and wellbeing into the future.

The primary sector's ability to adapt and grasp new opportunities has been underpinned by the robust research carried out by New Zealand scientists and the tremendous expertise they can access from their networks. Te Ao Tūroa – the Primary Sector Science Roadmap is designed to help science continue to play its part in this journey.

The range of challenges and opportunities that New Zealand's primary sector now faces is unprecedented. They include the speed and breadth of digital and technological change; the ability to use data to inform decisions across the value chain, from producers to consumers; and an ever-changing context for global trade. These challenges also include environmental and sustainability issues in areas such as freshwater quality and climate change.

In recent times we have seen important science and innovation-related developments, such as Fonterra's commitment to invest $240 million in a new mozzarella plant in South Canterbury, driven in part by the success of the Primary Growth Partnership programme, Ngāi Tahu investments in research, farming and seafood, and government, through Callaghan Innovation, has supported investments by joint venture Wood Engineering Technology Ltd., an innovative wood-processing facility in Gisborne to develop high-value wood products.

The Roadmap will help realise more of these sorts of successes and strengthen New Zealand's bioeconomy.

The Government's vision for science is set out in the National Statement of Science Investment. This recognises the critical role the primary sector plays in our economy and signals the Government's intent to increase research investment over time, incentivising research and development investments by industry. The Roadmap will guide this commitment by providing more specific signals about science for the primary sector. By supporting innovation in the primary sector it will also support the Government's Business Growth Agenda goals to build a more diversified and resilient economy, which will underpin the wellbeing of all New Zealanders.

The Roadmap has benefited from input from a diverse range of people and organisations from across the primary sector. It provides an integrated view from the sector of what it sees as the most important needs and opportunities for science. With this shared view of the opportunities and challenges, the Roadmap will help give effect to the science that matters to our primary sector and its success.

Hon Nathan Guy
Minister for Primary Industries

Hon Paul Goldsmith
Minister of Science and Innovation

1 Te Ao Tūroa – the Roadmap at a glance

Te Ao Tūroa – the Primary Sector Science Roadmap (the Roadmap) has been designed to strengthen New Zealand's bioeconomy. It provides an integrated 10 to 20 year outlook on the science needs and opportunities of most importance to protect, grow and enhance New Zealand's primary sector, and support the wellbeing of New Zealanders.

The Roadmap identifies four areas that science needs to support, eight science themes that contribute to these, and summarises the most pressing areas where research focus and science capability development are required. Figure 1 outlines these components of the Roadmap, highlights their interconnectedness, and indicates where they are located within the document.

This Roadmap has been developed to provide a shared view of New Zealand primary sector science and technology needs that will give direction to strategy and investment decision-making by funding agencies, research and development providers, industry, and government departments. It provides a starting point for discussions and decisions needed to develop more aligned and optimal science capability, knowledge and tools for New Zealand's primary sector.

Further detail on the development of the Roadmap can be found in Appendix 1.

The Ministry for Primary Industries provides oversight of the Roadmap, and is working with partners to support its use throughout the sector and will update it over time to ensure it is a living document.

"We need to have our primary sector on the edge of innovation, on the edge of technology, leading the world so that we are delivering the products that people will pay a premium for. We cannot be the same as everybody else."

Ian Proudfoot, Member of the Roadmap's Strategic Advisory Group, and Global Head of Business, KPMG

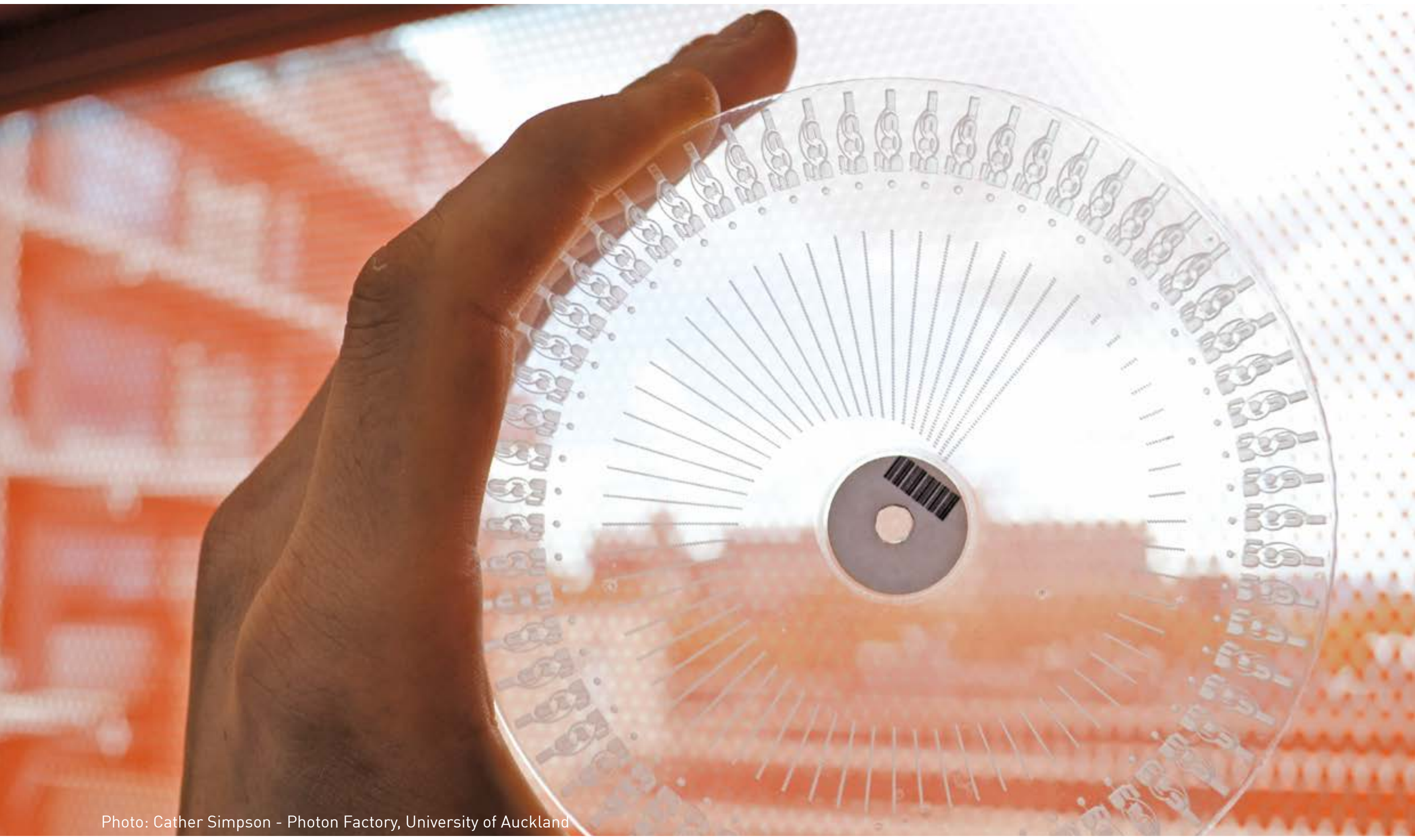

Photo: Cather Simpson - Photon Factory, University of Auckland

Figure 1: The Roadmap components and where to find them

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Adding value
Achieving greater profitability across the supply chain, driven by consumer and market insights and preferences, and co-innovation, resulting in a greater diversity of high-quality products and services.

Harnessing the value and power of data
Advancing the definition and collection of critical data, use of connected data sources, data handling, interoperability, management and governance for more efficient and adaptable production systems that have a positive impact on the environment.

Innovating with advanced technology
Developing and implementing new technologies, including advanced, disruptive, and transformational technologies to ensure the New Zealand primary sector is globally competitive.

Innovating through genetics
Creating knowledge and techniques leading to plant and animal production that is more efficient, safer and adaptable, with less negative environmental impact, allowing rapid development of new generations of food and non-food products.

Innovating through Kaupapa Māori
Contributing through Kaupapa Māori research approaches to distinctive and transferable primary sector innovation informed by tikanga Māori, mātauranga Māori and science working together.

Protecting and sustaining resources
Future-proofing new and existing production systems so that terrestrial- and aquatic-based resources, are mapped, measured and monitored to protect the resources and support their use under rapidly changing conditions.

Deriving value from complex systems
Enhancing sustainability of diversified and multifunctional, terrestrial- and aquatic-based systems and the development of novel products through better understanding and using complex systems.

Integrating people and values
Supporting the development of future primary production systems that are publicly and socially integrated and enabling uptake of science and technology through effective engagement and partnerships.

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Section 6 | Capability and capacity needs for primary sector science

In the future, New Zealand's primary sector workforce will need a higher level of skills in the areas of science, engineering and technology. The primary sector will continue to rely on a range of pure and applied science and technology experts. It will be important that these skills are used in partnership and through interdisciplinary, cross-sectoral and cross-cultural approaches. Continued emphasis on extension and translation of science is needed to help the sector more rapidly adopt and adapt new knowledge and technologies for innovation and sustainability.

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Section 7 | Putting the Roadmap into action

The Ministry for Primary Industries led the development of the Roadmap, working with sector and science partners, and will continue to lead the oversight and monitoring of the Roadmap. Putting the Roadmap into action will require ongoing involvement and leadership from the science and primary sector partners, Māori and government organisations.

2 Science for the primary sector

New Zealand's primary industry sector is a vital part of our economy and way of life, and must increasingly become a key sector in supporting te ao tūroa. It is responsible for over 78 percent of our product exports. As well as directly contributing to the economy, our primary sector provides critical inputs for manufacturing and energy production, produce for our hospitality sector, and is part of what tourists come to New Zealand to see.

To maintain and increase the value we derive from the primary sector we need sustainable growth in productivity and profitability, including significant growth in product value. We also need diversification of products and to respond to challenges such as those of climate change, biosecurity and food safety. The health of soils, and freshwater and marine environments, are paramount in future planning.

Growing populations, changing demographics, and changes in global trade, regulations and consumer demands, emphasise the importance of people and markets in our thinking. Social and cultural acceptability has become central to future sector development.

SCIENCE IS CRITICAL TO NEW ZEALAND'S PRIMARY SECTOR, ENABLING US TO:

- develop robust government policy and regulation to protect and enhance natural resources through effective partnerships;
- develop new and higher-value products and help industry to innovate;
- increase productivity within environmental limits, particularly those related to soil and water;
- provide evidence that underpins our reputation in overseas markets;
- adapt to the impacts of climate change;
- develop and maintain regulations that ensure the safety, sustainability and integrity of primary production and the safety of those working in the sector;
- have robust food safety, biosecurity and animal welfare systems;
- build connections to international centres and networks of experts and entrepreneurs to extend our capability for decision-making and innovation;
- contribute to addressing global issues, such as food security and sustainable fisheries;
- understand the needs and drivers of people, producers, processors and consumers.

Success of the primary sector will only be achieved through effective partnerships which meet the needs of society including obligations under the Treaty of Waitangi.

Why a Roadmap?

Science is critical to New Zealand's primary sector. It provides knowledge and evidence to strengthen primary production practice and product innovation, support market access, and improve care and management of the environment that the sector relies upon. Science also supports the sector in making potentially bigger shifts over time to different production landscapes and systems, reflecting drivers such as new technologies, greenhouse gas mitigation, water quality and animal welfare concerns.

Science has provided the knowledge about New Zealand's distinct production environment, and enabled us to trade on the world stage and develop an enviable reputation for great products. The primary sector must continue to harness the power of science and its key role in innovation in order to be even more successful into the future.

This Roadmap is a response to concerns that there is no widely shared view of future science and technology capability needs and opportunities across the sector, from paddock, orchard, forest, estuary and ocean, through to processing and transportation systems, and on to markets and consumers. By providing an integrated shared view, the Roadmap will give direction to strategy and investment decision-making by funders, research and development providers, industry, and government departments. While there is significant investment in primary sector science, there have been missed opportunities to align investments across the range of funds and funders in our science system.

The science needs described in this Roadmap will have impact through translation of science into innovations by the primary sector. Appropriate regulations and infrastructure will be needed to ensure that this translation maintains New Zealand's strong capabilities in agricultural and biological sciences, and developing a higher level of skills in social science, engineering and technology, as well as further developing our leadership, marketing, commercialisation, language and cultural awareness capabilities.

For this Roadmap to be effective, resources will need to be allocated by funders and research providers to reflect the needs identified. Making a difference will require strong partnerships between industry, policy-makers and research providers to ensure that science is translated into strong business, policy and management decisions. The Roadmap will be a living document; its implementation will be monitored and evaluated, and it will be periodically reviewed to ensure it remains relevant.

By addressing future sector needs for innovation with well-targeted science, we can maintain and increase our competitive advantages in global trade, improve profitability, and ensure that our production systems are environmentally, culturally and socially acceptable.

Scope of the Roadmap

The Roadmap covers all industries involved in New Zealand's primary sector, across the value chain. This includes industries involved in designing and developing food and fibre (wood and wool fibre) products, and the biomaterials and by-products from terrestrial- and aquatic-based production systems. It supports the strategic and policy directions of the primary sector by focusing specifically on research and development needs and opportunities.

Scientific disciplines in scope for the Roadmap include the biophysical, social, engineering, information technology and economic fields. Tikanga and mātauranga Māori are integral knowledge and practice systems to the Roadmap as they provide opportunity to learn from and work collaboratively with Te Ao Māori, Māori values and aspirations.

The Roadmap will inform research conducted by New Zealand science and technology teams and organisations, and their partnerships with international collaborators.

Relationship with other government science initiatives

This Roadmap is aligned to the Conservation and Environment Science Roadmap. Production from agriculture, horticulture, forestry, aquaculture and fisheries is dependent on natural capital and ecosystem services, and conservation and environmental management are often linked to primary sector activities. Both Roadmaps address shared pressures, such as biosecurity, climate change, and marine, freshwater and soil health. They also identify opportunities to improve policy development and management, for example, through better support for and use of mātauranga Māori and investment in technology platforms.

An illustration of the shared connections between the two Roadmaps can be found in Appendix 2.

This Roadmap is part of the Government's overall strategy for the science system, which is set out in the National Statement of Science Investment 2015–2025. The strategy emphasises excellence and impact as the two pillars underpinning our future science system and the important role the primary sector plays in our economy. This Roadmap supports the principles and vision of the strategy and provides more specific science direction to the primary sector.

The Roadmap will also be an important guiding document for the strategic directions of the National Science Challenges, seven of which are relevant to the primary sector. It will help to ensure that key science priorities common across the Challenges are well aligned.

MĀORI AND THE PRIMARY SECTOR

Building on a long history of entrepreneurism and export, Māori remain integral to the future of the primary sector. Māori primary sector businesses, industry groups and resource managers such as iwi and hapū have bold aspirations for the development and management of their significant land and water interests in order to achieve their social, environmental, cultural and economic goals. Adoption of technology and innovation are fundamental to the growing wave of high-performing Māori enterprises.

NEW ZEALAND'S INDIGENOUS ADVANTAGE

Māori worldviews, values, knowledge and relationships with the natural environment all provide rich opportunity for the development of distinctive, innovative products and systems.

Research, informed and led by Kaupapa Māori, can deliver new, transferable value to the primary sector in New Zealand and globally. Science system capability to fully engage with Māori in many settings, valuing distinctive inputs, such as tikanga and mātauranga Māori, are important to delivering on the future science requirements and opportunities highlighted in this Roadmap.

A CASCADE OF INNOVATIONS IN OUR SHEEP INDUSTRY

New Zealand's lamb production (by kilograms) was the same in 2016 as it was in 1991 while the total sheep population fell from 55 million to 28 million.

This was made possible by productivity improvements though New Zealand-specific breeding programmes, and the use of flexible farming systems and management. These improvements enabled 20 percent more lambs to be born per ewe, and lamb slaughter weights to increase from 14.5 kilograms to 18.3 kilograms over that time.

From the mid-nineteenth century, New Zealand-specific breeds, such as the Corriedale, were developed by cross breeding and were followed by the Coopworth, Drysdale, and Perendale from the mid-twentieth century. These new breeds have been driven by the enthusiasm of New Zealand science pioneers, such as Professors Coop and Peren.

More recent improvement of specific traits has been through the introduction of new breeds in the mid-1980s, such as the Texel for lean carcasses, the Finnish Landrace for its high-lambing percentage and the East Friesian for its milk production.

The adoption of new breeding programmes, technologies and management practices has resulted in greater diversification in the products produced, better adaptation to New Zealand's unique farming conditions, and significant improvements in productivity and efficiency.

3 Navigating the future

Our vision for the role of science and technology in ensuring New Zealand's sustainable future, te ao tūroa:

Science and technology accelerates innovation and growth for intergenerational economic and environmental sustainability of the primary sector, leading to increased wellbeing for all New Zealanders.

Science in an uncertain future

The future of New Zealand's primary sector will be shaped by multiple interdependent, often conflicting, opportunities and pressures, acting at all scales from global to national to regional to individual businesses. Although there are many uncertainties associated with these opportunities and pressures, we do know that New Zealand's primary sector in 20 years will be different from today. Science, technology and innovation will play a critical role in guiding the direction and pathway we take (see Figure 2).

There are many examples that illustrate how New Zealand's science teams and their industry partners enable the primary sector to respond to global drivers and uncertainties. For example, opportunities to enhance productivity and profitability through the application of new technologies for precision measurement are helping to optimise resource use and reduce costs. Over 50 New Zealand companies and institutes, many in partnership with government, are engaged in precision agriculture research and development.

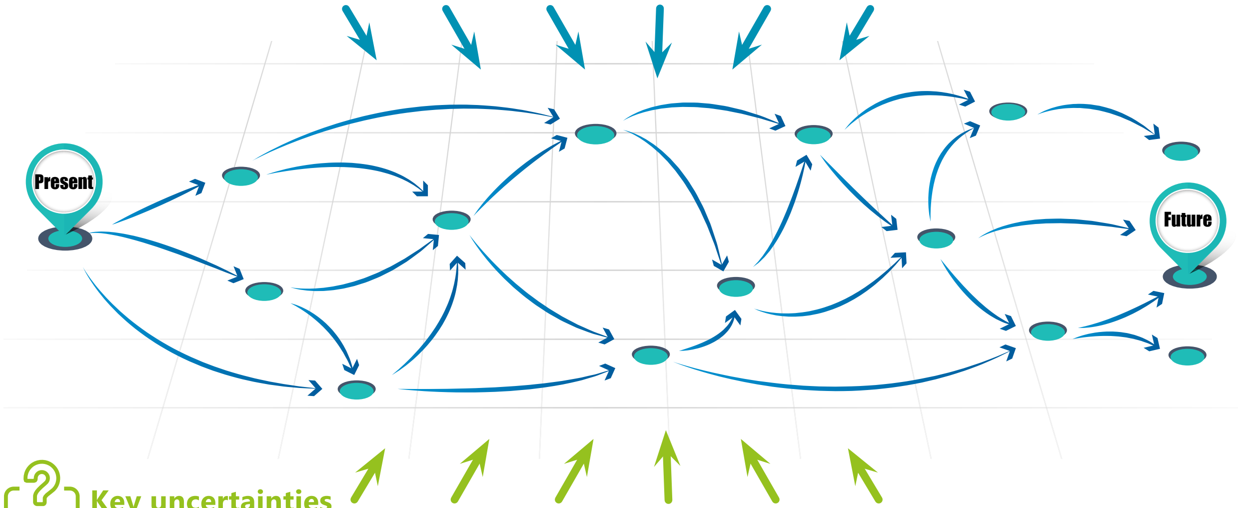
Emerging markets in the Asia-Pacific region are being met with innovative food and fibre products, broadening the range of products and services we offer and giving our economy resilience to adapt to change.

Challenges exist with the growing use of new technologies, such as robotics, genetics, biotechnology and automation. These technologies will require engagement among science, industry, Māori and the public to consider social and cultural licence for their use and their potential impacts on employment and the environment.

Figure 2: Key drivers and uncertainties for the future of New Zealand's primary sector. Science can support adaptive pathways by acting on key decision points (indicated on the figure as nodes) toward preferred outcomes.
Information from Ministry for Primary Industries and OneFarm, Dairy Industry Scenarios 2015.

Key drivers

- Shifting patterns of trade and globalisation
- Accelerating pace of technological change
- Changing consumer markets
- Increasing importance of food safety, quality and security
- Increasing global demands for water, food and energy
- Growing concerns about environmental degradation and climate change
- Empowerment of citizens including through enabling technologies



Key uncertainties

- Trade rules and globalisation
- Biological threats
- Natural environment and resources: value, availability and limits
- Social and economic impacts of technology
- Community and cultural factors
- Regulation of resources
- Impacts of climate change and ability to adapt
- Human resources and skills
- Consumer perceptions about food safety and animal welfare

We also need to be alert to disruptive change. There could be mounting pressure to move to more plant-based food production systems, away from livestock, because of greenhouse gas, water quality and animal welfare concerns. Research on biofuels and biorefineries, alternative foods, carbon economy and greater diversity in production systems could lead to a substantially different production landscape in New Zealand. To make these sorts of shifts, we need to ensure that we have the science necessary to provide evidence for decision- and policy-making.

The potential for science and technology to drive transformational change will require an appropriate enabling environment. This will involve regulations, infrastructure and capability that are responsive to new research and development opportunities. This is necessary to allow new scientific advances to be tested and trialled both at the science provider and industry level. This applies to potentially revolutionary technologies, such as gene editing, as well as to farming, forestry and aquaculture systems, where environmental, genetic, safety and welfare regulations need to be informed by robust science and sound evidence.

Whatever the future holds, science-based innovation will be critical. Curiosity-driven research will give us important opportunities that we cannot anticipate. Equally, science priorities that push the boundaries of knowledge must be directed by our understanding of future needs. Integrating scientific knowledge with good communication, business, market intelligence, management and policy will help ensure a future we all want.

“We see shifts in how people eat, the food they want, the technologies that can produce new foods, and the environmental requirements placed upon us. And just like all the challenges our sector has faced, we recognise that we need to adapt how and what we’re farming to keep up. It’s just that our adaption this time will need to be much faster than it has been before.”

Steven Carden, Chief Executive, Landcorp New Zealand

4 Changing demands for science

Four areas have been identified during the development of the Roadmap, where the demands for science are critical and rapidly changing, and that encapsulate the sector's research and capability needs in the next 10 to 20 years.

These interrelated areas encompass the value chain from resource (genes, biota, soils, land, water and air), to production and handling systems, to product development, storage and transport, right through to the consumer. The areas are:

- **Sustaining, protecting and adapting our natural resources;**
- **Growing productivity and profitability with environmental, social and cultural acceptability;**
- **High-value products for consumers;**
- **Integrating primary production systems, people, communities and values.**

Taken together, the areas require a well-functioning primary sector, fully supported by an innovative and integrated science system. These cross-sector areas serve as a focus for our future science and technology needs and opportunities.

Sustaining, protecting and adapting our natural resources

Growing productivity and profitability with environmental, social and cultural acceptability

High-value products for consumers

Integrating primary production systems, people, communities and values

Sustaining, protecting and adapting our natural resources

New Zealand's primary sector will continue to rely on effective resource protection and management to deliver value from our natural resources. Kaupapa Māori approaches will provide leadership in this area. The ongoing collection of baseline data and ensuring these data are accessible and usable will be increasingly important. This will lead to greater understanding of our biota, soil and water resources, their interconnectedness with each other and the wider social, cultural and political landscape. This will allow for a more holistic future-proofing of our production systems and require culturally and socially acceptable approaches.

The environmental pressures on natural resources mean that their management requires adaptability to ensure both short- and long-term resilience and, where possible, enhancement. Changes in land and water use and in production systems, coupled with population growth and urban development, will continue to present significant environmental issues such as nutrient pollution, poor water quality, pests and diseases, and changed habitats including those important for our wild fisheries.

The significance of environmental pressures is highlighted by three major reports in the last five years by the Parliamentary Commissioner for the Environment that link water quality with land use and nutrient pollution. For instance, large-scale conversion of land, or the intensification of land use, can lead to increased nitrogen and phosphorus loss from the land into water, and increased pathogens and sedimentation. Changes in primary production practice can help mitigate environmental impact, as demonstrated on research farms where improved nitrogen use have meant losses have been reduced by as much as 50 percent.

Climate change (including sea-level rise and ocean acidification) will increasingly impact on our seas, freshwater, land, biodiversity, biosecurity and economy; and our primary sector must be prepared. New Zealand is committed to reducing its greenhouse gas emissions by 30 percent of its 2005 level by 2030 under the Paris Agreement. With approximately 50 percent of our emissions coming from agriculture and with plantation forestry acting as an important carbon sink, it is clear that the primary sector will play a vital role in achieving our greenhouse gas mitigation goals. Beyond greenhouse gases, climate change may have profound impacts on the nature and distribution of our primary production. For example, crops may need to be developed with a greater ability to adapt to temperature and drought; and land-use

CLIMATE CHANGE IMPACTS ON NEW ZEALAND FISHERIES

New Zealand earns approximately $1.8 billion in seafood exports each year, with wild capture fish stocks managed through a Quota Management System. Climate change poses a significant risk to New Zealand's seafood industry.

Until recently, our knowledge of the possible physical impacts on the marine habitat around New Zealand due to climate change has been limited. A recent study, the Climate Changes, Impacts and Implications project, funded through the Ministry of Business, Innovation and Employment, included a marine case study that has added significant new knowledge.

The study found that if global atmospheric concentrations of greenhouse gases continue to rise for the next several decades in accordance with observed rates of increase, by the end of this century seawater around New Zealand could be as much as 2.5 to 3°C warmer than at the start of the century.

Decreases in the sea-surface layer of chlorophyll-a, nitrate, phosphate and pH are also expected, accompanied by shallowing of the nutrient-rich surface layer. Primary production in surface waters (affecting the food available for fish) is projected to decline by an average of 6 percent from the present day, under this scenario.

Other greenhouse gas scenarios and mid-century projections were also assessed. The new data and information provided by this study means that we now have a better understanding of the future effects of climate change on fisheries productivity.

decisions will need to address different types of plant and animal production for different regions and soil types. Overall, our science needs to ensure that we have greater adaptability and flexibility in sustaining and managing resources.

Effective management of our natural resources can also have benefits for other sectors, for example, protection of human health through a reduction of diseases transmitted from animals, and a higher-value tourism experience of our natural environment.

Our biosecurity system has been designed to protect terrestrial- and aquatic-based primary production, and preserve our biodiversity, taonga, health and lifestyle. Innovation in biosecurity can drive smarter, more effective and efficient ways of detecting and managing biosecurity risk throughout the system. We also need to protect, grow and develop novel germplasm to improve productivity and resilience, as well as explore the potentially valuable properties of our indigenous flora and fauna.

Our current and future approaches to managing the pressures that the primary sector places on our natural resources will continue to require a robust science base, coupled with new research that pushes the boundaries of knowledge and encourages and supports the development and adoption of innovative technologies. Understanding and implementing landscape- and ecosystem-based resource management presents a critical opportunity for New Zealand.

Future outcomes that science needs to support

Nationally accessible, up-to-date and standardised information, databases and collections for our critical resources (soils, water, and biota) informing land-use and water-use (freshwater and marine) decisions and management and supported by tikanga Māori and other regulatory protocols.

Precision management of resources to optimise sustainable production.

Soils protected and managed so that they provide a strong and adaptable productive capacity supported by new technologies and integrated data systems.

Land-use and water-use (freshwater and marine) decisions informed by integrated systems-based environmental and production models, such as kaitiakitanga, that incorporate natural, cultural and social capital and ecosystem services.

Re-forestation programmes integrated into urban development plans, providing benefits for water use and quality, carbon mitigation and new bioenergy products.

A primary sector that is adaptive to a changing climate (including ocean acidification) and minimises greenhouse gas emissions.

Natural resources and production systems future-proofed against existing, new and emerging pests and diseases, and resilient to adverse events.

Growing productivity and profitability with environmental, social, and cultural acceptability

Increasing the value from our primary sector must come through increased productivity and profitability within environmental limits. Productivity is not just about producing more. It also includes achieving greater value from the same or fewer inputs in ways that are culturally and socially acceptable, addressing future constraints on land use, improving water quality, and supporting adaptation to climate change.

Maximising export returns through productivity and value gains across the production and value chain can be achieved by: implementing data-driven technologies and systems; capturing quality premiums from existing product streams; developing new technology-based food and fibre production approaches for multiple land uses and diverse landscapes; and reducing waste and input costs, such as energy and labour.

Some of these new approaches and technologies may be disruptive to current systems and workforces, requiring effective management and engagement with a diverse range of partners, stakeholders, and communities. New uses and industries are part of the shift into high-value, while addressing national needs in energy and raw materials. For instance, biorefineries could become central to the New Zealand bioeconomy, converting biomass into fuels, chemicals, feed, materials and energy.

Achieving productivity gains and being more profitable with increasingly demanding environmental, cultural and social drivers, such as animal welfare and reducing chemical use in pest and disease control, will require system-wide and multidisciplinary research approaches. These research approaches can also result in environmental benefits, such as bioremediation, and human health benefits through the control of anti-microbial resistance. Productivity gains will also rely on a well-functioning regulatory regime for hazardous substances and new organisms. Adhering to new and existing regulations will drive the need for monitoring, modelling and investment in new technologies, and will address the needs of small- and medium-sized enterprises.

“The way we use and manage our land and water will be transformed by: innovative resilient land and water use; collaborative capacity; and greater value in global markets.”

Our Land and Water National Science Challenge

Unlocking productivity will depend on building and maintaining global partnerships, with researchers, industries, businesses and government. New Zealand can benefit from international developments and adapt new science and technology.

Future outcomes that science needs to support

- Precision, digitised and data-informed terrestrial- and aquatic-based production systems with more efficient use of energy and resources to maximise profitability.
- Minimised production system waste and development of commercial value from by products and end-of-life products.
- Kaupapa Māori approaches used to support the development of indigenous and other species for new food, fibre and biomaterial products.
- New products from biotechnology and a protected and expanded national germplasm and genetics base.
- A diversified production landscape with a new generation of livestock, aquaculture and fisheries breeds and species, plants grown for the production of new and unique materials, and new crops with enhanced productivity, high health and targeted to high-value novel food products.
- Multiple use of diverse land categories and poor soil types, including repurposing these areas for carbon capture and co-location of forest and agriculture.
- New forest ecosystem services such as biorefinery forests, the use of short-rotation trees for biomass and bioenergy products.

BUILDING A DAIRY BUSINESS IN PARTNERSHIP WITH THE ENVIRONMENT

Kaitiakitanga is at the heart of a Central North Island dairy company's business decisions. Miraka is a dairy processing company that has made Taupō's volcanic activity its strength. Geothermal steam provides the company with a renewable source of energy to power its manufacturing plant, located less than 85 kilometres from its milk supplying farms. The company's strong research and development culture has helped develop high-quality and innovative products in collaboration with science organisations, farmers and customers. In addition to using renewable energy, dairy by-products are recycled through vermiculture (composting with worms) in the vicinity of the plant, and adjacent farm land is irrigated with the water extracted during the manufacture of milk powder. The company also uses GIS platforms to monitor and evaluate its environmental impacts. Miraka's intergenerational view of business and partnership with Māori landowners' aims to protect the environment and improve productivity and profitability for future generations.

High-value products for consumers

Shifting the balance of our primary production from commodity to high-value products with high marginal return will increase the diversity and complexity of New Zealand's exports. This shift is important for productivity growth and our ability to adapt to the changes and opportunities in global markets. While not a new direction, significant change and innovation will be required if we are to achieve business growth objectives for the sector.

Consumers and markets will continue to demand more sustainable and ethical production, processing and distribution of food and fibre, along with convenience, safety assurance, and demonstrated health and nutritional benefits. As a result of this demand, there has been a growing use of industry environmental, societal, and international performance metrics and related labels (for example, Health Star rating, certified organic labels, recycling symbols and source-of-origin) on product packaging. To date, there has been little research to evaluate the environmental, social and economic benefits of this type of labelling, but it will need sophisticated tools and capability to meet food safety, provenance, transparency and traceability to source requirements for both official and consumer assurances.

There is increasing concern about food integrity and food waste. Current global data shows that in developed countries, food waste and loss can be 30 percent or more at the retail and consumer end of the supply chain. Provenance narratives that focus on sustainability, indigeneity and cultural significance are also increasingly important in point of difference marketing and these will rely on tikanga and mātauranga Māori to meet acceptability measures. There is also a trend towards increased consideration of the distance between where food is produced and the consumer, and growing awareness about animal welfare. A rapidly emerging trend is greater support for plant-based proteins as alternatives to meat, novel food sources, and New Zealand's primary sector may be able to play a role in these.

There is a need for a more sophisticated understanding of consumers and their preferences, including emerging methods of purchasing such as e-commerce, in new and existing markets, to drive product development, and influence and shape consumer behaviours and markets trends. The world is moving on from technology push to technology pull (mainly driven by brand owners), with attendant issues for science implementation and new products. There are opportunities for more diversified higher-quality systems and products of distinctive New Zealand origin. We also need to determine the position New Zealand should take in response to major consumer shifts, such as synthetic foods or meat substitutes from plant resources.

Our primary sector needs to consider the whole supply chain in achieving greater value from our production systems. High-value from plant and animal genetics needs to be enhanced through the supply chain, including tailored production methodologies, quality maintenance from postharvest technologies, and sustainable, energy efficient packaging, transport and handling processes. New value gained from science and technology needs to be realised at all points of the supply chain to ensure that all actors in the chain benefit with increased profitability.

Future outcomes that science needs to support

Understanding people's preferences and values and how these inform and motivate the development of new or improved products through the supply chain.

Mechanised, traceable, information technology-driven supply chains providing safe, healthy, unique, eco-friendly and ethical foods.

Pharmaceutical, nutraceutical and biofuel products from traditional and new grown-for-purpose crops that will satisfy current and future consumer assurance requirements.

New engineered (natural) products, such as from using biopolymers to create plastic-like materials suitable for 3-D printing, engineering components and furniture.

Food products with new and high-nutritional (for livestock and humans) values targeting individual genetics, and ethnic and other new demographic and regional markets.

Linking local and national products and practices to national and international indicators around multiple dimensions of wellbeing for New Zealand, social progress indicators, and Sustainable Development Goal indicators.

Low energy and animal welfare-friendly transport, shipping and handling systems with sustainable, recyclable packaging across all products.

Advanced engineering and technologies such as nanotechnology providing new non-conventional processing approaches.

OVERCOMING THE CHALLENGE OF DISTANCE IN OUR FOOD INDUSTRY

Being on the other side of the world from many of our key markets has historically driven New Zealand food producing industries to develop innovative ways to get high-quality products to consumers. For example, the first successful shipment of frozen meat to Britain on the Dunedin in 1882 was a turning point for the New Zealand, paving the way for the huge trade in meat and dairy products that became the cornerstone of our twentieth-century economy.

All industries in the primary sector have had to meet these challenges through science and innovation. As a further example, in the seafood sector, the most valuable fish is one that is delivered live to the customer. Processes and technologies for stress-free capture, storage and transport have been developed for a number of species, particularly crayfish. Live crayfish shipment stress factors include temperature shifts (increasing or decreasing), low humidity, low oxygen, overcrowding and rough handling.

International- and New Zealand-based engineers and materials scientists, working in partnership with New Zealand's seafood industry, have developed insulated polystyrene boxes that are reinforced with a high-strength but low-weight steel casing for crush-resistance, which are often lined with wood wool (made from wood shavings) to maintain an optimal temperature (around 5°C) for shipping the live animals to countries like China.

Such innovations have arisen to reduce the effects of the distance to international markets, and in the process have added significant value to our products. Photo: T&J Enderby.

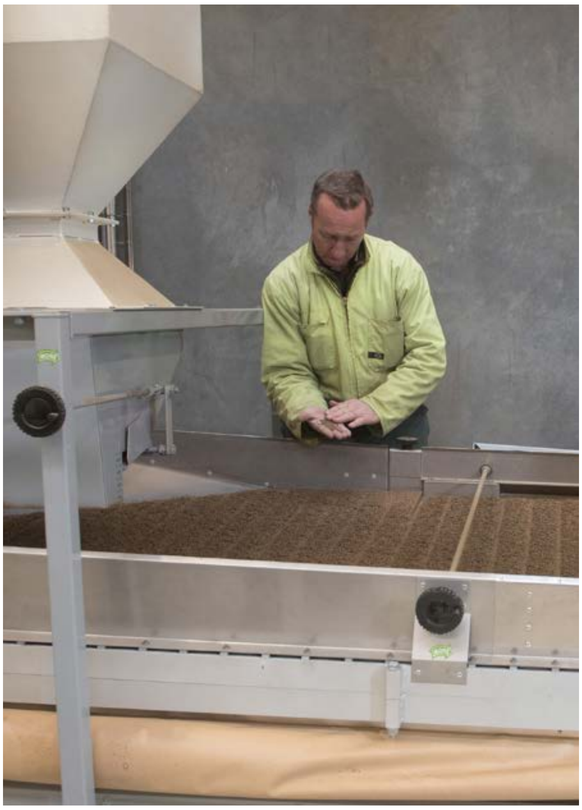
Integrating primary production systems, people, communities and values

This area addresses cross-sector and cross-value chain engagement with people, communities and values. It includes primary sector business models, the translation and extension of science for end-user implementation, and the development of a coherent Aotearoa New Zealand story. It is core to our primary sector, encompassing social and cultural licence to operate, understanding Te Ao Māori and public perceptions and preferences.

Production systems are part of the wider environmental, social, cultural and political systems, with integrated systems management likely to be increasingly important for the future. An example of such an integrated system is the sustainable land and water management systems that arise from applying the values and knowledge systems in Te Ao Māori, including kaitiaki roles and the multiple aspirations of iwi, hapū and whānau within different settings.

“The way we have farmed in the past won’t get us into the future, so we need to start applying our collective minds, expertise and networks to bring in the millennial generation, industry-wise heads, as well as second career people.”

Traci Houpapa, Chair of Federation of Māori Authorities and Landcorp New Zealand



The demands and opportunities arising from regional employment, rural and urban interactions, social and cultural acceptance of production systems, public perception and assessment of risk, changes in land and water use, and the central place of the individual and the collective, must be more effectively integrated into long-term decision-making. We need to understand how the corporate, co-operative, individual, collective or overseas ownership of primary sector enterprises will impact on growth aspirations, and how multiple knowledge bases and practices, including science and technology may contribute to this.

Management approaches and decisions made in isolation can lead to potentially undesirable environmental, economic, animal welfare or social impacts. Primary production that is considered a part of a holistic ecosystem which includes social, cultivated and natural systems, facilitates sector growth while addressing social, cultural and environmental concerns.

Science and technology developments need to flow through to all parts and participants of the value chain, and lead to practical benefits and opportunities for adding value. This takes time, especially when there is a significant research and development pipeline involving both fundamental and applied science (for example, breeding new plant varieties with specific traits). Having early and ongoing engagement with end users is important, as is having a clear implementation pathway. More research into the design of New Zealand primary sector-specific research and development projects that result in optimal uptake is needed. In particular, gaining a greater understanding of the strategies required to support the adoption or adaptation of research and technology by various end users.

More work needs to be devoted to developing a coherent and unique to Aotearoa New Zealand primary sector story. This has been done already by many individual primary sector businesses (such as Kono: pure taste of New Zealand) or industries (such as the New Zealand red meat story), but there needs to be greater cross-industry collaboration to maximise the saleability and profitability of Aotearoa New Zealand-branded primary sector products.

Both terrestrial- and aquatic-based production systems increasingly need to be addressed in the context of tourism, New Zealand's fastest growing economic sector. Much of the success of tourism relies on landscapes and seascapes, and the knowledge and perceptions of environmental properties such as water quality, pests and diseases, biodiversity and recreational demands. The future of the primary sector should be considered in tandem with the current and future needs of tourism, with a long-term focus on the benefits to both the primary sector and the wellbeing of all New Zealanders.

Future outcomes that science needs to support

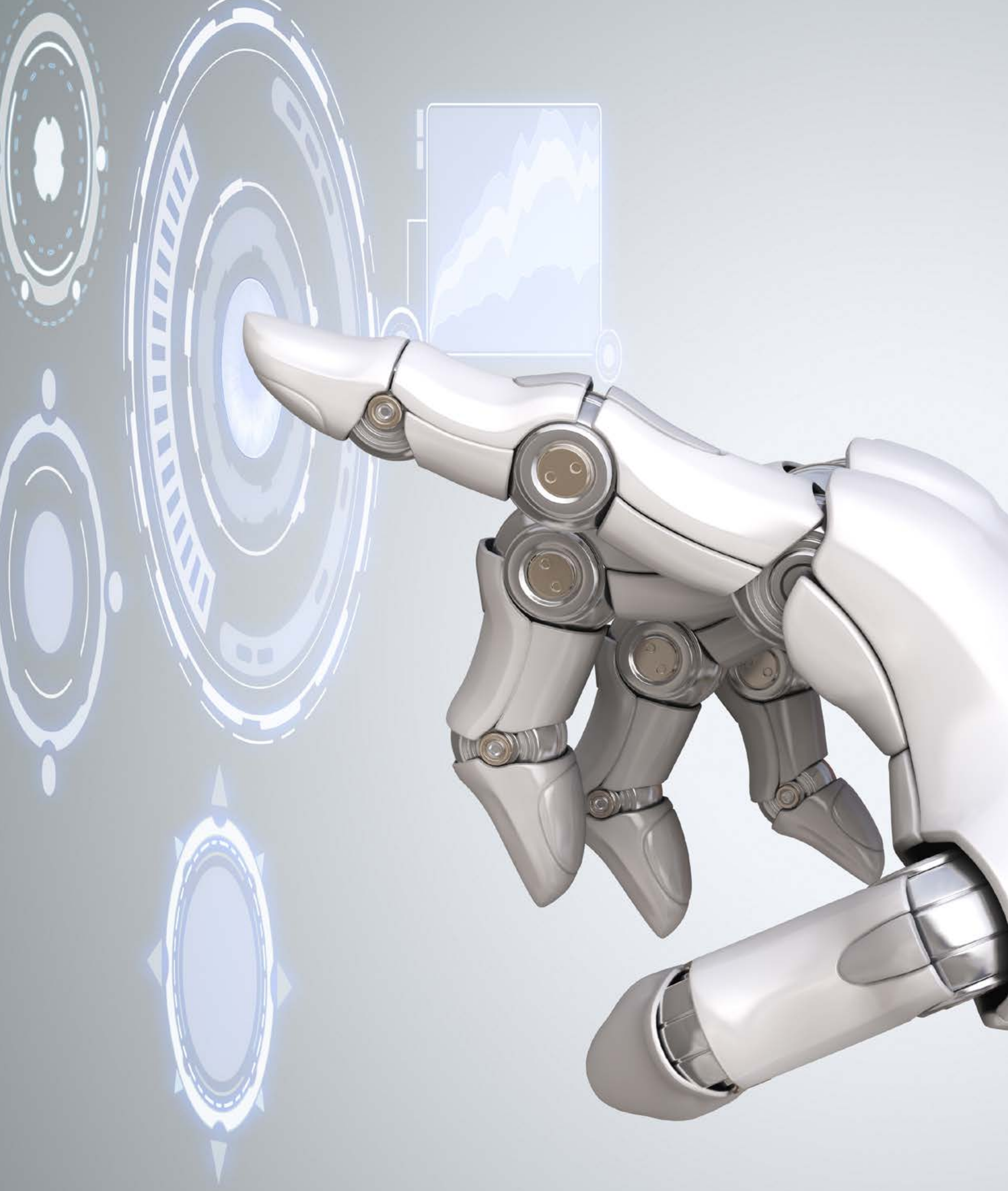
Informed public engagement and understanding of risk and consequences enabling co-development and implementation of new and innovative primary sector science and technologies.
Effective rural and urban public engagement in the science process used for sector development, and land-use and water-use (freshwater and marine) decision-making.
Kaupapa Māori approaches guiding innovation across production systems to encourage long-term social and environmental sustainability.
Māori primary sector businesses supported to adopt or adapt science and technology to achieve their development aspirations.
Effective means for adoption and communication of primary sector science.
A coherent Aotearoa New Zealand primary sector story, emphasising key product attributes based on provenance (such as cultural values, food safety, health benefits and quality) and is highly marketable.

TAILORING TO INFORMED AND CONNECTED FUTURE CONSUMERS

Millennials (born between the 1980s and mid-1990s) and Generation Z (born between the 1990s and mid-2000s) will be the largest generational cohort globally by the 2030s. By then, they will be in their prime spending years and the dominant consumers of food and other products.

Social science approaches based on surveys, interviews, group discourse and data-mining are being used to better understand the characteristics, outlooks, preferences and ideologies of this cohort. They are the first group of digital natives, having grown up in an established technology driven world with immediate and easy access to digital information and social media. They have a greater awareness of issues related to health and the environment, are generally more risk averse, and are particularly interested in social issues across all scales from local to global.

In a 2015 Global Health and Wellness survey by Nielsen, four in every ten Generation Z respondents said ingredients sourced sustainably were very important in their purchase decisions. Such information on generational behaviour and preferences is fundamental when it comes to targeting them as future consumers.



5 Themes: the science we need

Eight themes have been identified as important for the primary sector. Each theme contributes to the four areas identified in this Roadmap (Section 4), and are relevant to all primary industries (terrestrial- and aquatic-based). The themes are interconnected and are expected to have the biggest impact on the future of the primary sector. Priority directions for the science within each theme are contained in the box under the title of each theme.

The themes are:

- **Adding value**
- **Harnessing the value and power of data**
- **Innovating with advanced technology**
- **Innovating through genetics**
- **Innovating through Kaupapa Māori**
- **Protecting and sustaining resources**
- **Deriving value from complex systems**
- **Integrating people and values**

Adding value

Science in this theme needs to support the primary sector to achieve greater profitability across the supply chain from high-value products sold in local and international markets. This will be driven by consumer and market insights and co-innovation, and will result in a greater diversity of high-quality products and services.

Context

New Zealand's future primary production success and profitability is likely to be dependent on a significant shift from commodity to more diverse and high-value products, by-products and services. This will be driven by increasingly complex consumer and market demands and be enabled by the application of new science and technology. It may also require new models of value chains, with new combinations of players finding new ways to collaborate. The bioeconomy requires more active communication and co-operation between sectors, and science has to work within a more interdisciplinary production environment.

Adding value to products can be achieved in many ways, for example through the application of advanced technologies, developing new product types (for example, high-performance speciality wood products from non-radiata pine trees) and functionalities (for example, seaweed extracts for cosmetics), or innovations in product design and marketing (for example, 3-D printing using natural products such as biopolymers). This theme focuses on the importance of science related to consumers and markets in adding value, and ensuring that value is captured across the supply chain.

New high-value diversified products and entry into new markets demand appropriate consumer and market intelligence and a sophisticated understanding of sensory science and consumer preference in target markets, both domestic and international. This knowledge of the consumer and markets must be a driver in developing the value chain, feeding back into the fundamental stages of production, such as breeding programmes.

More research is needed to enhance and maximise the value from our existing products for New Zealand producers and manufacturers. Research into Knowledge Intensive Business Services includes optimal business models to increase returns, collaborative market-oriented value chains, and social science research into factors inhibiting value capture from the market. Enhancing value from existing products needs to focus on uniquely New Zealand attributes and factors that are embodied in what we produce, such as the cultural, social and environmental integrity in which the products are produced; in other words our Aotearoa New Zealand story.

The focus of in-depth research is conventionally on components of the value chain, for example, development of bioadhesives and resins for new wood-based products, or extracting high-value ingredients from milk. For this to be successful, there is an increasing need to ensure that new value injected into the supply chain is backed by science at all stages. For example, developing a new fruit cultivar requires research in growing systems and management, postharvest handling, and sensory and consumer science. Likewise, new wood fibre-based biomaterials may need new research in genetics and silviculture, and greater regional focus on the value proposition.

Some of our greatest challenges and opportunities in diversifying and creating more value are driven by consumers and markets, such as the interest in low-chemical use in pest and disease control, concerns around the quality of water in our streams, rivers and lakes, and issues of animal health management. We need to be more agile in addressing a more informed consumer with changing purchase mechanisms, such as e-commerce, and their demands for greater transparency and traceability.

We can benefit from new insights about customers, for instance taking into account purchase and consumption environments, and the social science behind understanding reasons for consumer preference. Currently, it is possible to gather an abundance of personalised data at reasonable cost and sufficient scale, including consumers being able to access their own genomic information. Much of this information is gathered by international agencies. As a result, the primary sector will have more opportunities for tailored, high-value products aimed at more sophisticated market segments.

Greater diversity and higher value demands a sophisticated manufacturing sector, with engineering, processing and information technology skills linked into the more fundamental research and development environment. This is also the case in the move from conventional food products to more innovative production, for example, new plant protein-based food, and food from previously-considered non-food sources. This shift in food production will require taking risks to develop new production systems and products that will need whole-of-supply chain research, from genetics through to market research. There needs to be scanning of food trends, market opportunities, infrastructure innovations, and population and demographic trends to future-proof primary sector export growth. Such changes will continue to need robust regulations and standards in food safety, biosecurity and animal welfare, and a well-performing regulatory regime for new organisms and hazardous substances.

The development of high-value and desirable products requires new concepts and practices such as co-creation, where different parties, such as producers and consumers, work together to research and identify new product opportunities. Development of cultural competency is also needed to develop new foods for overseas markets.

Current research approaches

New Zealand already has some good examples, such as kiwifruit, where a systems approach was taken to identify research and development needs across a supply chain. As a country, we also have strengths in functional and high-value nutrition and food research, particularly in the areas of sensory and consumer science, and in

BIOPLASTICS FROM KIWIFRUIT WASTE

Novel uses for plant components provide a wealth of opportunities for the primary sector, particularly when they use residue or waste and can replace more traditional plastic or other oil-based products.

The Biospife is a spoon made from kiwifruit waste that is under development by Zespri supported by expertise at Scion. The technology used by Scion transforms the kiwifruit residue into a material which can then be formulated with other plastics, but allows the material to be renewable and compostable.

While not yet commercially available, the Biospife has the potential to reduce Zespri's carbon footprint by 3 percent. It also reduces costs by using the thousands of tons of kiwifruit waste that are dumped each year. This demonstrates the potential for what could be many more applications of biomaterials. Photo: Zespri.

engineering. Although much of our food research is embedded in a wide range of sector product lines, we have advanced research in innovative processing, packaging, postharvest and delivery mechanisms. Research on innovative packaging for the food industry, from wood and waste materials, has potential for cross-sector innovation.

Growing expertise in biomaterials, biomedicines and bioenergy are important for future diversification of the sector and, in these areas particularly, building on international developments is crucial. The identification of unique and innovative primary sector production systems that demonstrate Kaupapa Māori approaches to sustainable models of development can provide an opportunity for the development of new food, fibre and health products, and production systems, with an indigenous value proposition.

Many attempts at diversification of product type have failed due to a mismatch between science drive and market or consumer demands. We need to better link product development science with the science of understanding consumers. While sensory and consumer science is strong, the scope of such research, particularly in addressing ethnic and societal differences, still needs to extend to a wider range of sector product lines. Adapting to markets and consumers underpins the success in new export growth for some foods. There is an opportunity to expand on this approach for non-food products from the primary sector.

Research opportunities

Addressing the wider opportunities of the bioeconomy: new manufactured products such as new wood products, nutraceuticals, biomedicines and biomaterials from existing and new resources, production systems and waste streams.

Developing biofuels as a major part of the bioeconomy.

Using supply-chain modelling and management to incentivise value-add across the whole supply chain.

Using blockchain technology to enhance transparency, traceability and provenance of New Zealand products, integrating ingredients into high-value products, and allowing sustainability and food safety assurance demands to be addressed.

Determining the key values that are embodied in our existing products, and how these resonate with markets and consumers.

Developing potentially revolutionary plant- and animal-based food types, such as synthetic meat-substitutes, new crops, insects or marine microbiota.

Using Kaupapa Māori approaches to explore improved primary sector production systems and products with culturally distinctive value propositions.

Improving our understanding of consumer preferences and behaviour through new digital technologies, data capture and analysis, and social media.

Using models of co-creation, participatory action and co-innovation to generate innovative products.

Developing high health foods that are validated through medical and sensory science and human genome-based tailoring of foods addressing wellbeing and disease states.

Understanding psychographic, social and cultural factors that lead to rejection of anything new or unfamiliar, and overcoming barriers to acceptance of new foods and innovative food technologies.

Harnessing the value and power of data

Science in this theme needs to lead to production systems that are more efficient, profitable, and adaptable, and have a more positive impact on the environment through harnessing the value and power of complex data. This will require major advances in the definition and collection of critical data, smart use of connected data sources for real-time data-driven decision-making, and advances in data handling, interoperability, management and governance.

Context

Our ability to collect, connect, process and use data at all scales provides a substantial opportunity for future primary production to be transformed into a more efficient, precise and sustainable activity.

Challenges in harnessing the value of all types of data include establishing social, cultural and technical protocols; automating data processing; simplifying complex decision support tools; integrating new digital providers and technologies; and ensuring account is taken of values and capabilities of end users during design, development and extension.

There is significant potential for spatial and temporal high-resolution data (including observations, remote sensing information, model output, market and consumer analytics, and forecasts), linked with precision tools for agriculture, forestry, fisheries, aquaculture and horticulture, collected at decision-relevant scales and analysed and applied in real-time. Land Information New Zealand has identified a range of geospatial research and development opportunities for the primary industries, including development of tools related to the health status of stock, management of disease outbreaks, and optimisation of harvesting.

The effective use of data can enable producers and suppliers to make management decisions. This could mean lower input costs and gains in productivity through improvements to feed and nutrient management, intervention scheduling (for example, pruning, irrigation and harvesting), crop and livestock monitoring and testing, wild fish capture, and pest and weed control. Effective collation and analysis of pre-border, at-border and post-border biosecurity data could also revolutionise the biosecurity system, as identified in the Biosecurity 2025 Direction Statement.

Successful digitisation depends largely on the growing use by multiple businesses and private individuals of a wide variety of sensors, devices and machines collecting and processing data. The connection of all these data through the Internet of Things will be a significant and system transformative development. Cloud computing is expanding, providing a new dimension of data storage and management, and along with it the need for international protocols and standards for intellectual property, security, provenance and privacy. In this, there needs to be assurance of simplicity of access and application.

New Zealand, like many other countries, is still learning how best to collect, manage and make efficient use of the data that we currently generate. Much of these

MAXIMISING THE BENEFITS OF HIGH RESOLUTION WEATHER FORECASTS

Accurately predicting the weather over the coming hours to weeks has huge economic and environmental benefits and enables more efficient decision-making. This is especially true for minimising the impacts of weather-related hazards (such as drought, wildfire, flooding, storms and frosts) and managing water and nutrient resources.

These benefits can only be fully realised if the large multivariate datasets generated by numerical weather prediction models, which run on supercomputers and produce terabytes of data hourly, are managed so that location specific forecasts can be easily and instantly accessed. For example, NIWA's web-based subscription forecasting and information service (incorporating the EcoConnect and FarmMet tools) gives farmers and growers direct access to forecasts out to 15 days and allows individual users to set an alert when conditions pass (or are forecast to pass) a specified critical threshold, such as at what hour the overnight temperature is likely to fall below freezing. This level of detailed site- and time-specific forecast information is what is needed for frost fighting over vineyards.

data are underused, with the potential use of many existing datasets untapped because of the need for better quality checking and gap filling. As the primary sector becomes increasingly capable in the use of digital technologies, there will be an increase in the types of data being collected and required for best practice management. This will lead to significant challenges in the management and analysis of these data. Turning data collection into real-time decision-support information is a big challenge for the primary sector, and one that must be overcome to maximise the value of new technology. New Zealand researchers and data managers need to be actively involved in global data policy development, particularly relating to open data, or we risk being non-compliant and unable to keep up with global trends.

There is also a lack of data collection and management protocols and standards. There are a multitude of sensor options, analytics software and data storage providers, both nationally and globally. This is driven mostly from the private sector, with the Internet of Things sensor costs reducing, but there is little in the way of agreed protocols. Data quality control procedures, metadata collection and management, and data access mechanisms vary greatly. More research is needed on mechanisms for automated data handling (including collection and access) and processing. There is a pressing need for consistent data-sharing and charging policies, including open data commons policies, across proprietary data providers, such as iwi and hapū, Land Information New Zealand, research institutes and regional councils. Minimum standards are urgently needed to allow data to be more efficiently shared and linked to achieve multiple benefits across the value chain. Commercial advantage will need to be balanced with an all-of-New Zealand approach.

Big data collection will only be beneficial if we have the necessary infrastructure and capabilities for acquiring, storing and sharing data from multiple sources, and ensuring data are fit-for-purpose, decision-relevant, and easily accessible for other broader or unforeseen applications. Research is needed on taking data from the collection phase through to its final use, while ensuring this is done in a culturally and socially appropriate manner. The rise of business intelligence tools, and advanced analytics, will likely drive increased automation and it is important our primary sector can access the data that underpins these new tools.

Current research approaches

Big data management solutions are at the forefront of international research, covering issues of communications, storage, processing speed, access, quality control, privacy, governance, interoperability and data conventions. Aligned with this research, and often shaping its direction, is the rapid development of robotics, sensors, satellite and wireless communications technology, and fit-for-purpose analytic software applications. Research into the automation and optimisation of data collection and processing is advancing rapidly, with some New Zealand companies at the cutting edge internationally in the research and development of data storage and processing.

New Zealand remains mostly an adopter of international research in fundamental data science, although we have strengths in our whole-of-supply chain approach. We are leaders in some aspects of packhouse quality control, automated fruit processing systems, and in remote sensing, such as for plantation forestry. Our relatively small-scale, yet complex environment, provides a strong test environment and has a further advantage in the potential to be used across sectors; for example, technologies used in forestry can be tailored for use in other crop and pasture environments. In some cases, overseas expertise and solutions are not applicable to our requirements, so we need to continue to develop our own capabilities in data management and application. This is particularly relevant with respect to the use of multiple datasets for decision support.

Research opportunities

- Collectively managing data to ensure maximum benefit for multiple users and applications.
- Adapting and using complex data and innovative data sources to achieve more efficient and effective production systems.
- Developing best practice for precision data collection, storage, processing, governance, quality control, security and access.
- Developing indigenous biophysical data management systems.
- Integrating *in situ* data (for example, from machine sensors and animal monitoring), *ex situ* data (for example, weather forecasts and pricing data) and analytical tools (for example, real-time communications and interrogation software) to enable better real-time decisions, products, and supply-chain processes.
- Accessing, interpreting and applying international developments in open data, remote sensing, GPS, and the Internet of Things in New Zealand production and risk-management systems.
- Understanding New Zealand's border protection through harnessing the value of biosecurity data.
- Developing real-time geospatial information on the health status of all New Zealand stock and disease-carrying wild animals and birds.

Innovating with advanced technology

Science in this theme needs to ensure a globally competitive New Zealand primary sector through the development and implementation of new technologies, including advanced, disruptive, and transformational technologies, such as reproductive biotechnology, information and communications technology, synthetic biology, automation and robotics.

Context

Rapidly emerging technologies can create significant production and processing efficiencies, enable new ways of accessing and using information, and precisely automate current manual tasks (both physical and decision-making). Advances are being made in advanced engineering, nanotechnology, sensor technology, precision measurement, communications, genetics, automation, robotics, analytics, and decision support tools that can transform production systems while reducing environmental effects and ensuring a safe and traceable product supply. Growing produce in climate-controlled indoor settings is also becoming more cost effective, as the cost of photonic technology falls. The drive for new products in the context of environmental limits, social and cultural acceptability, and regulations in New Zealand mean that these technologies will form an important part of integrated systems management.

The more specific opportunities for harnessing data generated by technology and genetic technologies are addressed in the themes on data and genetics, respectively.

Globally, there is an ever-increasing array of innovative technologies being developed and implemented in the primary sector, and costs are reducing. For example, new manufacturing processes, including 3-D printing, are being adapted using New Zealand natural products. New Zealand has historically been an early adopter of new technology; however, we also need to be adaptive so that the technology meets the needs of our unique environment. To remain competitive in the uptake of technology, continued scanning and adoption and adaptation of overseas technological developments will be important. Collaboration in international research programmes is a crucial part of this.

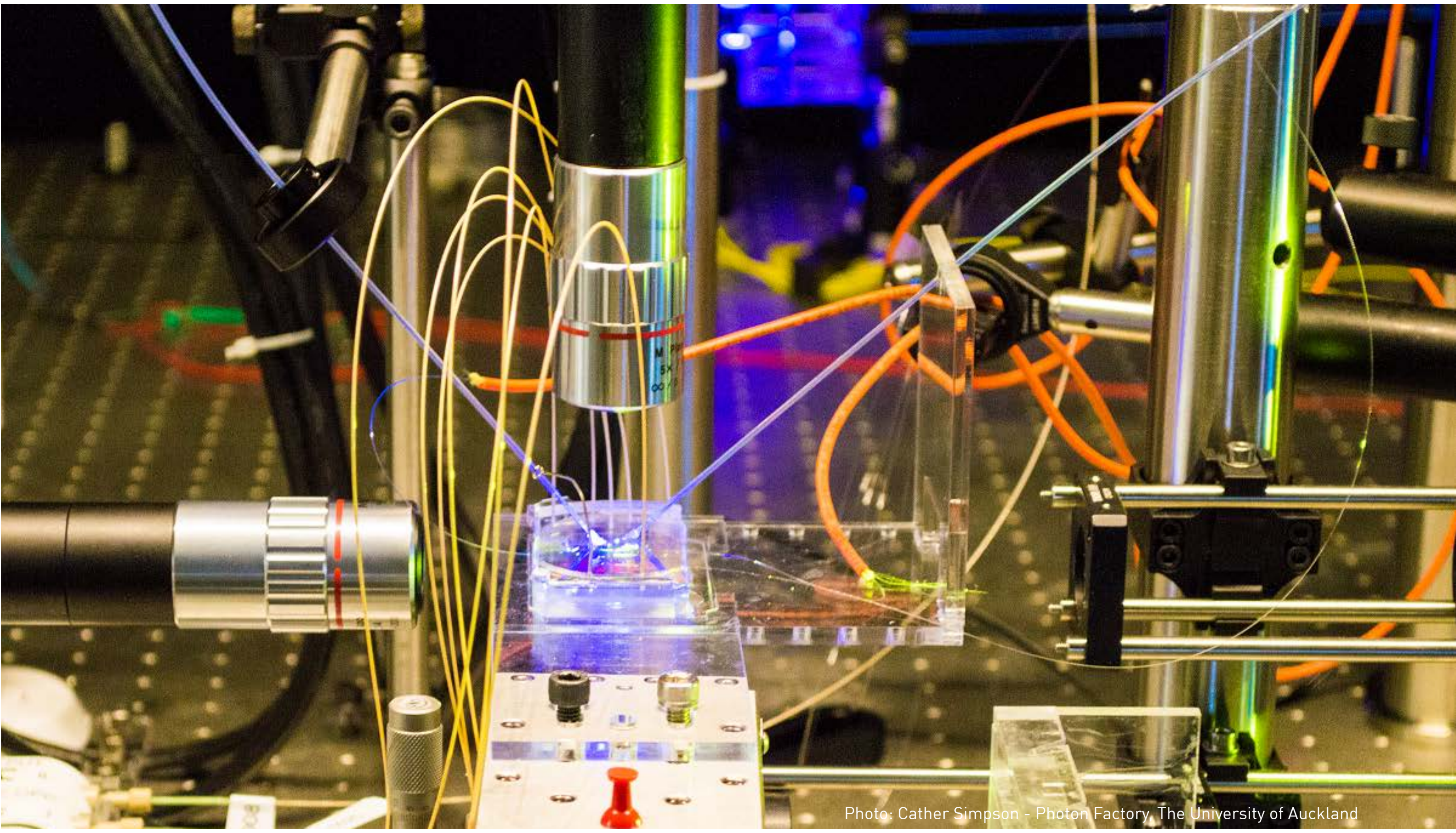


Photo: Cather Simpson - Photon Factory, The University of Auckland

Advanced technology challenges and opportunities include:

- **Robotics and mechanisation:** Innovation in forestry harvesting practice comes from development of geospatial software and technology, and remote-controlled robotics, allowing safer, and more efficient and precise, working of steep terrains; automated milking systems can positively impact on farm management, efficiency and animal welfare; and advanced physical sciences such as optics, sensors and nanotechnology can support innovation, for example for pest and disease detection, management or eradication.
- **Process, extraction and fermentation engineering**: New technologies in wood, fibre and food processing, and bioengineering are needed to meet the demand for greater product value and diversification, particularly in biomaterials and functional foods. Plant and marine resources need to be researched for new livestock and fish food sources.
- **Synthetic biology and non-gene biotechnology:** Opportunities exist for new organisms in food production and processing, bioremediation or biocontrol; and reproductive technologies allow more rapid selection and introgression of new traits into livestock breeding programmes.
- **New engineering for production systems:** Areas such as irrigation are already well-advanced in the application of engineering; however, more research is needed on technologies to transport water over large distances of sometimes complex terrain, or novel ways of collecting and distributing water to mitigate the impacts of localised droughts. There is potential for the application of advanced engineering in ocean farming, deep-sea aquaculture and fisheries, vertical farming in urban environments and indoor facilities, and in the use of novel energy sources (thermal, solar and biofuels) for more efficient closed production systems.

TRANSFORMING HILL COUNTRY FARMING TECHNOLOGIES

Fertiliser is an essential part of farming operations. It is often spread uniformly without taking into account different soil fertility and nutrient needs. This is in part because it is a challenge to measure soil fertility of farmland, particularly on hill country.

MPI and Ravensdown are investing in a Primary Growth Partnership programme called Pioneering to Precision that is developing technology to assess soil fertility from the air. The aim is to couple this aerial remote sensing technology with Ravensdown's own work on developing automated variable rate spreading and placement verification technology, which is GPS driven and controlled by computer. A spreading map developed by this technology is sent wirelessly to the plane, specifying areas and blocks where fertiliser should be applied, and should not be applied.

A very promising map has been produced showing proof of the variable-rate release at a field trial on Tautane Station, a 3374-hectare hill country station on the east coast of the North Island owned by local Ngāti Kahungunu iwi. During the trial, 347 hectares of sensitive areas and waterways were removed from the areas to be fertilised, and this fertiliser was reallocated to other parts of the farm. This technology has the potential to transform hill country farming by helping to improve productivity and protect the environment.

Success in the use of new technologies will depend on appropriate investment (including in science, technology, engineering and mathematics education) and value propositions for implementation, commercialisation (including ability to upscale), and public acceptance of their uptake and management.

There is a particular need for engineering and information technology skills to be at the interface between science and commercial implementation. Early and sustained engagement with partners, stakeholders and impacted communities will be key to effective uptake of new technology.

Strong partnerships with iwi and hapū will be required to develop cultural licence for the adoption or adaptation of new technologies. Technologies relating to sustaining, and the commercial product development of, indigenous flora and fauna will also require satisfactory ownership arrangements.

Current research approaches

Remote sensing technology and mechanisation is becoming widely used across plantation forestry, fishing, horticulture and pastoral farming. In forestry, this particularly focuses on increased worker safety and precision in harvesting technologies. For pastoral farming, this increasingly involves monitoring the location of individual livestock for pasture management and potentially for identifying animal welfare issues. Real-time sea surface temperature imagery can be used operationally to identify potentially-optimal fishing grounds. Postharvest sensor technologies to discriminate product quality are advanced in domestic and export horticulture. Advanced engineering, including in irrigation systems, is already in broad use and becoming increasingly sophisticated.

Research into advanced mechanisation and the use of robotics is at different stages of development and application in different sectors. It is advanced in forestry with novel scanning and robotics technology being developed to assess wood properties that affect the quality of timber products. The dairy industry is already experimenting with once-a-day automated milking. Other areas of current development are robotic weeding, pollination, fruit harvesting, chemical applications and pruning. More experimental farming is needed to explore the consequences and benefits of advanced automation; initially through automating current manual practices. Once a critical level of automation is achieved, additional opportunities often open up to transform the overall process in order to gain further efficiencies.

Research opportunities

Developing and adopting new technologies for high-value products from deep-sea fishing and seafood farming.
Addressing the increasing need for transparency and traceability in the supply chain through research on technologies, for product source validation.
Developing advanced capability to put robotics outdoors in the New Zealand forestry and farming environment in a robust, reliable and modular way, with connectivity to networks and sensors.
Exploring synthetic biology as a disruptive technology to benefit development of new food and non-food products.
Adapting artificial intelligence for the primary sector, such as self-learning decision support systems.
Developing sensor technology for monitoring and precision phenotyping of animals in remote areas to assist genetic improvements.
Supporting emerging technologies to protect or improve consistency in the quality of (animal and plant) products in variable environments (for example, hill country, plains, coastal) and also in indoor facilities, and to capture and re-use nutrients, wastage and energy.
Developing sensor standardisation across the primary sector to facilitate interoperability and data sharing.
Exploring the implications of social and cultural licence for technological development and uptake.
Incentivising uptake and implementation of advanced technologies through early inclusion of partners and stakeholders, better value propositions for the wellbeing of all, understanding of users' needs and drivers, and social and cultural understanding of technologies and their impact on social cohesion.

Innovating with genetics

Science in this theme needs to lead to plant and animal production that is more efficient, safer and adaptable, while minimising negative environmental impact, allowing rapid development of new generations of food and fibre products.

Context

New Zealand's primary sector has a long and successful history of using genetics to improve traits in plants and animals. Breeding systems, quantitative genetics and lab-based plant and animal reproductive technologies have proven to be key tools for improving productivity, introducing new high-value plant cultivars, new traits into animal breeding lines, and improving environmental performance, disease resistance, animal health and adaptability.

The increasing use of genetic markers, computational genomics and associated technologies, such as high-throughput screening, are broadening our ability to select for new consumer-driven traits and to rapidly introduce new cultivars in response to pests and diseases or environmental pressures. These technologies have already helped us to understand the genetic structures of weed, pest and diseases in New Zealand's primary sector. Gene-based technologies will continue to provide opportunities for significant advancement in: plant, animal and human health; nutrient and water management; monitoring of environmental health indicators; biosecurity and biocontrol; food safety; land use, production and sustainability under environmental change; and new food and fibre products.

Recent developments in gene-based technology have the potential to further transform our primary sector. Rapid international developments in precise gene editing (for example, zinc finger, TALENs and CRISPR-Cas9) as well as the use of genomic selection methodologies and next generation sequencing are changing the landscape of what is possible in biotechnology.

To benefit from these technologies, we need high-quality genome assemblies and international collaboration to properly annotate the genome, and better genetic dissemination mechanisms, such as shorter generation times in breeding cycles. These developments are

GROWING THE VALUE OF NEW ZEALAND'S FORESTS

Continuing improvements in the quality and productivity of our plantation forests through extensive breeding and silviculture practice underpins the increasing value that we derive from our forests. Scion established the first genetic gain trials in 1978. These trials have been monitored for over 30 years and represent one of the most extensive datasets of its kind internationally.

Scion has also partnered with industry on tree genetic programmes to improve tree stocks using quantitative genetics approaches. These programmes have focused on improving the growth rate and the form of radiata pine (such as reducing branching) and increasing resilience to diseases. Together, these genetic improvements have increased the net present value of the national radiata pine estate by an estimated $3.5 billion. The introduction of more highly improved tree stocks is underway, with an estimated value uplift to the industry of $8.5 billion compared to using unimproved material. This work makes a major contribution to providing credible scientific evidence that links genetic improvement to productive gains in volume and density in 30-year stands.

New Zealand has yet to realise the full potential of genetic improvement to improve productivity and uniformity within and between trees. Genetics also has a significant role to play in making this industry more resilient to potential challenges from diseases, pests and climate change.

challenging conventional views on gene technology and therapy and are presenting an emerging issue for national and global regulations.

Our increasing understanding and analysis of biology and genomes, in particular the underlying traits of importance and their genetic control, will allow greater precision in management of soils, crops and animals. Established views of genetically modified organisms are also being challenged by new methods that allow very precise changes to DNA that can be rapidly incorporated into breeding programmes without the end-products containing foreign DNA. New techniques such as gene drive raise the possibility of securing rapid genetic changes through populations and generations that might have impact, for example, in controlling harmful insect incursions. Breakthroughs in biocontrol are occurring from advanced population genetics and new techniques for rapid integration of genes into populations.

The biggest challenge ahead is finding ways to benefit from revolutionary gene-editing and sequencing technologies in a way that is culturally and socially acceptable to New Zealanders, as well as to overseas consumers and markets. Scientific advancements in this area should not come at the cost of an animal's overall welfare and should assess the potential environmental impact. Many countries are revising legislation for the use of new genetic technologies. For New Zealand, a clear and well-functioning regulatory regime for new and modified organisms will be key to realising potential research opportunities.

There is an opportunity for New Zealand's primary sector to harness greater benefits from cross-sector approaches in bioinformatics and breeding methods, for example, working across plant and animal breeding systems, especially for the implementation of advanced tools involving genomic selection and statistical genetics. We already use international capability in gene sequencing, and while much of our genetics is particularly focused on New Zealand's biological economy, strong international collaboration will be necessary if New Zealand is to benefit from, and contribute to, global biotechnology advances.

Current research approaches

Genetics has proven crucial to our international competitiveness. Across the primary sector, genetics has led to substantial gains in productivity (for example, around 1 percent per year in wood yield) and new export industries (for example, gold kiwifruit). Genetic-based techniques have been a major factor in improving lamb productivity and milk production per cow in the dairy

GENETICS IS AT THE HEART OF NEW ZEALAND'S COMPETITIVE ADVANTAGE IN EXPORTING FRESH FOOD

New Zealand became a leader in developing kiwifruit as a global export crop after many years of selecting suitable varieties and developing an extensive germplasm collection. Breeding programmes were coupled with postharvest and consumer science, crop physiology and crop protection. A comprehensive breeding pipeline resulted in the uptake of the gold variety and a new high-value export product.

When this variety was devastated by the bacterial pathogen Psa (*Pseudomonas syringae* pv. *actinidiae*), the industry was saved by a new gold variety already in the breeding pipeline and able to be rapidly taken up by the industry.

The kiwifruit industry will continue to be world-leading with the development and introduction of new and novel kiwifruit varieties that meet consumer and market demands, coupling breeding with lab-based biotechnology, development of genetic markers and high-throughput screening. Genetics will be the key to New Zealand's success in fresh food exports.


Photo: Zespri

sector. Active and efficient breeding programmes have allowed for rapid recovery from devastating diseases such as the bacterial vine disease Psa in kiwifruit.

While genome selection is embraced by some of the fish and shellfish industries, there is large potential for more genetic approaches here, particularly for aquaculture. New Zealand has a history of strong and beneficial science in plant and animal breeding using lab-based technologies which could be adapted for other uses across the primary sector.

There will be a need to use our systems to focus on adaptive traits for climate change, for example, reduction in methane emissions from ruminants or temperature and nutrient responses. Moreover, the move to high-value export products means that more specific consumer traits such as high-health benefits will be of particular interest for breeding programmes.

The development of genetic tools to support biosecurity and systematics, both the new approaches to identifying pests and diseases and the underlying systematics, is increasingly important for both biosecurity management and market access.

Our breeding programmes, gene technology and informatics activities are becoming more international in approach as we link to off-shore capability (for example, in genome sequencing) or use international programmes and collaborations to test new genetic material.

Research opportunities

Using gene technologies to produce new cultivars and breeds adapted to changing environmental conditions, modify our environmental footprint, increase resilience to pests, address animal welfare issues and support eco-remediation.

Preserving and maintaining genetic diversity (for example, heritage cultivars) to safeguard future options.

Increasing understanding of the impact of selectively-bred fish stocks on wild populations, and development of technologies that produce farm stocks that do not spawn.

Using molecular phenotyping (for example, nutrigenomics) via the study of gene expression and DNA methylation to enhance production efficiency in plants and animals and development of new high-health food products.

Developing Kaupapa Māori approaches to enhance uptake of new gene technologies to advance cultural imperatives such as preservation, conservation and commercialisation of taonga species and maintenance of whakapapa.

Using advanced gene technologies (for example, gene editing, next generation sequencing, low-cost genotyping technologies such as genotyping by sequencing) to accelerate development of new cultivars and breeds with known improved traits, as well as in more developing sectors (for example, new crops and livestock).

Developing key bioinformatic and statistical tools to maximise value from genetic data for breeding programmes.

Developing and effectively using metagenomics in resource management, product quality assessment, food safety and traceability.

Using gene technologies (for example, gene editing, new RNA-based technologies, such as non-gene RNAi, and gene drive) to control biosecurity incursions, monitor environmental health indicators, identify new biocontrol agents, and improve pest and disease management.

Innovating through Kaupapa Māori

Kaupapa Māori research approaches need to provide distinctive and transferable primary sector innovation informed by tikanga Māori, mātauranga Māori and science working together.

Context

Māori hold a nationally significant stake in land and water management. Building on proven histories of entrepreneurialism and export, Māori enterprises are increasingly leading sustainability-focused, innovative ventures in key primary sector industries. Kaupapa Māori approaches, defined and led by Māori, with a wide range of partners are well placed to lead collective innovation.

Māori enterprises in the primary sector typically have some distinctive features. These can include:

- culturally-informed business models focused on intergenerational sustainability and long-term social, cultural and environmental benefit;
- practicing the kaitiakitanga integrated systems approach to resource management;
- governance and management practices sourced in Māori values and tikanga Māori;
- co-management and co-governance arrangements with the Crown, regional councils and other agencies to manage and develop natural resources;
- ownership over Māori freehold land, customary land, and also Māori general land;
- diverse structures including trusts, incorporations arising from intergenerational hapū and iwi ownership, and Post-Settlement Governance Entities arising from Treaty settlement;
- diverse portfolios;
- large and complex shareholding arising from collective asset ownership;
- commitment to intergenerational asset ownership.

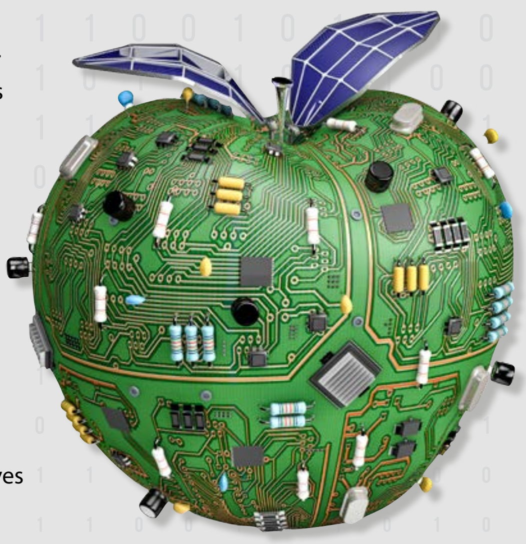
Māori primary sector enterprises require access to science and research that genuinely understands and meets the distinctive requirements of a diverse range of commercial and cultural contexts and aspirations. Development of the business models practiced by Māori and kaitiakitanga-based approaches to managing the environment have enduring transferable value as they can provide leadership to the wider primary sector as it seeks more integrated, sustainable management practices.

DATA TRANSLATION: FROM KNOWLEDGE TO SMART MOVES

Waka Digital is an Information Technology company that harnesses the power of data to provide businesses with a range of innovative tools and services for land management decision-making. This company also plays a leadership role in providing infrastructure and strategy for a number of high-profile projects.

Over the last eight years, Waka Digital has been involved in the following Ministry of Business, Innovation and Employment-funded science projects: Oranga Taiao Oranga Tangata – Knowledge and toolsets to support co-management, Manaaki Taha Moana – Restore and enhance coastal ecosystems, and Ma te matau ka ora – Creating shared value through understanding our land and its potential. These collaborative Kaupapa Māori research initiatives have led to the development of toolsets that integrate Western science and mātauranga Māori knowledge.

Waka Digital also provides the information technology platform for Ikanet, an online customary fisheries management system helping iwi exercise their fishing rights and manage mahinga kai and kaimoana resources. Similarly, the eWhenua research platform aggregates public and private datasets to provide real-time information for Māori growers and producers in various primary sectors (viticulture, kiwifruit, forestry and pipfruit). This aggregation of data enables timely evidence-based decisions, which gives business owners greater confidence in managing assets through more control in risk management and resource planning.



As Treaty partners, Māori also have rights and responsibilities to manage natural resources sustainably, for current and future generations, within and across particular tribal areas. This will require increasingly effective tools, processes and frameworks sourced in Māori values with which to undertake those management and co-management roles. Kaupapa Māori research approaches are designed to manifest this cultural and social value.

Kaupapa Māori research is a robust, dynamic investigative discipline that generates new knowledge and innovative solutions, tools, processes and frameworks which are explicitly sourced from tikanga and mātauranga Māori. Kaupapa Māori research approaches and activities draw on a range of interconnected values and participatory practices. They are informed by a holistic worldview in which land and water are respected and partnered with to support the overall wellbeing and balance or mauri within integrated living systems. Tikanga and mātauranga are integral elements of Kaupapa Māori research approaches.

Tikanga Māori, meaning doing things in ways consistent with Māori values, sets the rules for effective investigative partnership with people and the environment in Kaupapa Māori approaches. Using tikanga Māori is a proven way of facilitating Māori engagement in science processes and enables access to valuable mātauranga Māori. As such tikanga Māori drives a depth of engagement that non-tikanga Māori-supported science approaches have traditionally not been able to achieve.

Photo: Miraka.

Mātauranga Māori is a dynamic and constantly evolving knowledge system based on extensive years of co-existence with the natural world extending back into Polynesian knowledge. It encompasses traditional knowledge and values along with local and contemporary knowledge in a wide range of domains. It provides Māori with unique, culturally-infused perspectives, knowledge sets, and world views. Although tending to be locally specific and of distinct iwi or hapū tribal origin, many elements of Māori knowledge are becoming more widely applicable. Consequently mātauranga is becoming increasing fused with other knowledge forms including science. Māori require intellectual property rights mechanisms to protect indigenous cultural identity, assets and resources, particularly indigenous flora and fauna, from unauthorised exploitation and commercialisation. Gains here will improve science uptake and impact.

Kaupapa Māori research, although largely Māori-led, is often interdisciplinary, integrated, and tailored to address Māori issues and build Māori capability. It is linked strongly to other areas of science research. More effective inclusion of Kaupapa Māori-led approaches in the research and science choices available to Māori in the primary sector, and others wanting to use a holistic, integrated systems approach, has the potential to accelerate innovative growth and transformation into new enterprises, products, brands and markets. Access to culturally-infused approaches to environmental management and commercial development lies at the heart of Māori becoming leaders and more active partners in the primary sector.

Better connectivity, co-innovation, and integration between Kaupapa Māori and science will help address many of the complex and serious challenges we are facing such as climate change, resource degradation, impacts on biodiversity and ecosystems, and challenges to maintaining natural capital while enhancing production systems within limits. A transformative approach is needed where Māori organisations such as producer collectives or iwi and hapū, are leaders in the science system, and can be active partners in the determination and formulation of key research directions and questions that are relevant to them.

Developing Kaupapa Māori approaches within the primary sector will require a significant strengthening of Māori engagement capability and capacity across many organisations. A strategic approach is required. It will require Kaupapa Māori and mātauranga Māori, and researchers who have expertise in these, to be better understood, supported and used appropriately in the science and innovation system.

Current research approaches

A long-term approach will identify and build on current Kaupapa Māori research expertise and leadership structures.

Ngā Pae o te Māramatanga is New Zealand's Māori Centre of Research Excellence funded by the Tertiary Education Commission and hosted by the University of Auckland. This centre provides strong leadership in Kaupapa Māori research and activities and is central to the network of researchers involved nationally with this approach. Ngā Pae o te Māramatanga invests in integrated, inter-sectoral projects across the research spectrum, but ensures these projects are grounded in mātauranga Māori, Māori science, kaupapa Māori and tikanga Māori. Its Natural Environment theme is of particular significance to the primary sector, as a research platform within the domain of environmental integrity and sustainability, bringing together a multidisciplinary team of Māori researchers with expertise in developing solutions derived from indigenous knowledge and science.

The National Science Challenges all have Vision Mātauranga components in which Māori are engaged that are highly relevant to the primary sector, particularly Our Land and Water, Deep South, Resilience to Nature's Challenges, Sustainable Seas, New Zealand's Biological Heritage and Science for Technological Innovation. Many current Ministry of Business, Innovation and Employment-funded and other programmes also have a Vision Mātauranga focus with high relevance to the primary sector. The National Science Challenges have also established various Kāhui arrangements in which Māori leaders and experts are providing governance oversight and management support to National Science Challenge programmes.

A number of iwi already have independent research capability, or are partnering with local and global science providers, to achieve their research agenda.

Research opportunities

Using mātauranga Māori and Kaupapa Māori approaches to address critical issues such as biosecurity and climate change, and co-develop innovative solutions.
Using kaitiakitanga concepts to sustainably manage land and water resources within environmental limits and the regulatory process.
Developing integrated frameworks and improved tools for Māori land-use and water-use decision-making.
Optimising Māori land performance through Kaupapa Māori approaches and mātauranga Māori, with an emphasis on multi-functional ecosystem, whole-catchment or landscape planning.
Recognising the role of Māori in protecting and sustaining resources, especially as a partner in regional and national resource management decision-making.
Developing appropriate protocols for accessing and using mātauranga Māori (for example, at local, regional and national level) to ensure culturally- and contextually-informed decision-making in the primary sector.
Developing new products, systems and value chains better integrating Māori values and indigeneity.
Incorporating Kaupapa Māori and mātauranga Māori into monitoring and evaluation programmes that use indicators to measure success and performance (for example, key performance indicators) across primary sector developments and enterprise.
Enhancing Māori rangatiratanga to enable self-governance of their own land and water.
Increasing Māori participation at all levels in research and innovation by establishing effective partnerships with Māori organisations and Māori enterprise.

Protecting and sustaining resources

Science in this theme needs to ensure that new and existing production systems are future-proofed so that terrestrial- and aquatic-based resources, both physical and biological, are mapped, measured and monitored to protect the resources and support appropriately adaptive and multiple uses under rapidly changing conditions.

Context

The primary sector is reliant on finite physical and biological resources and to a very large extent on non-indigenous species. Understanding the long-term environmental effects of primary sector activities is key to ensuring that we can sustainably use them – a core value of Te Ao Māori and the Conservation and Environment Science Roadmap. Sustainable resource use involving effective biosecurity is also important for the reputation of New Zealand-made products in our high-value export markets.

In New Zealand, there is a current focus on ensuring resource use in the primary sector is achieved within environmental limits, preserving intrinsic ecosystem values and services. We do not fully understand the quantum and quality of our physical and biotic resources, such as plants and animals (including marine), soil biota and our available plant germplasm, or what their environmental limits are for sustainable primary production.

We will need science that will help us to use our resources sustainably and also understand the intrinsic values of ecosystems and their biodiversity, the values placed by individuals and groups on the quality of the environment, and the needs of future generations. Māori land management models have potential to inform better management systems that integrate social, environmental, cultural and economic goals using a robust sustainability framework. These considered views of biodiversity, taonga species, and sustainable natural resource use across the productive and natural estates, serve to support our bioeconomy.

One of the most demanding resource challenges facing the New Zealand primary sector is related to land- and water-use policies (for example, sediment, nutrient and water management policies implemented in regional-, catchment- and farm-scale plans) and the decreasing availability, particularly with urbanisation and changing land use, of productive land and good soil. Future science and technology will need to address changes to our resources that may be irreversible, cumulative and accelerating, and the scale at which these occur.

Biosecurity is integral to the protection of New Zealand's primary sector as reflected through the Government Industry Agreement (a partnership between the primary sector and the government to manage pests and diseases) and the Biosecurity 2025 Direction Statement. In the future, we can expect an increasing risk of incursions and establishments of new pests, diseases and weeds through increased trade, tourism and climate change. We need science and technology to help stop or delay the most significant threats, and to be ready to manage them if they do arrive. Biosecurity is not just about preventing loss of base production, but also about preventing interruption of our exports (with loss of markets to our competitors) and reducing threats to our food safety (through increased pesticide use) that could place the integrity of our exports at risk and limit our future options. The current weed, pest and disease burden is not static and will change with climate change and other external pressures.

We need to be adept at foreseeing and adapting to the pressures and uncertainties of changing climates and environments. This includes taking a longer-term view of how to increase productivity while adapting to climate variability where the speed of change can be difficult to predict. This is equally applicable to managing soil erosion, animal welfare and biosecurity threats. New Zealand is frequently affected by natural hazards, both climatic and geological, which significantly disrupt production and can result in new or greater limitations on resource use. We need to explore the use of more resilient genetics for dealing with adverse events, such as drought and wildfire, which may be more severe in some areas in the future.

Biological resources, including soil micro-organisms, terrestrial invertebrates, indigenous flora, and marine micro- and macrobiota, need research in quantitative genetics, taxonomy and systematics, molecular diagnostics and metagenomics. This research will not only provide protection but also the opportunity for identifying species and varieties with specialised qualities for future industry development. Likewise, biodiversity and ecosystem stability, while usually associated with the natural estate, are equally important to land, freshwater and marine production systems.

Current research approaches

Conservation and protection of natural and other resources, such as databases, collections and germplasm, while maximising productivity, preserving biodiversity, and optimising land use, are critical for New Zealand and challenging both domestically and internationally. Improving renewable energy efficiency, recycling and waste reduction, managing biosecurity risks, using new technologies for precision agriculture, and improving resilience to hazards through risk management are all addressing the protection and maintenance of resources. The National Science Challenges are addressing some of these topics.

New Zealand is strong in genetic resource optimisation through germplasm, such as the maintenance and study of genetic resources for the purpose of animal and plant breeding. There is also increasing effort in soil, climate and water monitoring, mapping and modelling, and germplasm use (including the consideration of climate change) for adaptive land-use decisions. Developments such as hybrid pines showing greater tolerance of cold and dry conditions, allow for greater range of land-use options under a changing climate. There is a renewed emphasis on how we protect, improve and expand our databases and collections. There is also emerging research on studying integrated systems management and complex networks, which capture the whole spectrum of soils, water, nutrients, introduced genetics and indigenous flora with the objectives of new diversified primary commercial products.

Research opportunities

Defining, at an ecosystem (terrestrial- and aquatic-based), catchment and production unit-level, the current and future limits for sustainability and enhancement of our resources (soils, water, plants and animals) using robust sustainability frameworks and integrated modelling.

Developing innovative technologies across the biosecurity sector (readiness and response) to mitigate the introduction and impact of invasive species.

Understanding and demonstrating sustainability of fisheries, their impact on marine resources and habitats, and the needs and aspirations of iwi and hapū, recreational fishers, and tourist operators.

Using Kaupapa Māori approaches to develop kaitiakitanga-led responses to challenges such as climate change, ecosystem management, the need to optimise productivity, manage biosecurity threats, and support decisions on the optimal use of land or water.

Improving understanding of carbon cycle processes and improved models, technologies and practices targeted to reducing greenhouse gas emissions.

Integrating adaptive species, water and soil conservation, carbon emissions, and mixed production models to optimise environmental and social sustainability in future forestry development.

Continuing to develop and ensure that New Zealand has enduring, digitised and appropriately curated and maintained databases and collections that underpin future productivity and land-use and water-use (freshwater and marine) decisions.

Preserving the intrinsic value of biodiversity in production ecosystems.

SAFEGUARDING THE FUTURE OF OUR KAIMOANA

Recent research programmes, in partnership with iwi, have improved our biological baseline understanding of a number of fish and shellfish species, including pāua, kuku (green lipped mussel), tāmure (snapper), and more recently kourarangi (scampi) and pātiki (flounder).

Whether it is to enhance wild stocks for harvest or conservation, or to farm in coastal or offshore structures, the first critical step is to "close the life cycle" under controlled conditions in a lab. Once this is achieved the scientists' efforts are then focused on ensuring the hatchery progeny can survive under real-life conditions and reach the adult stage. Technologies to monitor the environment are becoming more accessible and practical for fishers and farmers to use.

Phone apps could be available in the near future to provide real-time data to help plan harvesting or movements of stock between sites, or warn of pest or disease outbreak in the vicinity.

Deriving value from complex systems

Science in this theme needs to enhance sustainability of diversified multifunctional, terrestrial- and aquatic-based systems and the development of novel products through an improved understanding, analysis and use of the concepts of complex systems, feedbacks, networks and particularly of the microbiome.

Context

Our production systems, both terrestrial- and aquatic-based, are part of a complex biological network of both micro- and macrobiota, extending from the soil, riverbed or seabed through plants, animals, fresh products, the human consumer and the social structures surrounding this network. Complex systems can be defined as the interaction of autonomous components in time and space. The more we understand their interdependencies and feedbacks, and their interactions with the environment, the better we are placed to make informed management decisions, optimise sustainable productivity, protect ecosystem services, minimise occurrence of unwanted phenomena, and enhance wellbeing.

Ecosystem and network approaches to our production systems can make them more resilient, particularly to pest and disease pressure and in response to environmental challenges. The microbiome is a good example of this. Microbiome components, such as soil microbiota, endophytes in forage plants, mycorrhizae in crop plants and the rumen microbiota, have profound impacts on productivity, properties of plant and animal products, biodiversity, and the general health of the ecosystem. There are opportunities to use our understanding of microbial population dynamics and properties across the supply chain, and our understanding of complex biological networks to modify plant and animal products, produce new ones and ensure favourable impacts on the environment.

In New Zealand we use plant-microbial associations such as ryegrass fungal endophytes and mycorrhiza to enhance plant and animal productivity. The livestock rumen microbiota are also relevant in greenhouse gas mitigation and animal productivity. There is increasing interest in development of symbiotic platforms where microbes are used to provide resistance of higher plants to pests and diseases. Microbial organisms figure large in biosecurity areas such as crop protection and animal disease issues that can impede production gains and the sustainability of our production systems. Biodiversity, which includes soil, pasture, orchard, forest and aquatic flora, fauna and microbial communities, is now recognised as part of the natural capital of ecosystem services. Greater diversity in species and land use can help support a more enduring and resilient production system.

HIGH-PERFORMANCE RYEGRASS USING NOVEL FUNGAL ENDOPHYTES

New Zealand pastures depend on a perennial ryegrass that uses a fungus called an endophyte which grows inside the plant and is passed to the next generation via the seed.

One widely used strain (AR37) selected by scientists helps protect the plant from attack from insects such as black beetle. It also has beneficial effects on plant properties such as tillering, root growth and higher yields. This is a good example of using beneficial micro-organisms in plant production systems, in this case to produce high-performance grasses.

Continuing research (for example, using microbiology, agronomy, entomology and animal nutrition) is focused on searching for other fungal species and plant-microbial associations which will benefit plant and animal protection and production. Introducing such associations into other forage and pasture crops will help lift production while potentially providing greater adaptability to changing environments, climate, and new pest and disease pressure.

Given the increasing recognition of the importance of invertebrate and microbial populations and environments, our greatest challenge is realising their wider value. A better understanding of population components (such as species and genomes) is needed to manage and modify these populations for benefits in plant and animal production and products, as well as linking land management practice with soil microbial properties. A systems and network approach to the microbiome will result in a more comprehensive view of the processes and economics of components of the protein economy with plants and animals, and the cellulose economy with forestry. The microbiomes of our land, freshwater and marine systems present an opportunity for novel production, systems and products, greenhouse gas mitigation and successful adaptation to environmental change.

Successful management and use of networks, such as production system microbiomes, will require developing and applying scientific approaches such as network analysis, complexity theory and ways of analysing dynamic systems. Similarly, comprehensive systems approaches should underpin future fisheries management planning with the need to understand the dynamics, networks, and interdependencies among physical resources, climate and organisms (flora, fauna and microbial). Production benefits will also come from consideration of ecosystem services and associated management of complex networks, in both terrestrial- and aquatic-based systems.

Current research approach

There is a growing research effort in New Zealand on complex systems and networks, applicable across biological, physical and social systems. This should be applied more broadly across the primary sector to address issues of biosecurity, disease and pest control, biodiversity and the concepts of the productive biome in our value chain. Complex systems approaches, as used by Te Pūnaha Matatini (one of New Zealand's Centres of Research Excellence) suggest that all-of-ecosystem approaches to sustainability are likely to become more important and this requires an approach that incorporates cultural and social factors, as well as ecological drivers of resilience and ecosystem health.

A number of the Government's National Science Challenges, such as the Our Land and Water and Sustainable Seas Challenges, are also supporting research programmes aimed at increasing productivity and value in our primary sector in a way that maintains and effective uses our land, freshwater and marine environments.

Research opportunities

Exploring complex systems and networks, and ecosystems services, to improve our understanding of biodiversity with the objectives of greater productivity, ecosystem health and more diversified and novel end-products.

Exploring integration of whole organism and network information from new sources such as e-DNA (DNA sourced from environmental samples) to translate into decisions and management strategies, including using artificial intelligence, machine learning and modelling.

Using current and new plant-microbial associations in production systems to increase productivity, manage nutrient and water use, and provide novel properties that enhance cultural and social acceptability.

Improving the use of systematics and next-generation sequencing including e-genomics, to characterise plant, soil and aquatic microbiomes, chart diversity and response to environmental change, and identify microbial organisms as markers of change.

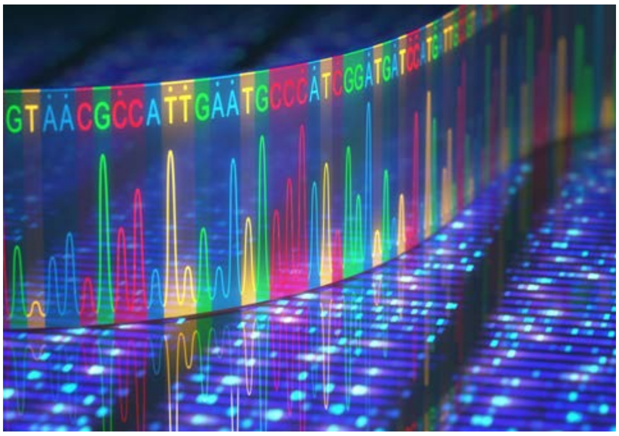
Using microbial metagenomics associated with plants and animals and analysis of ruminant microbiota and forage-microbial gut relationships, to reduce livestock methane production, and improve digestive efficiency and disease resistance in plants and animals.

Using analysis of human gut microbial populations and dynamics to target new high-health food products that are culturally and socially acceptable.

Optimising the selection and maintenance of effective and new biological control agents using genomic sequencing and advanced genome technologies to better meet ecological drivers.

Exploring the microbiome in aquaculture and fisheries systems, especially hatchery or nursery production, and undertaking research on impacts of ocean acidification on microbiota and biofilms, and on the interactions among land use, run-off and marine microbial systems.

Exploring how complex systems and networks can be better understood in terms of people and behaviours, and how this could improve social and cultural acceptability of multifunctional terrestrial- and aquatic-based production systems.



Integrating people and values

Science in this theme needs to support the development of future primary production systems that are publicly and socially integrated, both domestically and internationally, and enable uptake of science and technology.

Context

Understanding people's values, preferences and perception of risk, and what is driving them, is essential for ensuring effective public engagement with the development of new primary sector management approaches, and new technological products and systems, and facilitating their uptake. Obtaining and retaining social licence relies on understanding people's attitudes and values towards science, technology and the primary sector, and incorporating these in research and decision-making processes. Globally, there is a trend toward social science approaches being used to understand people's beliefs, attitudes, values and behaviours, and integrating this with biophysical science (including information gained through citizen science) and economics to better model production systems and their governance.

An engaged and socially-integrated primary sector that is sustainable in terms of people, infrastructure and profits, needs more than an understanding of an individual's or the public's values and preferences. Integration means incorporating into planning and future production systems, social structures at different levels (individuals, farms, rural and fishing communities, iwi and hapū, or regional structures) and a clear view that primary industries are integral parts of social systems. Social research is, therefore, fundamental for informing how we make transformational change in the primary sector.

The social landscape in New Zealand is complex. Social media allows rapid and far-reaching transfers of knowledge and information of varying quality. With this comes an increased awareness of issues both within a specific community and beyond it, and necessitates engagement at different levels across society. Increased awareness adds to social complexity. For example, the urban dweller has opinions on food quality, food supply and costs, animal welfare and the effects of food production on the environment, such as water quality. These opinions may be quite different from those of people living and working in rural communities.

New Zealand is also a multicultural society: Te Ao Māori is intertwined with a multitude of other cultures and beliefs and increasing cultural diversity is shaping the perspectives and behaviours of New Zealanders.

CITIZEN SCIENTISTS: TACKLING BIOSECURITY WITH ENGAGEMENT AND TECHNOLOGY

Effective surveillance is critical for biosecurity. Knowing the exact distribution of a pest and its likely rate of spread can lead to more efficient allocation of resources in any pest eradication or management response. Large-scale responses require large-scale surveillance, which can be a challenge. Citizen science has already been used successfully in a range of fields including ecology, astronomy and medicine. At its best, the data contributed from volunteers enables observations to occur over large geographic areas, to be faster and at much lower cost than professional teams. In 2016 Scion, working with the Ministry for Primary Industries, the Forest Owners Association, Lincoln University and NatureWatch New Zealand, launched the 'NZ Eucalyptus Pests' smartphone app to test whether a citizen science approach could work for reporting sightings of the eucalyptus variegated beetle. Anyone who has downloaded the app can photograph and report possible beetle sightings. These

photos are uploaded to NatureWatch New Zealand for initial identification and confirmed sightings are then assessed by staff from the Ministry for Primary Industries. The app also provides an easily adaptable template for enhancing surveillance through citizen science on future incursion responses, and has already been adapted to be used with some new-to-New Zealand pests, such as the giant willow aphid.

Peoples' behaviour is complex and changing patterns require an in-depth understanding of beliefs, attitudes and values of individuals, as well as the knowledge of changing social norms and specific sociocultural priorities.

The increasing cultural diversity in New Zealand presents a challenge and opportunity for emerging research and technologies important to the primary sector, such as those associated with climate change or genetic modification. It cannot be assumed that provision of research findings alone will shift attitudes and behaviour of individuals or groups. Rather, research findings will need to be embedded in informed discussion with multiple stakeholders, where varying views and knowledge are recognised and valued.

We need to better understand the role of communities, institutions, structures and systems (for example, catchment-scale management) and how these can enable better collective decision-making. Such approaches would also support the development of cooperative and collaborative partnerships, particularly with Māori. Increasing the diversity of scientists working in the primary sector (for example, women, Māori and Pacific peoples) is an opportunity to broaden perspectives in leadership and decision-making, and supports informed debate on social and cultural licence.

Current research approaches

Global studies on behavioural economics tell us that people's decisions to adopt new innovations are driven by more than just economics, and include values, culture and arguments on costs and benefits. For example, risk perception is the subjective judgement that people make about the characteristics and severity of a risk and is influenced by many factors.

To move beyond just understanding how decisions are made in an integrated sector needs more leadership from current social science approaches such as those on socio-ecological and agricultural innovation systems, and wider understanding of integrated systems management that lead to future change and response to new external pressures and demands. Communities and institutional structures associated with the primary sector are increasingly part of global decisions on future growth and change. The sector cannot move into the next two decades without engagement, dialogue and joint decision-making among people, collectives, interest groups, industry bodies and regulators and policy-makers.

Research opportunities

- Finding ways to produce socially-integrated science with diverse actors through the development of new collaborative processes.
- Identifying the drivers and barriers to change, and using co-innovation and adaptation models to develop and support the uptake of new science, technologies and practices to positively transform the primary sector.
- Understanding dynamic consumer preferences and how they are communicated throughout the supply chain.
- Learning how to safeguard and integrate individuals, family and business units, iwi and hapū, communities, regions, and the urban and rural dynamics into the planning and execution of future change in sector industries.
- Determining how values (including economic, environmental, social and cultural) provided by ecosystem services, and intergenerational environmental benefits and costs, can be identified and built into decision-making.
- Supporting transformational change by exploring attitudes and values of diverse communities and individuals (for example, on climate change) to co-ordinate diversity of positions and views.
- Using innovative approaches for developing citizen science as an effective collaboration among science and non-science communities, including information gathering resources and community access to scientific knowledge.
- Measuring the effectiveness of citizen science and digital technologies on policy- and decision-making in the primary sector.
- Using Kaupapa Māori approaches to determine the knowledge primary sector managers need to ensure a cultural licence to operate and assist them to apply this across the value chain.
- Determining the knowledge primary sector managers need to ensure that their production systems have public, market and consumer acceptance (social licence) and assist them to apply this across the value chain.

6 Capability and capacity needs for primary sector science

In the future, New Zealand will need not only an increased number and diversity of people employed in the primary sector to meet workforce needs, but also a higher level of skills, particularly in areas such as science, engineering and technology, as well as leadership, marketing, commercialisation, language and cultural awareness. This need for a growth in skills is described more fully in the Ministry for Primary Industries' report *People Powered – Building capabilities to keep New Zealand's primary industries internationally competitive*.

This Roadmap highlights the breadth and depth of the anticipated advanced skills demand, and the specific changes in science capability and capacity that will be needed.

> **"World-class dairy farm-related research capability resides in industry good organisations, Crown research institutes, universities and commercial companies. This capability is connected with global expertise and global research efforts."**
>
> Making Dairy Farming work for Everyone: Strategy for Sustainable Dairy Farming 2013–2020

Each of the science themes has a related requirement for capability, capacity and infrastructure to deliver and use the science. There are also cross-theme capability and capacity issues. For example, the current science and innovation system needs to build Māori and non-Māori capability and capacity to better support Kaupapa Māori approaches and the use of mātauranga Māori. Māori organisations and iwi groups can play a leadership role in addressing these needs. In addition, there is a shortfall in the number of indigenous scientists and researchers with a strong Kaupapa Māori background, and many of those that are available are often positioned in support rather than leading roles in nationally funded research.

Meeting capability and capacity needs is complex and is rarely something that can be "turned on or off" quickly. It can come through New Zealand's education system, through on-the-job training, or from sourcing expertise domestically or internationally. There is a need for fundamental and applied science capability and capacity across the biological, physical, chemical and social sciences. In some areas we need critical basic capability in New Zealand, while in others we need to position ourselves as fast followers or adapters of international science. In New Zealand, the levers for capability and capacity development sit with research institutions and industry, and are influenced by government funding.

Science infrastructure is also critical. Government currently invests in major research infrastructure ranging from research vessels to high-performance computers. Science organisations and industry also invest in critical research infrastructure to support science and innovation in the primary sector. New Zealand may need to enhance computing and genomics research infrastructure, given the increasing reliance on those fields.

To achieve the purpose and vision of the Roadmap, we need to have a clearer view of the critical needs for capability and capacity in primary sector science and to support succession planning. Looking across the themes we know that the future of the primary sector will rely on, amongst other disciplines, more pure and applied science and technology expertise in:

- animal welfare;
- automation and robotics;
- bioethics and biotechnology;
- bioinformatics
- consumer and sensory science;
- ecotoxicology;
- integrated multi-scale modelling and management;
- Kaupapa Māori;
- mātauranga Māori;
- microbiology, molecular diagnostics and metagenomics;
- natural capital and ecosystem services assessments;
- plant and animal genetics
- process engineering and new product development;
- resource economics;
- synthetic foods;
- taxonomy, informatics and data management;
- value-chain optimisation;
- values and behaviour science.

Equally important to building capability and capacity is how we do our science and who we do it with. Scientific inquiry needs to involve interdisciplinary, cross-sectoral and inter-cultural approaches; to focus on impact-based outcomes with clear benefits; to include extension and uptake of science and technology; to involve industry, community and collectives in effective engagement, co-design and co-innovation; and to be highly collaborative. Success with multi-partner approaches to science will need people with excellent leadership and communication skills.

New Zealanders are generally good at connecting with overseas science organisations. We contribute to international research and have a crucial role in providing scientific and technological expertise to developing countries, especially in the Pacific. New Zealand researchers are involved in many collaborative partnerships which have benefited New Zealand's primary sector, and this will continue to be critical. It will also guide where we focus development of our own capability and capacity (for example, on novel methodologies and indigenous data collection), and where we rely more on international expertise.

Scientific and technological literacy in the primary sector and in the wider population is also fundamental. We need to build the foundations for a society that is able to appreciate scientific concepts and approaches, and contribute to science-based innovation in the primary sector through informed dialogue on acceptable technological development.

It will be essential to adopt a participatory approach and form enduring partnerships to meet both skills and infrastructure needs over time within the science themes. This will also require embracing the way of thinking and global interconnectedness of a new and diverse generation of scientists and technologists.

MULTIPLE CAPABILITIES NEEDED TO TACKLE BIOSECURITY RISK

The brown marmorated stink bug has the potential to become a significant pest requiring costly control and management programmes, if it establishes in New Zealand.

The insect, found in Asia, Europe and the United States of America, feeds on more than 300 different host plants, primarily fruit trees and field crops but also woody ornamentals. Work is underway in New Zealand, requiring capability across multiple science disciplines, to prevent the arrival and establishment of the stink bug and to ensure early detection and readiness for an effective response if it does arrive.

Research is being conducted on understanding potential pathways of entry, use of sniffer dogs for detection, developing cost-effective traps, investigating lures, and undertaking host-range testing of potential bio-control agents. For example, sniffer dogs,

which have 84 percent detection accuracy in the United States of America, may be used if we have an incursion.

Other research indicates that sticky traps, in combination with a lure, may be a cost-effective method of surveillance. Host range testing of a parasitic wasp is also underway to support an application to release this bio-control agent, should the stink bug establish. This collaborative, multidisciplinary approach is needed to help New Zealand stay stink bug-free.

7 Putting the Roadmap into action

This Roadmap is designed to guide activities throughout New Zealand's science system, influencing choices in research strategy and projects, science capability and capacity planning, and partnerships with local and international science collaborators.

The shared view of science and technology needs that it supports will help science funders, providers, educators, and industry to act collectively and collaboratively to identify common opportunities and direct effort toward outcomes of importance to the primary sector.

The Roadmap is a part of the Government's strategy for science, described in the National Statement of Science Investment, 2015-2025. It will support science excellence and impact for long-term benefit across the sector and is a tool for government to engage with industry to build research capability and make effective use of the science and technology produced.

The Roadmap will be a living document; its use will be monitored, and its effectiveness evaluated. In line with the Conservation and Environment Science Roadmap, this Roadmap will be reviewed regularly.

Using the Roadmap

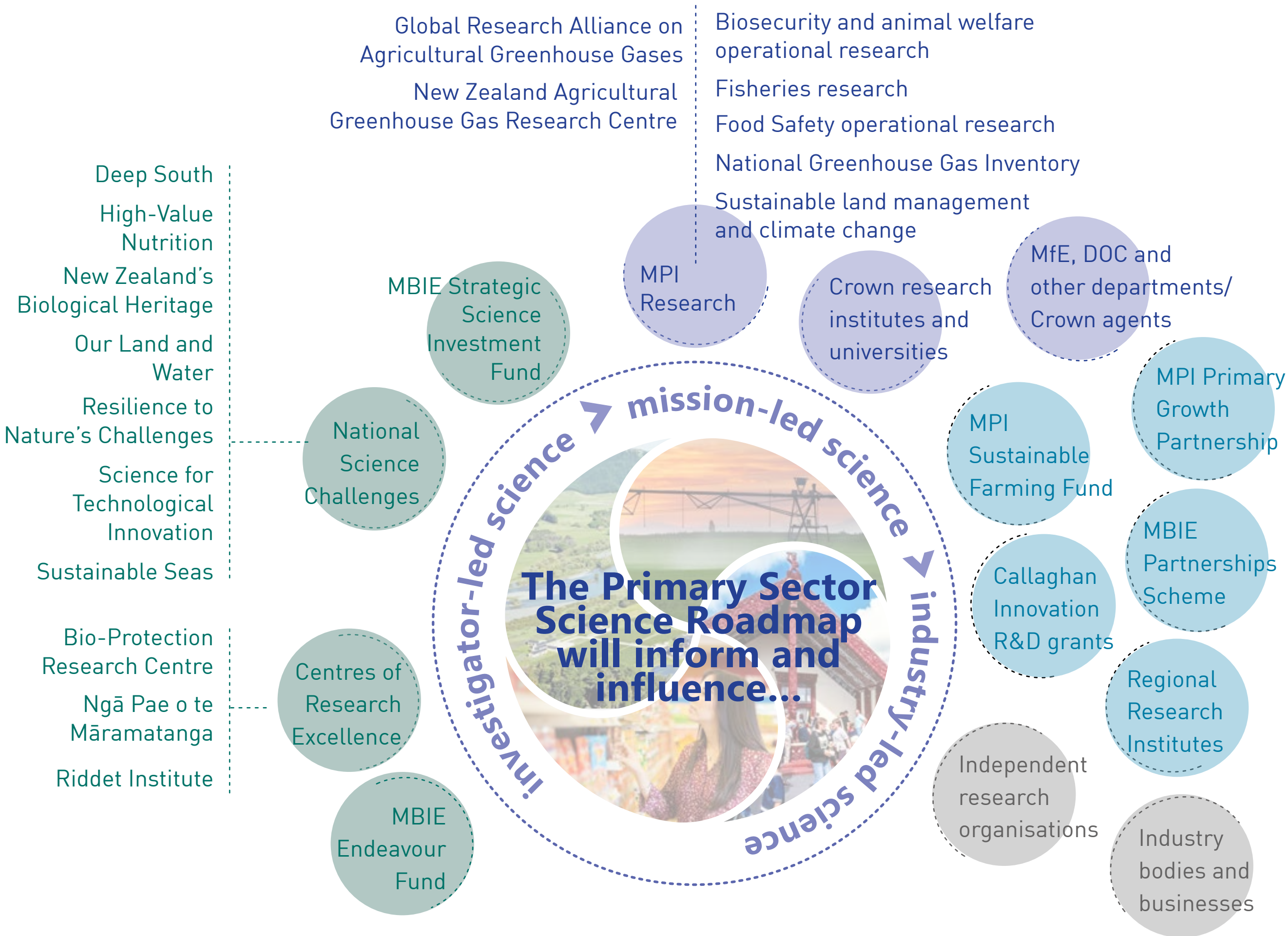
The Roadmap will be used by a range of partners and investors such as:

- **Scientists and research teams,** to build understanding and support discussions of science needs and opportunities for the primary sector, and to guide national and international science and research activities. For science activities supported through public science funds, the Roadmap will enable applicants and grant holders to identify and respond to opportunities to enhance the impact and excellence of science.
- **Science and research institutions,** such as Crown research institutes, universities and independent research organisations, to guide science strategies and activities, capability investments, graduate course design and PhD research programmes, and partnerships with industry or other research organisations, in line with their core purpose or organisational mission.
- **Industry research organisations** that are levy-funded, such as DairyNZ, the Foundation for Arable Research, and Beef and Lamb New Zealand, to understand science needs, opportunities and priorities at the whole-sector level and as an input to their own sector specific strategies for research.
- **Primary sector businesses and enterprises,** to understand the Government's directions and commitment to science, to build confidence in decisions for investment that may be reliant on public or sector-wide science capability, and to help forge or maintain partnerships with research organisations.
- **Iwi chairs and National Science Challenge Kāhui**, to support Māori to develop their own research opportunities and ensure they are included at the design phase of any science and innovation agendas. This will need to be better managed in the future if Māori are to be confident of playing their role in setting research and funding agendas and leading transformational change across the primary sector.
- **Funders and policy-makers,** such as the Ministry for Primary Industries; the Ministry of Business, Innovation and Employment; and the Tertiary Education Commission, to understand primary sector specific science needs and opportunities, to help applicants and decision-makers be aware of and give effect to its signals, and inform policy that enables science including any future changes in the design of funding mechanisms.

The Roadmap will be relevant to a range of funds administered by the Ministry for Primary Industries (such as the Global Research Alliance, fisheries research, Primary Growth Partnership and investments in animal welfare, biosecurity, climate change and food safety research) and the Ministry of Business, Innovation and Employment (such as the Strategic Science Investment Fund, the Endeavour Fund, Partnerships Scheme, and the National Science Challenges).

Figure 3 illustrates the range of funds and organisations that can use the Roadmap to guide activities. Appendix 3 provides an overview of the research investment through these funds that is relevant to the primary sector and to the Roadmap.

Figure 3: Overview of New Zealand science funding and organisations informed by the Primary Sector Science Roadmap



Key and Notes

- Public science funds
- State sector organisations
- Public science and R&D funds with industry/non-government contributions
- Industry organisations and businesses

Only those National Science Challenges and Centres of Research Excellence with primary sector relevance included in the map.

MPI: Ministry for Primary Industries
MBIE: Ministry for Business, Innovation and Employment
MfE: Ministry for the Environment
DOC: Department of Conservation
R&D: Research and development

Roles and mechanisms

The Ministry for Primary Industries led the development of the Roadmap, working with sector and science partners, and this role will continue for its oversight and monitoring.

Putting the Roadmap into action will require ongoing involvement and leadership from science and primary sector stakeholders and partners. A new Roadmap Steering Group, with membership from industry, science, Māori and government organisations, will be set up to help champion and steer the effective use of the Roadmap.

Key activities for the Steering Group, which will be supported by the Ministry for Primary Industries, will be to:

- develop and put in place an engagement plan to ensure stakeholders are aware of, and progress research activity aligned with, the Roadmap;
- enable the Roadmap to inform and respond to industry science strategies and investments;
- support alignment with the Conservation and Environment Science Roadmap, including identifying and enabling progress on science needs common to both Roadmaps;
- enable the incorporation of the Roadmap into relevant public science investment processes, including those administered by the Ministry for Primary Industries and the Ministry of Business, Innovation and Employment;
- monitor and evaluate the Roadmap and its impacts, and periodically refresh the Roadmap.

The Ministry for Primary Industries will also use the Roadmap to support discussions and consideration of areas such as:

- current and future science capability needs for the primary sector;
- enablers and barriers in the broader policy or regulatory environment to the development or use of science and technology;
- where and how science can inform and influence government policy.

Tracking the difference the Roadmap is making

Monitoring and evaluation of the Roadmap will be guided by the outcomes model shared by the Primary Sector Science and the Conservation and Environment Science Roadmaps (Appendix 2) and will involve collection of information on:

- understanding by stakeholders of primary sector science needs;
- use of the Roadmap by funders and applicants;
- alignment of funding decisions and capability building activities;
- level of integration and resourcing of the Roadmaps' themes;
- research outputs and their impact.

To collect and be able to make use of these data will require development and use of a set of evaluation metrics, some shared with the Conservation and Environment Science Roadmap.

Photo: Alistair Scarfe - Robotic Plus.

8 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.
Bioeconomy	Set of economic activities relating to the invention, development, production and use of biological products and processes.
Bioinformatics	Analysis and interpretation of biological data using computer science, statistics, mathematics and engineering.
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.
Cultural capital	Social assets of a person, such as education, intellect, style of speech and dress, which promote social mobility in a stratified society.
Cultural licence	Ability of an organisation or industry to undertake business in a culturally acceptable way with confidence from Māori Treaty partners and iwi.
Ecosystem	Biological community of interacting organisms and their physical environment; a complex network or interconnected system.
Ecosystem services	Benefits people obtain from ecosystems. Ecosystems are widely considered to provide four categories of services: supporting (such as soil nutrients); provisioning (such as food and freshwater); regulating (such as flood control); and cultural (such as recreational benefits).
Endophytes	Bacteria or fungi that live for some or all of their lifecycle inside plants in mutualistic, symbiotic or parasitic associations.
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.
Greenhouse gas emissions	Atmospheric gases that contribute to the greenhouse effect by absorbing infrared radiation produced by solar warming of the Earth's surface, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour.
Hapū	Subtribe.
Informatics	Systems and processes used to collect, curate, manage and interrogate information.
Internet of Things	Network of physical objects with internet connectivity, and the communication that occurs between these objects and other internet-enabled devices and systems.
Iwi	Tribe or people.
Kāhui	Leadership group with responsibility for expert guidance and oversight.
Kaitiaki	Guardian or custodian.
Kaitiakitanga	Guardianship, 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.
kaupapa Māori	Māori projects, purposes and aspirations that may or may not be undertaken through Māori-led research approaches.
Kaimoana	Food from the sea.
Macrobiota	Macroscopic organisms, usually visible to the naked eye.
Mahinga kai	Garden, cultivation, food-gathering place.
Mātauranga Māori	Māori knowledge systems, encompassing traditional and contemporary knowledge, wisdom, and understanding and human-environment relationships.

Mauri	The life force, the essential quality and vitality of a being or entity.
Metagenomics	Genome-level characterisation of communities or their members, using high-throughput genomic methods.
Microbial	Concerning micro-organisms, such as bacteria.
Microbiome	Community of micro-organisms that inhabit a particular environment (for example, soil, plants, animals, the animal rumen, the human gut).
Microbiota	Microscopic organisms, not usually visible to the naked eye.
Nanotechnology	Technology executed on the scale of less than 100 nanometres and used, for example, to create computer chips, microscopic devices or novel materials.
Natural capital	Stocks of natural assets, including soil, air, water and all living things. A wide range of services (see ecosystem services) that make production systems and human life possible are derived from natural capital.
Nutraceutical	Product derived from food sources with extra health benefits.
Nutrigenomics	Study of how an individual's genetics interacts with food in relation to personal disease and health status.
Phenotyping	Measuring an individual's characteristics or genetic traits expressed in, for example, morphology, biochemistry, development or behaviour.
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 aquatic-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.
Productivity	Economic measure of output per unit of input, such as the efficiency of production.
Rangatiratanga	Sovereignty, self-management, tribal authority to govern.
Social capital	Networks of relationships among people who live and work in a particular society, enabling that society to function effectively.
Social licence	Ability of an organisation or industry to undertake business in a socially and environmentally acceptable way with confidence from society.
Supply chain	Production system extending from breeding through to the market and the consumer.
Tangata whenua	People of the land, hosts, indigenous people.
Taonga	Treasured item, such as land, water, flora and fauna.
Tapu	Sacred, set apart.
Te Ao Māori	The Māori world, world views.
Te ao tūroa	Concept that includes notions of intergenerational sustainability and commitment to enduring wellbeing of people and the environment.
Tikanga Māori	Customary system of values and practice that have developed over time and are deeply embedded in social context, code, practice and protocol.
Value chain	Value added to products and processes across the production system or supply chain.
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.
Whakapapa	Genealogical networks.
Whānau	Extended family.

Appendix 1: Development of the Roadmap

Professor Sir Peter Gluckman initiated discussions with the Minister for Primary Industries regarding the need for a document that provided an integrated view of the critical science needs for the primary industries.

In March 2016, the Ministry for Primary Industries initiated the work toward this Primary Sector Science Roadmap, which is co-sponsored by the Minister for Primary Industries, the Minister for Science and Innovation, and the Prime Minister's Chief Science Advisor.

Ministry for Primary Industries' Departmental Science Adviser, Dr Ian Ferguson, led the development of the Roadmap, supported by a Working Group and a Strategic Advisory Group[1] that included government, science and primary industry members. The Chief Science Advisor for the Department of Conservation, and the Departmental Science Adviser for the Ministry for the Environment, were observers on both groups.

A range of public research organisations, industry bodies, government agencies, Māori science and primary sector business organisations, and individual scientists contributed to the Roadmap in late 2016 and early 2017. This process involved workshops and written feedback to establish the themes, a series of meetings with senior representatives of key industry and government funders of primary industry science, Māori science and primary sector business organisations, and a review of the themes by science and mātauranga Māori experts.

The Roadmap was launched at the National Agricultural Fieldays on 13 June 2017.

1 Strategic Advisory Group members were: Dr Stephen Goldson (Chair), Virginia Baker, Gary Bedford, Professor Hugh Blair, Dr John Caradus, Dr Ian Ferguson, Chris Kelly, Ian Proudfoot, Dr Charlotte Severne, Graham Smith, and Professor Alison Stewart, with observers Dr David Wratt and Professor Ken Hughey.

Appendix 2: Outcomes from the Primary Sector Science and Conservation and Environment Science Roadmaps

Outcomes from the Primary Sector Science and Conservation and Environment Science Roadmaps

Problem definition

1. Stakeholders lack a shared view of New Zealand's future science priorities and capability needs
2. Multiple funding agencies and processes – so alignment and leveraging of investments is not optimised
3. Risk that critical science will not be available to meet future needs

Key activities

1. Development of Conservation and Environment Science Roadmap
2. Development of Primary Sector Science Roadmap
3. Needs/gap analysis
4. Implementation planning (for example, public engagement processes, regular Roadmap refreshes, monitoring and evaluation)

Short-term outcomes	Medium-term outcomes	Long-term Agency outcomes
The Roadmaps communicate key stakeholders' **shared view** of New Zealand's future science research and development needs and priorities.	The Roadmaps are living documents that remain fit-for-purpose over time.	New Zealand has a highly dynamic science system that enriches New Zealand, making a more visible, measurable contribution to our productivity and wellbeing through excellent science *(Ministry of Business, Innovation and Employment, Vision for Science System 2025)*.
Needs/gap analysis clearly identifies the science **knowledge, tools and capability** that New Zealand requires and results in plans to address future needs.	New Zealand produces the right science research and development **capability.**	The **primary sector** is agile, resilient and operates within sustainable environmental limits while maintaining and improving productivity and enhancing value.
	New Zealand produces the right science **knowledge and tools**.	
Science funders, providers and end users align funding decisions and capability building activities with Roadmap priorities.	Improved uptake of **knowledge and tools** enhance decisions and practices of end users.	**The capacity for the environment to sustain itself** is safeguarded and the use of the environment, including natural resources, is optimised for the betterment of society and the economy now and over time.
		New Zealanders gain environmental, social and economic benefits from healthy functioning ecosystems.

People in New Zealand make and implement **decisions** that **benefit society,** the **economy,** and the **environment**.

Appendix 3: Overview of investment in primary sector research

Primary sector research in New Zealand is funded through a range of public and private sources. Government is a key investor, supporting institutional funding managed by organisations such as Crown research institutes and universities, as well as contestable and negotiated funds for particular purposes. Industry makes investments in research managed by industry levy-based organisations, individual businesses, and through co-funding of government funds. A number of iwi also invest directly in primary sector-related research to support their science and innovation needs.

Results from Statistics New Zealand's Research and Development Survey 2016 indicate that $542 million of research expenditure in 2016 was for the purpose of the primary sector, of which $266 million was carried out by business, $214 million by government (including Crown research institutes) and $62 million by higher education, principally universities[2]. This is 17 percent of the total research and development expenditure in 2016 of $3.2 billion. The primary industries data from this survey do not include the full value chain of the primary sector (for example, manufacturing of primary products is not included) so will underestimate the contribution of research to the primary sector, as defined by this Roadmap.

Research investment relevant to Roadmap themes

Government investment in research relevant to the Roadmap themes was also estimated through the use of science fund data, as shown in Table 1, as $428 million per annum[3].

Industry investment relevant to the Roadmap cannot be assessed as readily as government investment but, based on the 2016 Research and Development Survey data, will be several hundred million dollars annually and will include:

- investment in research and development by primary industry levy bodies, which for 2014/15 was estimated at $81 million;
- co-investment with government grants, such as Callaghan Innovation R&D grants, and the Primary Growth Partnership[4], typically with business contribution rates of 60 to 80 percent;
- direct investment in research carried out in-house or commissioned from external science providers.

Iwi investments relevant to the Roadmap themes will include support for work with industry, university, wānanga (a tertiary education institution that provides programmes in a Māori cultural context) or Crown research institutes on mātauranga Māori, science, technology and Kaupapa Māori approaches.

Future estimates of research relevant to the primary sector, and the Roadmap, will be supported by the Research, Science and Innovation Domain Plan, a cross-government national research information system on research inputs and outputs.

2 This survey includes mining exploration and extraction activities in the definition of the primary sector.

3 This approach allows a more detailed view of the use of public science funds than with the Research and Development Survey data. The estimate of $428 million per annum is larger than the sum of the expenditure from government ($214 million) and higher education ($62 million) recorded through Statistics New Zealand Research and Development Survey 2016 as the primary sector scope of the Roadmap is wider than this data set, for example including also primary sector-based manufacturing.

4 Industry co-investment in the Primary Growth Partnership programmes was $33 million in 2015/16.

Table 1: Indicative current government spend relevant to each Roadmap science theme (1). Except where indicated, figures represent committed funding for the 2015/16 financial year, in millions of dollars. The overall total has been rounded to the nearest million.

Schemes / Roadmap themes	Adding value	Harnessing the value and power of data	Innovating with advanced technology	Innovating through genetics	Innovating through Kaupapa Māori	Protecting and sustaining resources	Creating value from complex systems	Integrating people and values	TOTAL
Ministry for Primary Industries science funds (2)	4.5	3.8	2.2	0.3	0.4	36.2	1.6	3.1	**52.1**
Primary Growth Partnership programme (3)	10.8	5.8	9.0	2.0	0	3.5	4.9	5.1	**41.1**
Crown research institutes core funding (4)	20.9	19.1	12.3	11.6	0.6	62.9	15.1	16.4	**158.9**
Contestable/Endeavour Fund (5)	31.0	2.0	17.5	1.7	1.8	43.8	0.4	0.6	**98.8**
National Science Challenges (6)	6.6	1.5	1.1	0.2	1.4	7.9	0.9	4.0	**23.6**
Partnerships Scheme	9.2	0	2.3	7.0	0	4.8	0.5	0	**23.8**
Callaghan Innovation R&D grants (7)	10.8	0	5.5	1.0	0	0.8	0	0	**18.1**
Centres of Research Excellence (8)	3.3	–	–	–	4.9	3.3	–	–	**11.5**
TOTAL	**97.1**	**32.2**	**49.9**	**23.8**	**9.1**	**163.2**	**23.4**	**29.2**	**428**

Notes to Table 1:

(1) Alignment to themes is indicative, due to the interconnectedness of the themes and the multidisciplinary nature of many projects.

(2) Comprises science funding from: Aquaculture Planning Fund, Biosecurity Animal Welfare Operational Research Fund, Erosion Control Funding Programme, Environmental Economic Analysis Fund, Fisheries Research, Food Safety Operational Research Fund, Greenhouse Gas Fund, Global Research Alliance Fund, Hill Country Erosion Fund, Irrigation Acceleration Fund, Kauri Dieback, New Zealand Agricultural Research Centre, Sustainable Farming Fund, and Sustainable Land Management and Climate Change Fund.

(3) Data in table is Ministry for Primary Industries funding; industry contributions are additional.

(4) Data obtained from the Ministry of Business, Innovation and Employment. Crown research institutes' core funding transitioned to the Strategic Science Investment Fund from 2017.

(5) The Contestable Fund transitioned to the Endeavour Fund in 2016.

(6) Data from 2016/17. Includes Deep South, High-Value Nutrition, New Zealand's Biological Heritage, Our Land and Water, Resilience to Nature's Challenges, Science for Technological Innovation, and Sustainable Seas.

(7) Includes Project, Growth, Getting Started and Student grants.

(8) Three Centres of Research Excellence are included in this analysis based on the overarching focus of each centre: Riddet Institute ($3.3 million Adding Value); Ngā Pae o te Māramatanga ($4.9 million; Innovating through Kaupapa Māori); and the Bio-protection Research Centre ($3.3 million; Protecting and sustaining resources). Alignment to other themes not assessed.

Appendix 4: Related strategies, reports and roadmaps

New Zealand primary sector and science reports and strategies:

- AgResearch. (2016). Technological Foresight for Rural Enterprises and Rural Lives in New Zealand. Retrieved from https://www.academia.edu/29483978/Technological_Foresight_for_Rural_Enterprises_and_Rural_Lives_in_New_Zealand
- Beef + Lamb New Zealand. (2016). Hill Country Symposium. Retrieved from https://www.grassland.org.nz/images/newsletters/44_Hill_Country_Symposium_Position_Paper_Aug2016.pdf
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