The Aotearoa Circle

Mā te Kaitiakitanga ko te Tōnuitanga
Prosperity Through Guardianship

Modern Genetic Technology: Applications in Aotearoa Food and Fibre Production

pwc

Foreword

The Aotearoa Circle operates under a set of principles and values which includes that we are actions focused, we have a sense of urgency in our work and we are not afraid to show leadership, even when seeking progress might be a tougher path than the alternative. These principles and values were fully at play when it came to the decision to undertake the biotechnology work you see here.

Any conversation about modern genetic technologies is naturally fraught. There are strong opinions on the topic, ranging from those who believe that we must keep pace with, or even get ahead of, what the rest of the world is doing, through to those who believe that we must stay away from biotechnology at all costs.

The Circle is often described as a ‘neutral sandpit’ where people from different points of view can come together. In this case it was to enhance understanding of the environmental impacts of modern genetic technologies and of what the regulatory trade-offs might be, were we to adopt them in Aotearoa.

This was a recommended step in two of the Circle’s workstreams – the Agri-Sector Climate Adaptation Roadmap (ASCAR) and the Mana Kai Initiative.

Without the most up to date information about the risks, challenges and opportunities, the Leadership Groups from these Roadmaps felt we might miss out on learning more, and therefore miss being informed on the best way to address another fraught area – how we protect nature, enhance biodiversity and restore our natural capital for future generations.

As you will read here, the question about why we weren’t considering modern genetic technologies was raised with the ASCAR Leadership Group in 2023 by the rangatahi on our Rangatahi Advisory Panel, essentially a shadow board of young leaders who hold The Circle to account. They simply asked the question “if there is technology out there that can help us fight climate change and restore nature, why aren’t we at least looking into it?”

That is what this report aims to do. I should stress that it does not attempt to tell New Zealanders or our policy makers what we should do in this field. Instead, it is about being better informed about what we could do.

This report aims to empower decision makers to navigate innovation, while ensuring responsible practices for the long-term wellbeing of New Zealand’s environment and society.

I want to thank the incredibly hard-working team at PwC who put their hearts and souls into this report. Given the sensitivities and the thoughtfulness required, it was challenging work and they certainly rose to the task.

I also want to thank the many contributors from 38 organisations who gave of their time and their expert views, from the worlds of te ao Māori, the public sector, science, the private sector and more. And finally, I want to thank the rangatahi who asked the thought-provoking question in the first place. We hope this report is useful and timely for everyone, but for our rangatahi most of all, we want this to be a tool for conversation and consideration to help map a better future for them and the Aotearoa they will inherit.

Vicki Watson | Chief Executive Officer, The Aotearoa Circle

“We are pleased to see the depth of thinking that The Aotearoa Circle, PWC and the other contributors to this report have provided on this complex yet important topic for New Zealand’s food and fibre sector. The report encompasses a broad range of views, including perspectives from Māori, which helps to highlight many of the considerations that regulators will need to weigh up as they explore New Zealand’s approach to the availability of new tools and technologies. We believe this report fills critical knowledge gaps, specifically on the environmental benefits and drawbacks to modern genetic technologies, aligned with AGMARDT’s vision of a regenerating environment and a resilient and growing sector.”

Nick Pyke | AGMARDT Chair

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Secretariat services and lead author: PwC New Zealand

Perspectives from the Rangatahi Advisory Panel

The Rangatahi Advisory Panel (RAP) is an extraordinary group of young New Zealanders, all under 30, from The Aotearoa Circle's Leading Partner organisations. They have a governance role in The Aotearoa Circle's work – after all, The Circle's mission is to restore Aotearoa's natural capital and biodiversity for future generations. Having those future generations at the table is essential.

The RAP has three main objectives:

- To hold to account The Aotearoa Circle's Guardians and Leadership Groups of the workstreams;
- To provide learning and development for rangatahi employees of Leading Partners; and,
- To advise Leading Partners on a key piece of their work each year.

The 2024 RAP members are:

Bella Sigley (ANZ), Caleb Poe (BNZ), Tim Hodgson (Fonterra), Hinera Parker (Genesis), Bryn Wilson (Mercury), Cameron Johnson (Department of Conservation), Zoe Tilsley (Westpac), Maggie Powell (Silver Fern Farms).

The commissioning of this report was prompted by conversations with the 2023 RAP members. When discussing the Agri-Sector Climate Change Adaptation Roadmap and the Mana Kai Initiative, the 2023 RAP members specifically drew attention to the importance of considering all possible tools to augment New Zealand's "toolkit" for addressing present and future environmental challenges.

On 15 February 2024, the 2024 RAP members participated in a facilitated feedback session to discuss the work underway in The Aotearoa Circle's Biotechnology workstream.

The 2024 RAP specifically discussed the importance of 'not avoiding any elephants in the room', emphasising the need for a comprehensive approach rooted in systems and environmental perspectives. This led to the identification of four pivotal points for consideration in producing the report:

Remain purpose driven

The RAP stressed the importance of adhering to The Circle's 'why' and how taking decisive action in this domain is paramount in equipping New Zealand with the right tools for the future. They re-emphasised the pressing threat of climate change that underscores the need for urgent and comprehensive action on a national scale.

System shifts required

The RAP highlighted that none of the proposed applications of genetic technology should be considered independently from the system and behavioural shifts that will also be required to ensure benefits can be fully realised and sustained. This includes the need to educate consumers and producers about genetic technology and regulation change required for genetic technology to enter the market.

"These sorts of challenges are going to require behaviour and system changes — dramatic overhaul and new ways of thinking."

Scale of response

Similarly, the RAP raised the fact that many (if not all) of these proposed applications involve adaptation *within* currently established systems, yet the scale of challenges faced by New Zealand will require changes beyond this nature, including consideration of fundamental alternatives to current operations.

"We can't rely on technology that doesn't disturb the status quo — things need to be shaken up."

Explore other technologies

The RAP highlighted that genetic technology should be explored alongside other technologies available that would allow New Zealand to remain adaptive and responsive to a changing environment. This recognises that different problems may have different optimal solutions.

"We need to shift from 'once upon a time' and discussing opportunities. Today the risks of not doing things are what's most important."

Incorporating the insights of the RAP is central to The Aotearoa Circle's vision of restoring nature for future generations through active engagement of young voices. Consequently, these themes are woven through the structure and narrative of this report.

Purpose of The Aotearoa Circle

The Aotearoa Circle is a public private partnership, whose purpose is to restore natural capital for future generations to realise sustainable prosperity in New Zealand. Together we recognise nature is critical to our current, and future, economic success.

We are an apolitical organisation, using our convening capability to tackle difficult and complex work that is better done together. We aim to work quickly, efficiently and cost effectively, delivering solutions that will achieve buy-in from all parties. We work at a systems level. Our partnership model lets us design robust and lasting solutions with key stakeholders involved from the start.

Purpose/focus of Biotechnology workstream

This work seeks to support decision makers in their understanding of the potential environmental impacts of genetic technology and trade-offs of different regulatory approaches. This work aims to lay the foundation to guide decision makers in shaping a future that balances innovation with responsible practices, ensuring the long-term wellbeing of New Zealand's environment and society.

Contents

Key Terms and Definitions (1 of 2)

Several definitions and key terms within the biotechnology space can be used interchangeably or there may be many terms for the same thing, which can lead to confusion. For example, in the European Union (EU) what is referred to as New Genome Techniques (NGTs) is referred to in the United Kingdom (UK) as Precision Breeding Techniques (PBTs). Further, defining terms related to genetic technology is challenging, as these concepts often do not conform to neat categories or clear boundaries, making it challenging to establish precise definitions.

Before proceeding with this report, please take the time to read and understand the following key terms and definitions. This report aims to simplify the terminology around genetic technology - domestic or international regulatory definitions may differ.

Genetic technology
A form of biotechnology and the umbrella term for all techniques, methodologies and tools used to analyse and intervene in the genetic material of living organisms. The term genetic technology includes anything from traditional breeding techniques through to genetic modification.

Genetically modified organism (GMO)
Any organism that has been genetically modified through any genetic engineering technique, including transgenic organisms. This is a scientific definition, however this term has several legal definitions in different jurisdictions. Note, organisms that result solely from traditional breeding techniques are not genetically modified organisms.

Traditional breeding techniques (selective breeding)
The controlled breeding of plants and animals by human intervention with the goal of selecting for enhanced traits.

Gene
The basic unit of heredity passed from adult organism to offspring. A gene is made up of sequences of DNA, arranged one after another, at specific locations on chromosomes in the nucleus of cell.

Genetic modification (GM)
The act of utilising genetic technology to modify the genome of an organism, also referred to as genetic engineering. This does not include traditional breeding techniques.

Trait
A characteristic or attribute of an organism that is encoded by genes whose expression may be influenced by the environment and includes physical attributes, such as hair colour.

Wild-type
Wild-type refers to the form or version of a gene, organism or trait that is commonly found in nature or in a particular species, serving as a reference or standard, i.e. not genetically modified.

Genome
The complete set of genetic material present in a cell or organism.

Key Terms and Definitions (2 of 2)

New Genome Techniques

New Genome Techniques are a rapidly advancing field in science. The term covers a diverse collection of techniques all of which have different levels of specificity or precision.

All New Genome Techniques are techniques used to modify the genome of an organism.

For the purpose of this report, the term NGT encapsulates:

- Genetic modification and genetic engineering,
- New Genomic Techniques,
- Precision Breeding (PB),
- Genome editing,
- Gene-editing,
- New Precision Breeding Techniques (NPBTs),
- Precision Breeding Techniques (PBTs),
- New Plant Engineering Techniques.

Gene Editing

Gene editing is a precise form of genetic modification/genetic engineering that enables targeted changes to the DNA sequence. It is currently a controversial term, however, for the purpose of this report, it should be understood as above.

Release

The intentional introduction or dissemination of genetically modified organisms or altered genetic material into the environment, such as through field trials or commercial cultivation.

Containability

The ability to control and prevent the unintended spread or uncontrollable replication of genetically modified organisms or altered genetic material in the environment.

Reversibility

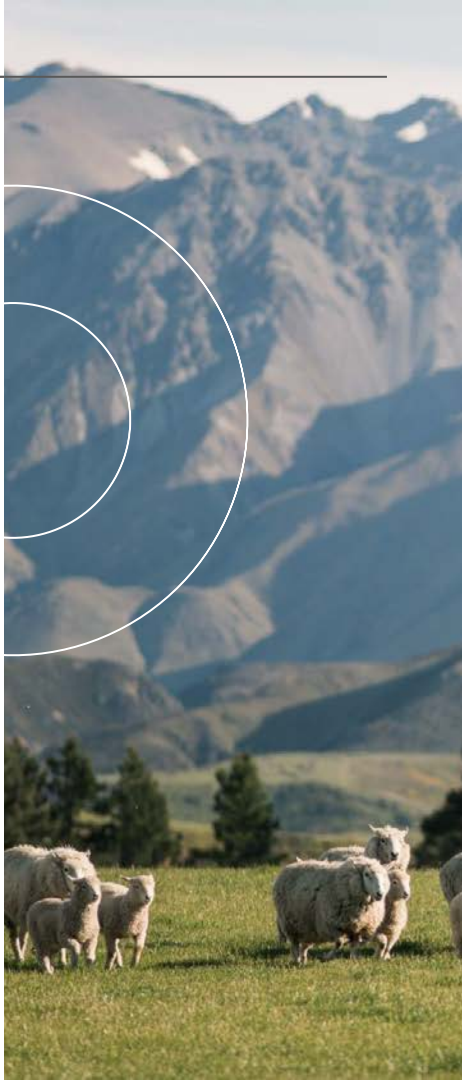
The ability to remove or eliminate the genetically modified organism from the system, restoring it to its original state without the presence or influence of the modified organism.

Traceability

The ability to track and identify the origin, history and movement of genetically modified organisms or products throughout their environment and supply chain.

Detectability

An element that contributes to traceability, the ability to identify and detect the presence of genetically modified organisms or altered genetic material in a sample or product using specific testing methods/techniques. In this report, this will be included within discussion around traceability.



Executive Summary

Executive Summary

Context

New Zealand's society and economy heavily depend on its natural resources. However, there are growing concerns about the degradation of its natural capital due to climate change and biodiversity loss. These challenges have a significant impact on the primary sector, with extreme and unpredictable weather events testing the resilience of communities and individuals. In response to these challenges, The Aotearoa Circle has been urged by the next generation to explore technologies, tools and practices that can mitigate environmental impact and adapt to these challenges.

This report builds upon The Aotearoa Circle's previous publications, namely the Mana Kai initiative and the Agri-Sector Climate Change Adaptation Roadmap. It focuses on the role of modern genetic technologies in improving climate resilience, safeguarding natural capital and optimising the value of the agriculture sector in New Zealand. The report specifically investigates the possible application of genetic technology in relation to the food and fibre system, evaluating the associated environmental impacts and risks.

Purpose

The primary aim of this report is to enhance understanding of the environmental impacts and regulatory trade-offs concerning genetic technology. By providing insights, this report aims to empower decision makers in navigating innovation while ensuring responsible practices for the long-term wellbeing of New Zealand's environment and society.

Overview

This report evaluates different case study applications of genetic technology in various production systems. Its objective is to demonstrate how these applications, along with other important considerations within the broader social and economic ecosystem, can have different environmental risks, benefits and impacts under potential regulatory frameworks.

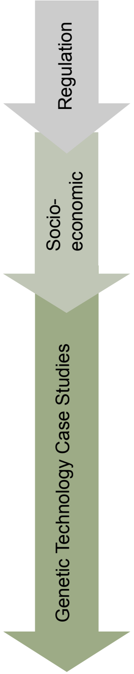
The chosen case study applications are selected to showcase a range of risk and environmental factors. They may not necessarily be the most suitable applications of genetic technology for New Zealand's food and fibre production. The regulation of genetic modification involves complexities and nuances, which this report aims to highlight through diverse case study examples and associated regulatory analysis.

While this report provides specific considerations to decision makers around socio-economic impacts, it does not delve into the market implications of genetic technology. Market implications are an integral part of developing a complete understanding of this issue in a New Zealand context, but they are beyond the scope of this report.

This report does not provide recommendations for the future of genetic technology in New Zealand. Instead, it presents the implications, both positive and negative, of releasing genetically modified plants and animals into New Zealand for their application in relation to food and fibre production systems, emphasising the importance of a considered regulatory approach.

Approach to this Report

There are three components explored throughout this report - **regulation, socio-economic factors, and genetic modification case studies.** This page describes the approach taken to developing these components (below), including comprehensive stakeholder engagement (discussed to the right).



Selecting regulatory frameworks
To evaluate the trade-offs between different regulatory approaches, the secretariat for this work (PwC) developed three regulatory frameworks based on a desktop analysis and interviews with stakeholders. These scenarios cover a range of approaches for regulating the use of genetic technology in New Zealand.

Understanding the broader socio-economic considerations
This report aims to highlight the socio-economic impacts of the use of genetic technology in food and fibre production. Socio-economic factors were identified through desktop analysis, and interviews were conducted with thought leaders and stakeholders with expertise in the potential social and economic impacts of genetic technology in New Zealand.

Selecting plant and animal case studies
The development and availability of genetically modified animals lags behind that of genetically modified plants. Due to this difference of evidence and understanding, this report examines the potential environmental impact, socio-economic considerations and regulatory implications of genetically modified plants and animals separately, with different approaches and methodologies.
For plant case studies: Specific applications of genetic technology were selected and models of their impact developed with input from existing empirical research and subject matter expert input.
For animal case studies: International examples of genetic technology were discussed in the context of the New Zealand environment. A conceptual analysis approach was employed to explore the potential environmental risks, benefits and impacts associated with each application with input from subject matter experts.

The development of the components in this report was underpinned by interviews and workshops with industry and government stakeholders, as well as subject matter experts. The secretariat engaged with the following groups throughout the development of this report. Different groups were engaged at different stages, for different purposes.

Core Advisory and Food and Fibre Sector Groups were engaged at every stage of the report development.

Core advisory group

The core advisory group consisted of science and industry organisations, Māori, and government observers. With their diverse expertise, they provided insights and feedback that supported refinement of the report's direction at each phase.

Food and fibre sector

Representatives of the food and fibre sector offered insights into the practical implications of adopting genetic technology within manufacturing and processing operations, and within each production system.

Subject Matter Experts were engaged where their expertise was needed.

- **Māori Researchers** provided insights into the cultural and ethical considerations of genetic technology.
- **Research Institutes** contributed scientific expertise, providing empirical evidence and rigorous analysis on environmental impacts.
- **Commercial Genetics Entities** provided insights into market trends and emerging technologies, assessing scalability and economic viability.
- **Government Representatives** offered regulatory expertise, aligning project recommendations with national priorities.
- **Industry Good** groups offered practical insights into production systems.
- **Thought Leaders (including the Rangatahi Advisory Panel)** challenged conventional thinking and identified emerging trends to enrich the project with forward-thinking strategies.

Regulatory Scenarios

Since 1998, New Zealand has adopted a conservative approach to evaluating the risks associated with genetically modified organisms (GMOs) by seeking to diminish risk (both real and perceived) through a cautious regulatory framework.

Under this framework, any proposal for the development or release of GMOs outside highly contained environments undergoes rigorous scrutiny by the Environmental Protection Authority. Applicants are required to provide extensive evidence to support their proposals. As a result of these stringent requirements, New Zealand has only approved 13 applications for GE plants for contained outdoor field trials since 1996, with no field trials being approved since 2010.

Due to its restrictive nature, this approach has a low likelihood of unintended consequences. It also means that New Zealand is currently not actively engaged in the development or testing of its own GMOs in open environments. Consequently, New Zealand may be missing out on benefits that this technology could offer.

In contrast, several of New Zealand's major trading partners (including the United Kingdom, Australia, India and the EU) have recently updated their GMO regulations or have proposed amendments. While none of these countries permit unfettered development or release of new organisms without oversight, they employ diverse regulatory models that take into account factors such as the nature of genetic alterations and the traits they elicit.

Throughout this report, three scenarios are used to explore the differences between these models and how they may relate to a New Zealand specific context.

Regulatory Scenarios

When designing a regulation, regulators select a trigger that they think best captures the risk associated with the release of genetically modified organisms. Three regulatory scenarios are explored in this report, the primary difference between these scenarios is the 'trigger' that is used to capture risk. The trigger can capture risk broadly through the **process** of creating a genetically modified organism, narrowly through the **trait** resulting from genetic modification or, as in most countries' frameworks, somewhere in between. Once risk has been captured, the management of that risk can vary through factors such as the administrative and evidential obligations placed on applicants. It is important to consider both risk capture and management when evaluating regulatory frameworks.

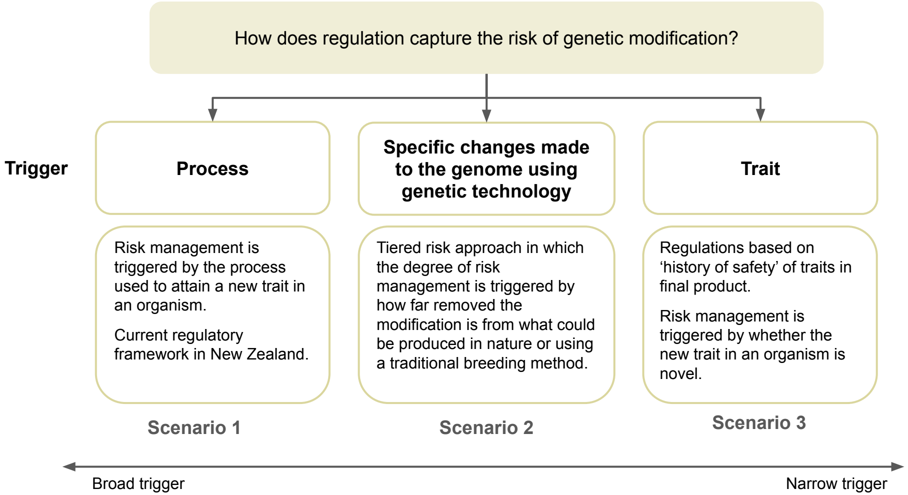


Figure 1: *Outlines three regulatory frameworks explored in this report. This is represents the spectrum of how different jurisdictions capture the risk of releasing genetically modified organisms.*

Socio-Economic Factors

When considering different uses of genetic technology, it is important to take into account the indirect effects it may have.

The infographic on the right illustrates various socio-economic factors that could be influenced by changing regulations related to genetic technology.

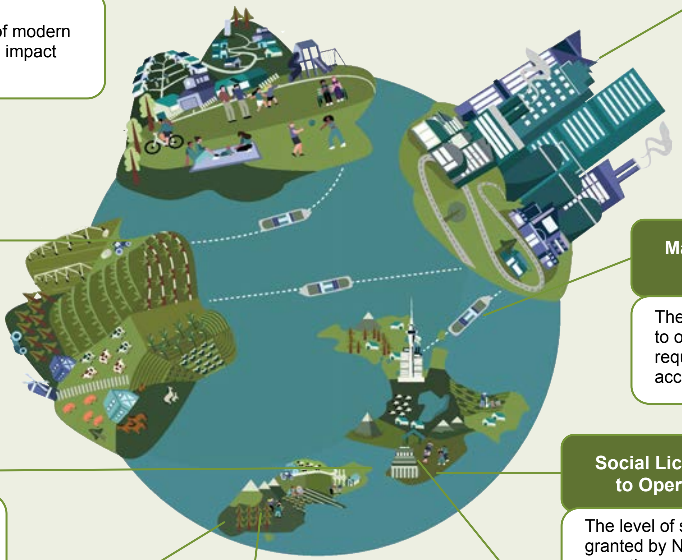
These impacts can be both local, affecting community values and social equity, as well as global, affecting market access and/or consumer preferences.

Consumer Response

The reaction or behaviour of consumers towards the use of modern genetic technology that could impact the sector.

Retailers and NGO Accreditations

Non-regulatory mechanisms used by buyers and third parties on New Zealand products to ensure their obligations are met and consumers can be assured of claims made.



Competitive Advantage

The potential change in New Zealand's competitive advantage in international markets as a result of adopting or not adopting modern genetic technology.

Market Access and Trade

The ability for New Zealand to export products to other countries and the associated requirements related to genetic technology to access these markets.

Community Values

The values of community members in New Zealand as individuals, groups and collectively that may be impacted by genetic technology use.

Social License to Operate

The level of social legitimacy and permission granted by New Zealanders for the continued operation or use of a particular technology or practice by an industry/sector.

Cultural Values

The values of Māori in New Zealand, as individuals, whānau, hapū, iwi and collectively that may be impacted by genetic technology use.

Equity

The fairness across groups and individuals of the costs and benefits associated with new genetic technology.

Innovation and IP Protection

The ability to create, distribute and generate value from new genetic technology.

Plant Case Studies

This report evaluates three specific plant case studies. Each case study is currently being explored by New Zealand scientists, in containment or overseas, to deliver environmental benefits to the food and fibre sector. These case study applications have the potential to deliver value, but require decision makers to consider how trade-offs align with New Zealand's priorities.

This report evaluates the potential socio-economic and environmental impacts for New Zealand specifically. To support this assessment, high-level modelling of the case study application has been completed and further discussion of the socio-economic factors that may be important for the public and for decision makers to consider are highlighted.

Rapid Flowering Apple Trees | Horticulture

This case study evaluates the use of Rapid Flowering Apple Trees to acquire black spot (common fungus) resistance compared to acquiring this trait via traditional breeding methods. This application of genetic technology can offer significant environmental and economic advantages for the horticulture industry, but it is important to consider the possible ecosystem interactions and community values.

High Condensed Tannin White Clover | Dairy

This case study evaluates the use of High CT White Clover to achieve lower emissions, reduce bloat and increase productivity. This application of genetic technology can offer significant environmental and economic advantages for the dairy industry, however, Hi-CT white clover has low containability. It's presence in non-target pastures may make non-GM claims more challenging, if they occur above market or regulated tolerance levels.

Sterile Douglas-fir | Forestry

This case study evaluates the impact of utilising sterile conifers in new plantations to prevent their contribution to wilding populations. The main impact is the reduction in the wilding infested areas caused by existing plantations and the flow on effects for biodiversity, land and soil, and water use. Further impacts are associated with unlocking the ability for the sector establish additional plantations.

Animal Case Studies

This report presents some of the hypothetical areas of genetic modification research in animals that has the potential to be of value to New Zealand. This report covers both the benefits and risks that are associated with the use of genetic modification in animals in food and fibre production systems within different environments.

It is worth noting that these applications are a long time (over fifteen years) away from coming to market and the empirical evidence base is comparatively weaker than plants (and in some cases non-existent). Therefore, this report discusses these cases at a high level, instead of choosing specific applications to evaluate.

Marine Environment

The marine environment tends to feel the impacts of climate change more severely when compared to terrestrial environments. Globally, there are notable advances in the use of genetic technology to develop fish species with traits that will support adaptation to environmental pressures. Consideration may need to be given to the release of genetically modified organisms in the marine environment, due to its vastness and interconnectedness.

Terrestrial Environment

Farming in the terrestrial environment, particularly pastoral farming, is facing increased challenges related to climate change and mitigating its environmental impact. To address these challenges, some applications of genetic technology have emerged globally as possibilities for supporting the sector in adapting to environmental challenges and limiting its impact on biodiversity, climate and animal welfare. While risk of the unintended spread of genetically modified animals is low, consideration may need to be given to the risk of off target effects in an animal and the impact on community values.

Ecosystem

This study explores applications which may have wider impacts not limited to one production system, such as the use of genetic technology to impact the breeding capability of pests. The effectiveness of this application of genetic technology is directly linked to its ability to spread through the environment. Consideration may need to be given to the ethical outcomes and community values.

Key Considerations for Assessing Environmental Risk of Genetic Technology

The following framework is provided to encourage decision makers to contemplate specific aspects that have been surfaced throughout the analysis. It is important to underscore that this framework does not prescribe actions or recommendations. Rather, it serves as a tool for fostering critical thinking and informed decision making regarding the integration of genetic technology in New Zealand's food and fibre production system.

The framework highlights key considerations gleaned from the examination of case studies and regulatory analysis. Decision makers are encouraged to reflect on these considerations within the context of their unique circumstances and priorities. By engaging with these insights, decision makers can better navigate the complexities and uncertainties surrounding genetic technology and make well-informed decisions that align with their objectives and values.

It is essential to reiterate that the framework does not advocate for specific courses of action. Instead, it empowers decision makers to weigh the environmental risks, benefits and impacts of genetic technology within the broader context of sustainable development and regulatory compliance. Ultimately, the aim is to facilitate a nuanced understanding of the implications of genetic technology and to support decision makers in charting a path forward that is mindful of both environmental stewardship and societal wellbeing.

1 What are the environmental challenges New Zealand is facing? What is the potential for genetic technology in addressing these challenges?

- What is driving environmental degradation? How will food and fibre sectors be impacted by environmental degradation?
- How can decision makers incentivise research and development of mitigative or adaptive solutions to environmental challenges? Particularly including research into the potential of modern genetic technology in a New Zealand context.
- What role can genetic technology play in adapting and managing the impact of these environmental stressors?
- Are there any alternative solutions that could address the impact of these environmental stressors? (i.e. selective breeding programmes).

2 What are the environmental risks and impacts associated with applications of modern genetic technology?

- What infrastructure and expertise is required to understand the environmental impacts and risks of modern genetic technology?
- How can regulation enable science and research to create a strong evidence base of efficacy, risks and impacts of modern genetic technologies?
- How could the use of genetic technology change production systems? Do these system changes have the potential to impact climate, water or biodiversity outcomes?

3 How might the use of modern genetic technology impact New Zealand society and the economy?

- How might the type of genomic technique impact community, cultural and consumer views?
- How might the purpose of an application of genetic technology impact community, cultural and consumer views?
- What approach are New Zealand's major trading partners taking to the use of genetic technology?
- How might different approaches to the use of genetic technology impact New Zealand as an exporter of food and fibre products?

4 How can environmental and societal risks and impacts associated with the use of modern genetic technology be mitigated?

- Is it possible to contain, reverse or trace the spread of an application of genetic technology through the environment?
- What processes, accreditation schemes and regulation are required to protect industry's ability to differentiate in the market?
- How can government and industry uphold equity of access and impact with new technologies?

5 What regulatory and adaptive governance approaches result in the best outcomes for New Zealand?

- How can regulations related to genetic technology encourage innovation and experimentation while maintaining risk management and accountability?
- What adaptive governance approaches can be employed to continuously update regulations regarding genetic technology based on evolving scientific knowledge, technological advancements and societal priorities?

Introduction

Introduction

New Zealand is dependent on natural resources for the wellbeing of its society and economy. However, there is mounting concern over the degradation of our natural capital, as New Zealand faces the dual crises of climate change and biodiversity loss. To ensure a future where subsequent generations continue to share New Zealand's natural resources, there must be a focus on building sustainability and resilience into a rapidly changing environmental landscape.

Our primary sector is on the frontlines of climate change and biodiversity impacts. The extremes are becoming more extreme and unpredictable, with more droughts, floods, heatwaves and cold spells. The resilience and adaptability of the sector, communities and individuals are already being tested as they are faced with this increasingly volatile and uncertain environment. Farmers and industry are beginning to look at available technology, tools and behaviours to mitigate their impact on the environment and to adapt to the environmental challenges they are being confronted with.

This report follows the work of The Aotearoa Circle publications - **Mana Kai Initiative** and **Agri-Sector Climate Change Adaptation Roadmap.** These publications outlined the importance of understanding the role of **modern genetic technologies** in the agriculture sector's future, including opportunities to optimise climate change resilience, protect our natural capital and maximise sector value. This report looks to further this conversation and the use of modern genetic technology in the New Zealand agriculture sector by exploring how our toolkit for addressing sector environmental challenges could be expanded and understanding what the associated environmental impacts and risks may be.

This report surfaces some of the possible environmental impacts and considerations of the use of genetically modified plants and animals in New Zealand food and fibre production systems, through the lens of three different approaches to regulating genetic technology. The impact of modified plants is evaluated through three focussed case study applications of modern genetic technology and includes a high-level, early-stage environmental impact screening and evaluation. The impact of modified animals is explored through a stocktake of genetically modified organisms currently in development in both the marine and terrestrial environments, which also includes a high-level environmental impact screening. Throughout the discussion of both genetically modified plants and animals, this report highlights the broader socio-economic considerations associated with the use of genetic technology in the sector. The report does not explore the specific market implications of genetic technology, but it should be acknowledged that this is an integral part of developing a complete understanding of this issue in a New Zealand context.

The primary objective of this report is to enhance comprehension regarding the potential environmental impacts of genetic technology and the trade-offs associated with various regulatory approaches. By doing so, this report aims to support decision makers to shape a future that balances innovation with responsible practices, ensuring the long-term wellbeing of New Zealand's environment and society.

A Brief Overview of Genetic Technology

Genetic changes can naturally occur without human intervention or modern genetic technology. These changes, known as spontaneous mutations, are a common phenomenon in any organism's genome. Depending on the type and location of the mutation, they have the potential to alter the traits exhibited by the organism.

Selective breeding, a traditional method utilised for millennia, takes advantage of this natural genetic diversity and enhances traits in crops and animals by mating individuals with desired characteristics. This is still common practice in agriculture, as this type of genetic change is not regulated as biotechnology.

In contrast, new genome techniques enable scientists to directly alter an organism's DNA utilising highly specialised lab equipment, swiftly introducing or modifying genes for desired traits. These are tightly regulated as biotechnology.

The key difference is that selective breeding naturally allows desired traits to become dominant within a population over time, while genetic modification directly includes specific changes.

Assessing the impact of a specific genetic modification involves two main aspects. Firstly, it requires evaluating the changes made to the organism's genome through the modification process. Secondly, it involves assessing the impact of the trait that is encoded by the modified genes.

Precision varies between techniques, with some, like base editing, being very precise, while others, like transposon mediated gene transfer, are less precise.

Some changes made through genetic modification mimic naturally occurring mutations, while others are entirely novel and would not arise without human intervention. The type of change made through genetic modification also doesn't necessarily determine the impact of the trait that is coded for. For example, even small point mutations can have significant effects, such as genetic disorders like cystic fibrosis.

The **types of changes made through genetic modification** can be categorised using several factors **(see right)**.

It is important to note that none of these factors inherently make a genetic modification good or bad. However, they do influence the ease or difficulty of determining the potential risk and impact of the modification.

The other key way to assess the impact of genetic modification is **examining the impact of the resultant trait** and the way it impacts an organism, the way the organism interacts with its environment, and the overall ecological consequences.

Understanding the impact of genetic modification requires comprehensive analysis, including evaluating factors, such as survival rates, interactions with other species, off-target effects from any genomic changes, invasiveness potential, and unintended effects on ecosystems or human health through laboratory studies, field trials, and rigorous risk assessments.

The cases outlined in this report provide a comprehensive exploration of different types of genetic changes and traits, allowing readers to consider the diverse elements and implications within this context.

Categorisation of changes made through genetic modification

Integrated or Non-integrated

Are traits passed onto future generations?

Permanent or Non-permanent

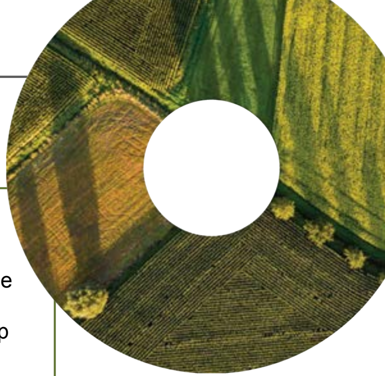
Will traits persist throughout the organism's lifetime?

Foreign DNA or Non-foreign DNA

If DNA is inserted, is it from the same, a closely related, or a foreign species?

Targeted or Non-targeted

Do we know exactly where changes will have been made in the genome without confirming after the change is made?



Approach to this Report

There are three key components explored throughout this report - **regulation, socio-economic factors and genetic technology case studies.** This page discusses the approach to developing these components.

Selecting regulatory frameworks

To evaluate the trade-offs of different regulatory approaches, the secretariat selected three regulatory frameworks based on a desktop analysis and interviews with stakeholders. These scenarios encompass a range of approaches for regulating the use of genetic technology.

Understanding the broader socio-economic considerations

This report evaluates the socio-economic impacts of the use of genetic technology in food and fibre production. Socio-economic factors were identified through desktop analysis, and interviews were conducted with thought leaders and stakeholders who possess expertise in understanding the broader social and economic impacts.

Selecting plant and animal case studies

The development and availability of genetically modified animals lags behind that of genetically modified plants. Due to a disparity between evidence and understanding, this report examines the potential environmental impact, socio-economic considerations, and regulatory implications of genetically modified plants and animals separately, with different approaches and methodologies. Further detail on this difference is discussed on the following page (page 19).

Plant case studies

Selecting case studies

Interviews were held with key science and industry stakeholders to identify potential applications of genetic technology in various food and fibre production systems. Through a series of workshops and assessment against specific criteria, these applications were narrowed down to three specific plant case studies.

Assessing environmental impacts of a single modelled farm

Interviews were conducted with industry representatives, geneticists, farm-systems experts and environmental scientists to gather insights and support the analysis of potential environmental impacts within the relevant production systems for the specific case studies. Models were developed with input from subject matter experts to provide a high-level quantification of some of the possible impacts associated with each plant case study application.

Animal case studies

Selecting environments to examine

Interviews were held with key science and industry stakeholders to identify potential applications of genetic technology in various food and fibre production systems. A large proportion of applications are more than 15 years away from the NZ market with some still requiring proof-of-concept, three classes of production system were selected to discuss broadly. Within these classes, the hypothetical impact of different genetically modified animals is evaluated.

Conceptual analysis approach

A conceptual analysis approach was employed to explore the potential environmental risks, benefits and impacts associated with each application. This was mainly a product of desktop analysis into current scientific literature concerning genetically modified animals.

Genetic Modification of Plants vs. Modification of Animals

The development and availability of genetically modified animals lags behind that of genetically modified plants for several reasons. These include stricter regulatory processes for animals, ethical concerns surrounding animal modification, and the greater technical complexity inherent in the biological systems of animals compared to plants. This variance is depicted in *Figure 2* below, illustrating the time disparities before genetic technology is likely to become viable in food and fibre production systems, regardless of regulatory permissions.

Several genetically modified plants tailored to address environmental challenges in New Zealand's food and fibre production have been successfully developed and field-tested either in containment or overseas. However, very few genetically modified animals meeting the same research and development standards have been approved for trial in New Zealand with none being approved in the agricultural field.

Due to this disparity in evidence and understanding, this report examines the potential environmental impact, socio-economic considerations, and regulatory implications of genetically modified plants and animals separately, with different approaches and methodologies.

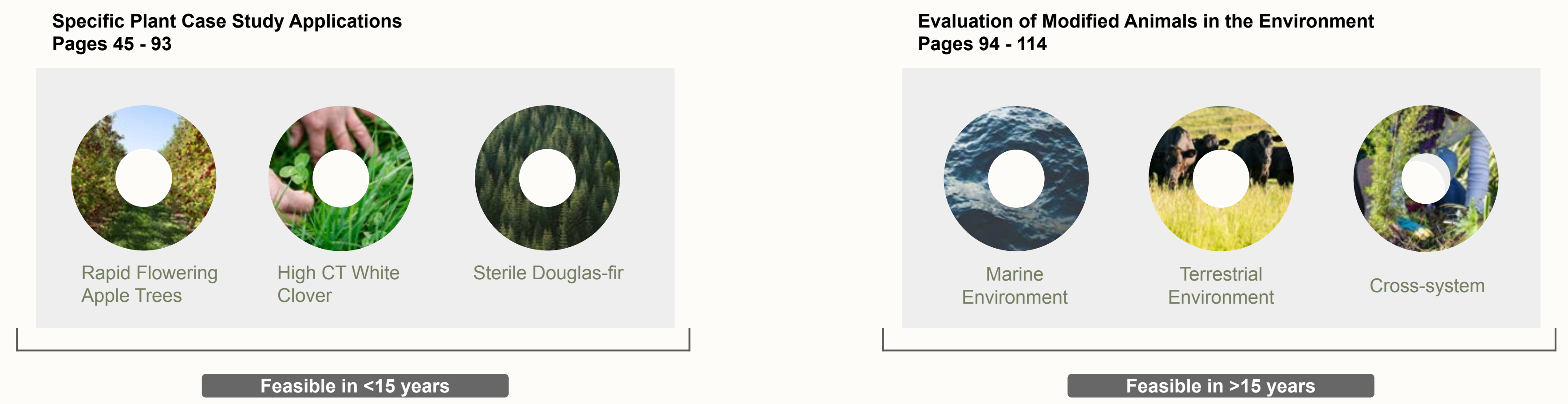


Figure 2: *Timeline of feasibility of modified plants and animals*

Engagement Groups and Their Role

The development of the components in this report was underpinned by interviews and workshops with industry and government stakeholders, and key subject matter experts. The secretariat (PwC) engaged with 38 different organisations, categorised into the following groups throughout the development of this report. Different groups were engaged at different stages, for different purposes.

Core Advisory and Agri-Sector Groups were engaged at every stage of the report development.

Core Advisory

The core advisory group consisted of science and industry organisations, Māori, and government observers. With their diverse expertise, they provided insights and feedback that helped refine the report's direction at each phase.

Agri-Sector

Representatives from the agriculture sector, including processors and exporters, offered insights into the practical implications of adopting genetic technology within manufacturing and processing operations, and within farm systems.

Subject Matter Experts

Māori Researchers	Māori representation within the core advisory group ensured that indigenous perspectives were integrated into the project from the outset. Additionally, one-on-one interviews with Māori researchers provided insights into the cultural and ethical considerations surrounding genetic technology. Their contributions helped shape insights that respected and aligned with Māori values and aspirations.
Research Institutes	Research institutes contributed scientific expertise, providing empirical evidence and rigorous analysis on environmental impacts, grounding the project in evidence-based narratives and strategies for sustainable development.
Commercial Genetics Interest	Experts in commercial genetics provided insights into market trends and emerging technologies, assessing scalability and economic viability.
Government Representatives	Government representatives offered regulatory expertise, aligning project recommendations with national priorities and frameworks, while identifying regulatory barriers and collaboration opportunities.
Industry Good	Representatives from industry organisations offered practical insights into farm systems science, operational implications, including market dynamics, consumer preferences, and supply chain logistics, informing adoption challenges and opportunities.
Thought Leaders (including RAP)	Thought leaders shaped the project's strategic direction, challenging conventional thinking and identifying emerging trends to enrich the project with forward-thinking strategies for harnessing technological tools in restoring the natural environment for future generations.

Regulatory Scenarios

Regulatory Scenarios Introduction

Purpose of section

The purpose of this section is to outline different frameworks for regulating the release of genetically modified organisms and their approaches to capturing the associated risk. These frameworks represent the global spectrum of regulation and will be used to analyse hypothetical New Zealand-based case study applications in the following section. Additionally, this section will also explore the current state of genetic technology regulation in New Zealand, future outlooks, and considerations related to trade partners and other factors impacting regulation.

Approach

The three regulatory frameworks have been selected to outline the different approaches taken by countries to capturing the risk of the use of genetic technology and release of genetic modified organisms. The primary aim of each regulatory framework is to maximise opportunities and minimise harm. However, each framework has different principles underpinning the judgement of harm vs. opportunity.

Methodology

This work builds on the report by Te Puna Whakaaronui, 'Modern genetic technology - what is it and how is it regulated,' released in early 2023. The report identifies two main approaches to regulatory design: process-based and trait-based. These approaches can be applied in a liberal or conservative manner based on a country's risk appetite. To identify the specific frameworks used in this report, recent global regulation developments were reviewed, with a focus on countries with existing trade relations with New Zealand.

Structure of this section

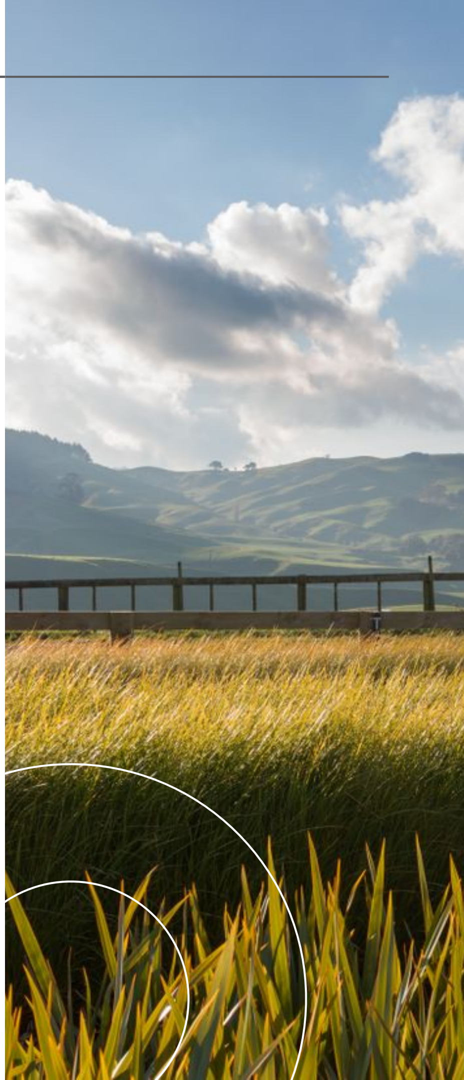
This section firstly explores the current state of genetic technology regulation in New Zealand, including the broader regulatory system and implications from Te Tiriti o Waitangi.

The section then explores the three different regulatory frameworks. The primary difference between each is the trigger for regulatory approval and how the risk is subsequently managed.

The three triggers are as follows:

- **Process-based**: This framework is similar to New Zealand's current regulatory framework. Risk management is triggered by the process used to attain a new trait in an organism.
- **Trait-based:** The fundamental principles of this framework are similar to (but do not directly replicate) Canada’s regulatory framework. Risk management is triggered by whether the new trait in an organism is novel.
- **Tiered risk-based:** This framework has fundamental principles similar to Australia, the Uk, and the proposed EU framework. In this framework,the degree of risk management is triggered by how far removed the modification is from what could be produced in nature or using a traditional breeding method

Finally, this section looks at some of the regulatory frameworks used abroad now, and how this might change by 2035. This leads into an overview of social and economic considerations across the three genetic technology regulation frameworks.



Current New Zealand Regulation

Development and release of genetically modified organisms in New Zealand

The Hazardous Substances and New Organisms Act (HSNO Act) is the primary legislation governing application of genetic technology. The HSNO Act sets out a comprehensive regulatory framework for assessing, managing, and controlling the risks associated with genetically modified organisms. The Act applies to a wide range of activities, including the import, manufacture and release into the environment of GMOs. The ERMA (later to become the Environmental Protection Authority (EPA)) was established in 1998, the same time as the HSNO Act came into force and is the body responsible for overseeing importation, development, field trials and release of GMOs.

When the framework came into effect it was considered one of the strictest in the world. Since then, other than in 2003, there have only been minor changes to the legislation.The Act is not an outright ban - it does allow scientists to experiment with GM techniques and organisms in a lab and in contained field trials, as well as release GMOs, subject to an approvals process. However, while there is a high use of genetically modified organisms in lab settings, the prescriptive nature of the criteria around field trials and the subsequent intensive administrative obligations are such that scientists have found it almost impossible to meet these criteria. As a result, the EPA has only approved 13 applications for genetically modified plants for contained outdoor field trials since 1996. No field trials of genetically modified organisms have been approved since 2010 [1].

Based on this context, within this report New Zealand's current regulatory system will be referred to as 'an effective ban' on release of products into the New Zealand environment.

Importing genetically modified food products into New Zealand

While the development and release of new organisms is highly regulated under the HSNO Act, genetically modified food is regulated by Food Safety Australia New Zealand (FSANZ) and is not subject to regulation under the HSNO Act.

Genetically modified food is allowed to be imported into New Zealand and sold once it has been approved by Food Safety Australia New Zealand (FSANZ) and has met other non-GM related importation requirements. Presently, with the exception of GM bananas [2], no GM fresh vegetables, fruit or meat is authorised for sale and importation into New Zealand.

Once an international GM crop has been approved by FSANZ, any ingredient made from that crop can be sold in New Zealand, with nine crops currently approved (Food Standards Australia New Zealand, 2021). These crops include soy, wheat, potatoes, corn, and rice.

Genetically modified organisms

It is very hard (effectively impossible) to meet the criteria to release genetically modified organisms in New Zealand Environment.

Genetically modified food products

It is possible for genetically modified food products to be sold and consumed in New Zealand, if approved by FSANZ.

Current New Zealand Regulatory Risk Management

Assessment and Approvals Process for Genetically Modified Organisms

As outlined on the previous page, if an organisms is defined as a genetically modified organism, as per the HSNO Act, an application must be submitted to the EPA to determine whether it can be imported, developed, or released. This includes a robust assessment of the risks and benefits to the environment, people and the economy. For new organisms, an application to the EPA involves disclosing and discussing:

Information about the genetically modified organism
Description of the host organism and the genetic modification, its biology and main features, close taxonomic relationships with other organisms in New Zealand. Discussion around whether the organism could form an undesirable self-sustaining population, and if so, how easily the new organism could be recovered or eradicated.

Information about the containment
Description of the nature and method of the field test, proposed containment. This includes how to contain the genetically modified organism(s) after taking into account its ability to escape from containment (i.e. the possible pathways for escape).

Māori engagement
Engagement with Māori undertaken and a summary of the outcomes is submitted. These responsibilities are described further on the following page.

Alternative methods and potential effects from the transfer of genetic elements
Discussion of any alternative methods of achieving the research objective. Discussion on whether there could be effects resulting from the transfer of genetic elements to other organisms in or around the site of the development or field test.

Rapid assessment eligibility
Determined if low risk or a qualifying medicine and does not require outdoor containment.

Risks, costs and benefits
The EPA undertakes a risk/benefit assessment of genetically modified organisms under the provisions of the HSNO Act on a case-by-case basis, including assessment of:

- **adverse or positive effects on the environment** (e.g. assessment of risk of significant displacement of any native species within its natural habitat, significant deterioration of natural habitats, significant adverse effect to New Zealand's inherent genetic diversity, causing disease, being parasitic, or becoming a vector for disease); and,
- **human health and safety**; and,
- the relationship of **Māori to the environment**, the principles of the **Treaty of Waitangi;** and,
- **society and the community**; and,
- the **market economy** and international obligations.

The Act's minimum standards for release require a significant body of proof and under current regulations, it is cost and time intensive to meet this requirement for the assessment and decision-making process. Subsequent to being approved under the HSNO Act, depending on the organism, there may be requirements for other approvals from additional regulators, which is discussed in further detail on page 26.

Note that while this report briefly touches on the regulatory risk management process, its primary focus lies in how regulation captures the risk associated with the release of a genetically modified organisms through different 'triggers'.

EPA and Applicant Māori Engagement Responsibilities

Overview

Across the spectrum of its work, the EPA acknowledges its obligations to Māori under The Treaty of Waitangi/te Tiriti o Waitangi, although these are largely guided by principles of good faith rather than hard requirements. The EPA's assessment and approvals approach emphasises active protection, partnership, participation and consideration of potential impacts on future Māori cultural and economic growth and development.

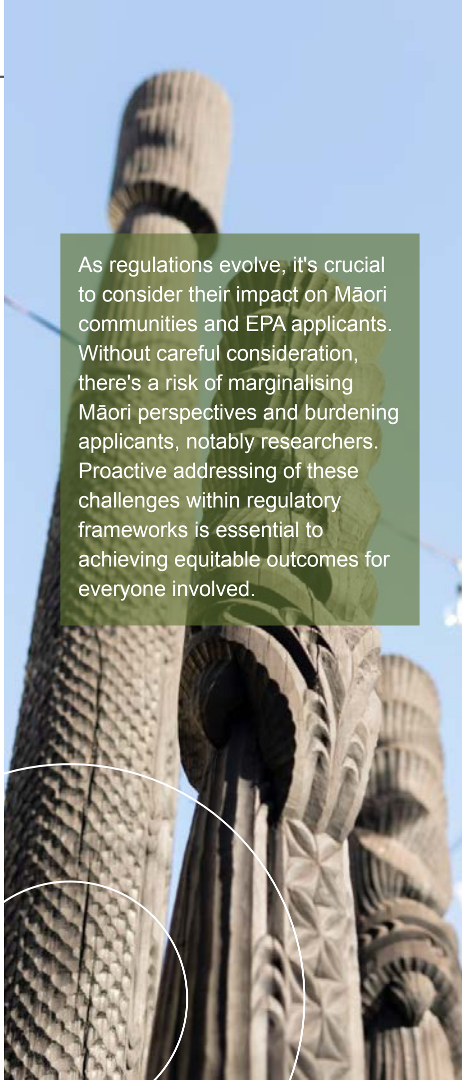
Requirements for applicants

Applicants seeking approvals from the EPA, for any reason, are advised to engage with relevant Māori groups throughout the application process. The EPA employs a framework for assessment of Māori engagement called He Whetū Mārama framework, which emphasises participation and early consultation with Māori. decision-makers are advised to recognise the significance of Māori cultural practices, knowledge and sites of significance. The EPA offers guidance to applicants on engaging with Māori groups, understanding Māori interests, and demonstrating how proposals consider Māori rights and interests.

Changing regulation and its impact to Māori communities

As regulations evolve, it is crucial to consider their impact on EPA applications from various stakeholders. For Māori communities, regulatory shifts may change their level of engagement and influence in environmental decision-making. If the engagement burden remains primarily on applicants, there is a risk of both marginalising Māori perspectives and overburdening community representatives with multiple consultations. Similarly, for applicants, namely researchers, the current framework requires each applicant to engage with Māori communities and integrate their perspectives into proposals. Depending on the project scale and its impacts across the country, researchers may face significantly increased administrative burdens and require more time and resources to meet regulatory engagement standards, potentially hindering research progress and innovation or the quality of engagement.

A streamlined approach becomes essential to mitigate potential challenges, balancing robust environmental protection with practical considerations for researchers and Māori communities. Without such consideration, there's a risk of increased burdens on both groups, potentially hindering progress and collaboration. By addressing these concerns, regulators can foster an environment conducive to positive outcomes for all stakeholders involved. Meaningful and genuine engagement with Māori in the development of new regulation may reduce engagement requirements later on and decrease the burden on both regulators and Māori.



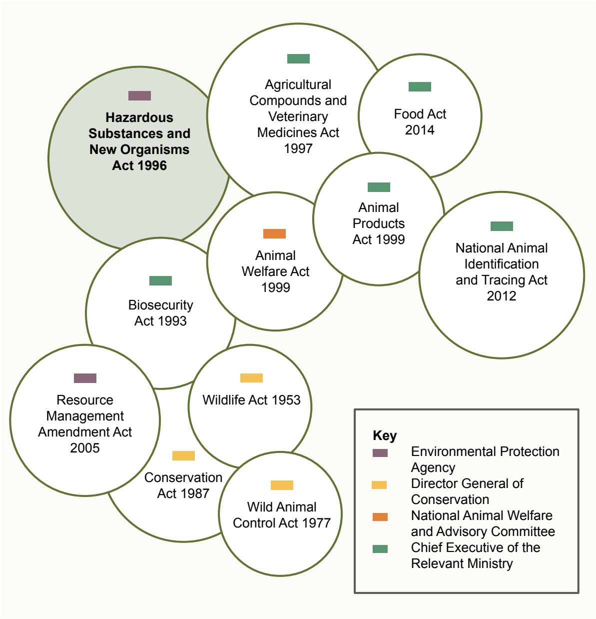
The Role of Other Legislation in Regulating the Use of Genetic Technology

The regulatory scenarios outlined in this report only consider the primary statute for regulating the use of genetic technology. In New Zealand, this primary statute is the Hazardous Substances and New Organisms Act 1996 (HSNO). It is important to note that even if HSNO is amended to ease restrictions on the use of genetic technology, all other legislation which also relates with the system would still apply. Legislation of relevance as they affect the food and fibre value chain include, but are not limited to, those in the table below.

Table 1: *Current regulatory systems that could intersect with regulating the use of genetic technology*

Regulatory system	Regulation and legislation	Purpose	Interaction with regulating genetic technology
Food safety regulatory system	Food Safety (The Food Act 2014), Animal Products (Animal Products Act 1999), Animal Compounds, and Veterinary Medicines (Agricultural Compounds and Veterinary Medicines Act 1997)	To provide safe and suitable food in New Zealand and for export. These regulations cover all aspects of food safety, including production, processing, transport, and retailing. Animal compounds and veterinary medicines, such as novel feeds, are also regulated to ensure no adverse effects on animals and their resulting food products.	Food products derived from genetic technology applications are regulated separately from the GM organisms themselves. In all three regulatory scenarios explored in this report it is assumed that the existing food safety system will manage the safety of these products for human consumption.
Biosecurity regulatory system	Biosecurity (Biosecurity Act 1993), Resource Management (Resource Management Act 1991), and the Environment (Conservation Act 1987, Wild Animal Control Act 1977, Marine Reserves Act 1971, Reserves Act 1977)	The biosecurity system covers the approval process for imported or newly bred organisms that may pose a pest risk to the environment and productive biological systems. A range of options exist to manage the varying risks of new organisms.	Approval for imported or newly bred organisms are covered by the biosecurity system. In some territorial authorities a plan change and/or a resource consent under the RMA would be required for introduction of an application of genetic technology. A genetically modified organism that is likely to have ecosystem or socio-economic effects detailed in the Act could then be incorporated into, or controlled by, pest management plans and/or conservation management plans.

***Figure 3:** The Hazardous Substances and New Organisms Act 1996 is the primary statute that governs the use of genetic technology, and is the legislation that is considered in this report. Overlapping bubbles indicate interacting provisions. Regulating authorities for each of the statues are presented in the key provided. This figure has been copied from the New Zealand Science Review publication, 'Gene editing pests and primary industries - legal considerations.' [3]*



Genetic Technology Regulation and Te Tiriti o Waitangi

Any change in genetic technology regulations must take into account the obligations of the crown under the Treaty of Waitangi. Genetic technology has the ability to directly and indirectly impact the economy, environment, and society and is therefore intricately linked to the Crown's obligations to iwi/Māori of partnership, participation and protection.

The recent legislative recognition of Māori as kaitiaki of taonga species under the Plant Varieties Act (2022) is an example of how Te Tiriti obligations can be interpreted in the wider context of biotechnology regulation. The Plant Varieties Act was updated to align with the outcome of the Waitangi Tribunal Claim and decision, Wai262*. The act creates a mechanism for Māori to have influence over the intellectual property rights of new plant variety rights for taonga species. This is achieved through the establishment of the Māori Plant Varieties Committee, which considers applications, assesses the kaitiaki relationship asserted and makes decisions on whether the applications should proceed or be declined.

Fundamentally, the regulation of genetic technology must align with the principles of Te Tiriti o Waitangi. In future, this could include the incorporation of provisions addressing the outcomes of claims similarly to the outcome from Wai 262, ensuring meaningful Māori participation in assessing the environmental risks associated with new technology applications. Equity of impact should also be considered in the design of regulations so as not to exacerbate the existing disparity of outcomes Māori experience in the food and fibre sector and in society generally.

The following regulatory scenarios do not assume alignment with Te Tiriti o Waitangi. High-level socio-economic impact of these scenarios does consider elements of alignment such as equity of impact, values, and equity of access however further work is needed in this area.

*Wai262, also known as the Wai262 claim, is a significant legal case to the Waitangi Tribunal in New Zealand that addresses the rights of indigenous Māori people over their traditional knowledge, cultural heritage and resources under Te Tiriti o Waitangi. The claim seeks recognition, protection and redress for Māori intellectual property rights and cultural interests in relation to flora, fauna, traditional knowledge and cultural practices.

Different Approaches to Genetic Technology Regulation

The purpose of regulating modern genetic technology is to reasonably manage risk. Countries implement regulatory frameworks that reflect their determination of risk, weighted against the perceived public benefit. On this basis, different countries' approach to regulating release of products created using genetic modification vary widely. The primary differences in regulation are between the 'trigger' that is used to capture risk. The trigger can capture risk broadly through the **process** of creating a genetically modified organism, narrowly through the **trait** resulting from genetic modification or, as in most countries' frameworks, somewhere in between.

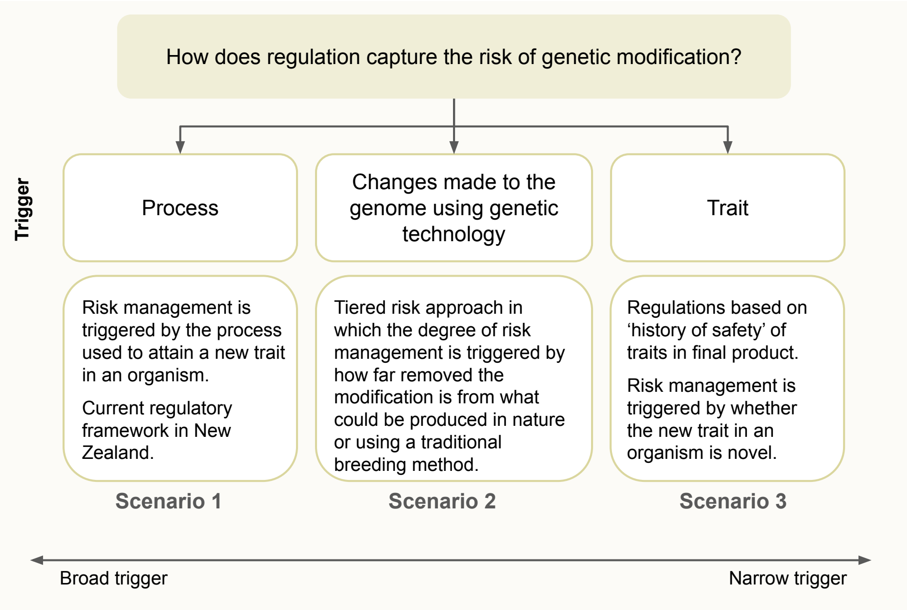


Figure 4: *Spectrum of approaches to triggering regulatory risk management processes.*

The regulatory scenarios focus exclusively on the different approaches to triggering regulatory risk management processes. The management of that risk is independent of the the trigger, and can vary through factors such as the administrative and evidential obligations placed on applicants. All countries discussed in this report have country-specific risk management measures in place to address safety, environmental impact and other concerns relating to the breeding or release of genetically modified organism, such as those currently required in New Zealand. How a country manages risk of the release of genetically modified organisms is determined by the risk trigger, the subsequent risk management process and the degree of risk aversion of the regulator.

Regulatory Scenario 1: Process-Based Approach

Overview

This regulatory scenario is modelled after New Zealand's current regulatory settings. While this scenario captures the fundamentals of New Zealand regulation on genetic technology, it has been simplified for the purposes of this report. The following explanation only provides high-level details sufficient to support the analysis in this report.

In this regulatory scenario, risk management of the release of an organisms is triggered by the processes involved in the development of the organism. All organisms created using new genome techniques are defined as genetically modified organisms; regardless of what the specific genetic changes are or the traits that these genes encode. Under this regulation, all organisms classified as 'genetically modified organisms' are prohibited from being developed, field tested, knowingly imported or released prior to regulatory approval. The regulatory risk management/approvals process is currently extensive with a significant administrative and evidential obligations. Therefore, this report classifies this scenario as an 'effective ban' on release of genetically modified organisms.

Process-Based Classification Framework

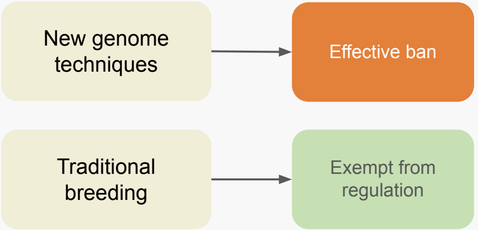


Figure 5: *Process-based classification framework*

Regulated by?

In this regulatory scenario all genetic technology applications are handled by a **central government entity.**
The Environmental Protection Authority (EPA) currently serves as the regulatory body for assessing and managing the environmental risks associated with GMOs in New Zealand.

Applied to?

In this scenario, regulatory settings apply to all agricultural related products including inputs, plants and animals which are released outside of a contained environment.

Similar Regulatory Frameworks

New Zealand

European Union (*Current)*

Regulatory Scenario 2: Tiered Risk Based Approach

Overview

This regulatory scenario is based on one currently proposed in Norway [4] and is broadly similar to that employed or proposed in many of New Zealand's trade partners (e.g. EU, Australia, USA, UK). The following explanation only provides a high-level of detail sufficient to support the analysis in this report.

This regulatory scenario takes a tiered risk approach in which the degree of risk management is triggered by how far removed the modification is from what could be produced in nature or using a traditional breeding method. It assumes that, from a scientific perspective, genetically modified organisms, where no new DNA has been introduced into the genetic material of an organisms, are unlikely to pose a greater risk than similar organisms produced with traditional breeding techniques.

The risk assessment takes a tiered approach, with genetically modified organisms with significant degrees of change triggering a higher tier level (tier 3) requiring greater administrative and evidential requirements, and those with changes similar to those obtained via conventional methods triggering a lower tier level (tier 1) requiring only notification to the regulatory authority.

Tiered Classification Framework

See page 31 for diagram of tiered risk based classification framework.

Regulated by?

In this regulatory scenario all genetic technology applications are proposed to be handled by a **central government entity.** This entity would conduct risk assessment, classification, permitting, consultation, monitoring and reporting, and review.

Applied to?

In this scenario regulatory settings apply to all agricultural related products including inputs, plants and animals which are released outside of a contained environment.

Similar Regulatory Frameworks


Norway (*Proposed*)


United States


Australia


Japan


EU (*Proposed*)


United Kingdom


India


Argentina

Tiered Risk Classification Framework

The framework to the right, informed by the work developed by the Norwegian Biotechnology Advisory Board [4] shows the tiered regulation approach based on type of genetic change. The framework is broken into four risk tiers:

Tier 0 - Organisms with temporary, non-heritable changes.
Risk management: Exempt from regulation.

Tier 1 - Organisms with changes similar to those which could be obtained via traditional methods.
Risk management: Notification of release required.

Tier 2 - Other genetic changes within the species.
Risk management: Expedited assessment and approval.

Tier 3 - Organisms with permanently introduced DNA from other species or synthetic DNA.
Risk management: Standard assessment and approval.

Risk increases left to right. Risk is determined by degree of change from what could occur naturally.

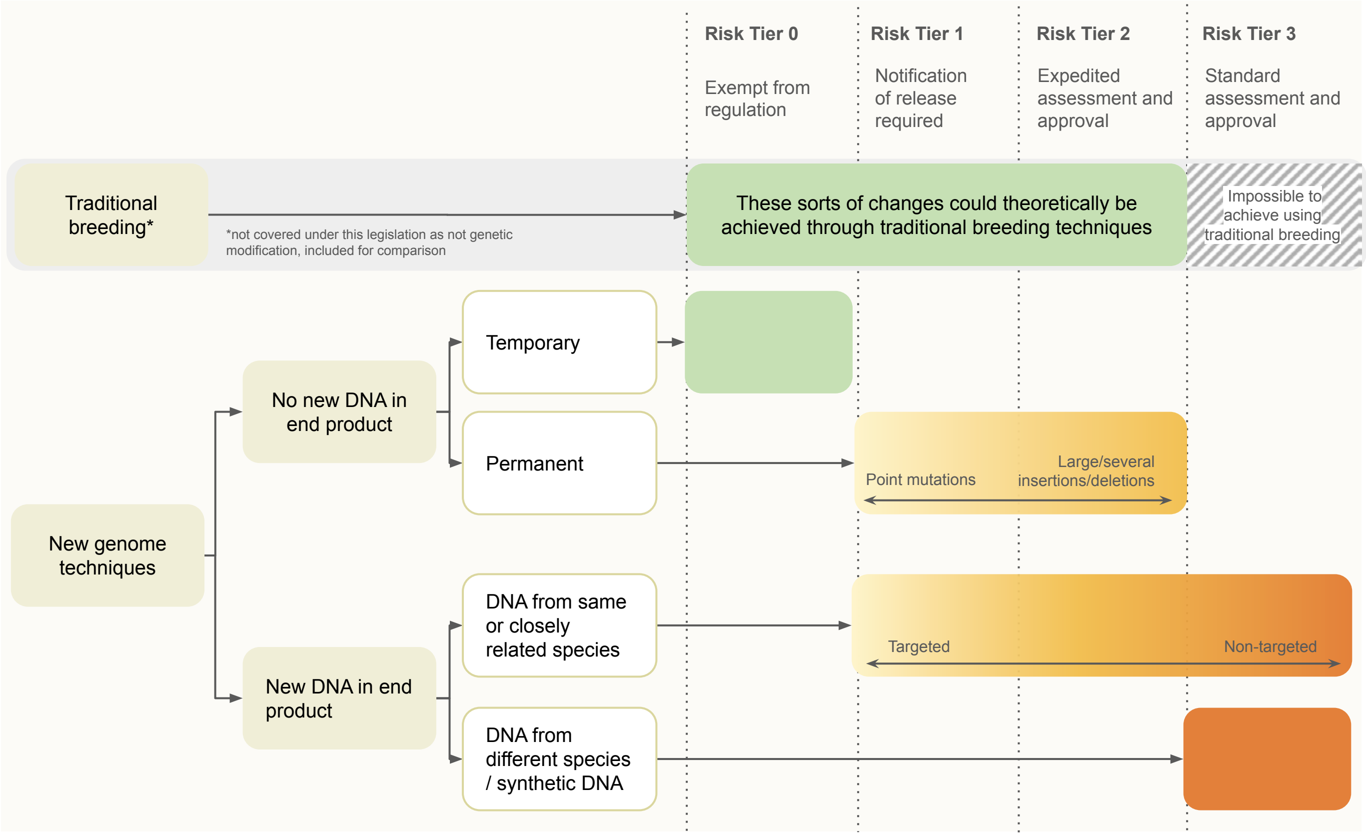


Figure 6: *Tiered risk classification framework*

Regulatory Scenario 3: Trait-Based Approach

Overview

This regulatory scenario is broadly modelled after the Canadian regulatory framework, but is not a direct representation of its full regulatory system. The following explanation only provides a high-level of detail sufficient to support the analysis in this report.

The scenario assumes that the trait in the final product which is released, is indicative of the risk the organism could present to society, regardless of the process used or change made. Risk management is triggered by whether the new trait in an organism is novel. If a trait is defined as 'non-novel' it is seen to pose no greater threat than that which currently exists in the open environment and is exempt from risk management. *See 'Non-Novel Criteria' box for assessment criteria for determining a novel trait.* For all 'novel' traits, a risk-based assessment and approvals process is required before release into the environment.

Trait-Based Classification Framework

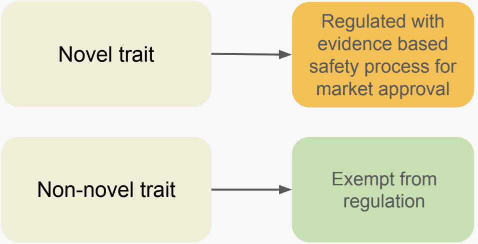


Figure 7: *Trait-based classification framework*

Regulated by?

In this regulatory scenario, all genetic technology applications are handled by a **central government entity** which conducts assessment, classification, permitting, consultation, monitoring and reporting, and review.

Applied to?

All agricultural related products with a novel trait and/or foreign DNA, including inputs, plants and animals, are regulated regardless of the process used to genetically engineer the plant.

Similar Regulatory Frameworks

Canada

'Non-Novel' Criteria

Products derived from genetic modification are exempt from regulation if they do not:

- modify a protein in a way that introduces or increases risk to human health.
- increase levels of known allergens, toxins, or anti-nutrients beyond the naturally occurring ranges in the species.
- significantly impact key nutritional composition or metabolism.
- intentionally change the intended food use of the plant or animal.
- result in the presence of foreign DNA in the final product.

Current Regulations

Currently, New Zealand regulations take a cautionary approach to regulating genetic technology. This page shows where New Zealand's **major trade markets** sit relative to New Zealand's cautious process-based regulatory approach. The below diagram shows this spread of regulatory regimes by country. For the food and fibre sector, in order of value, China, United States, Australia, and the EU are New Zealand's largest markets [5].

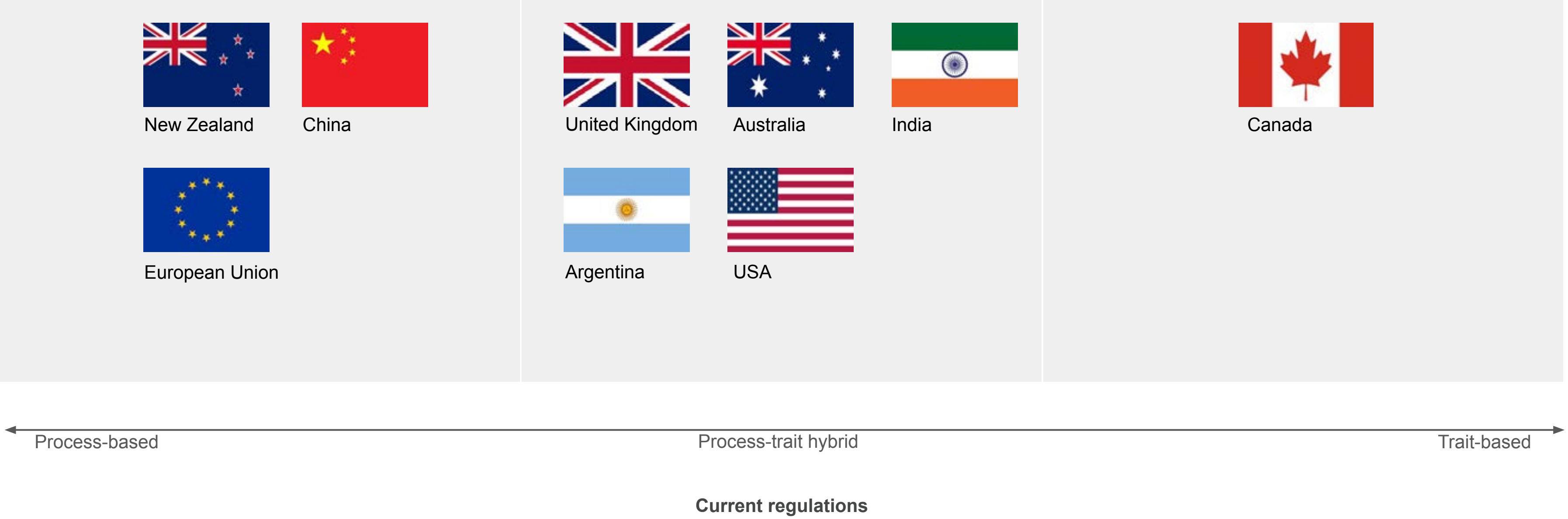


Figure 8: *Current regulations of key markets*

Potential Regulations of Key Markets in 2035

In ten years, the time horizon the report is considering the regulatory scenarios broadly within, the state of regulations in New Zealand's key market's is likely to change significantly. Based on the current proposed regulations each of the three regulatory scenarios have been mapped as well as where New Zealand's key trade market countries may *potentially* sit in 2035. Please refer to the reference section for supporting evidence regarding the proposed shifts in China and European Union's regulatory frameworks.

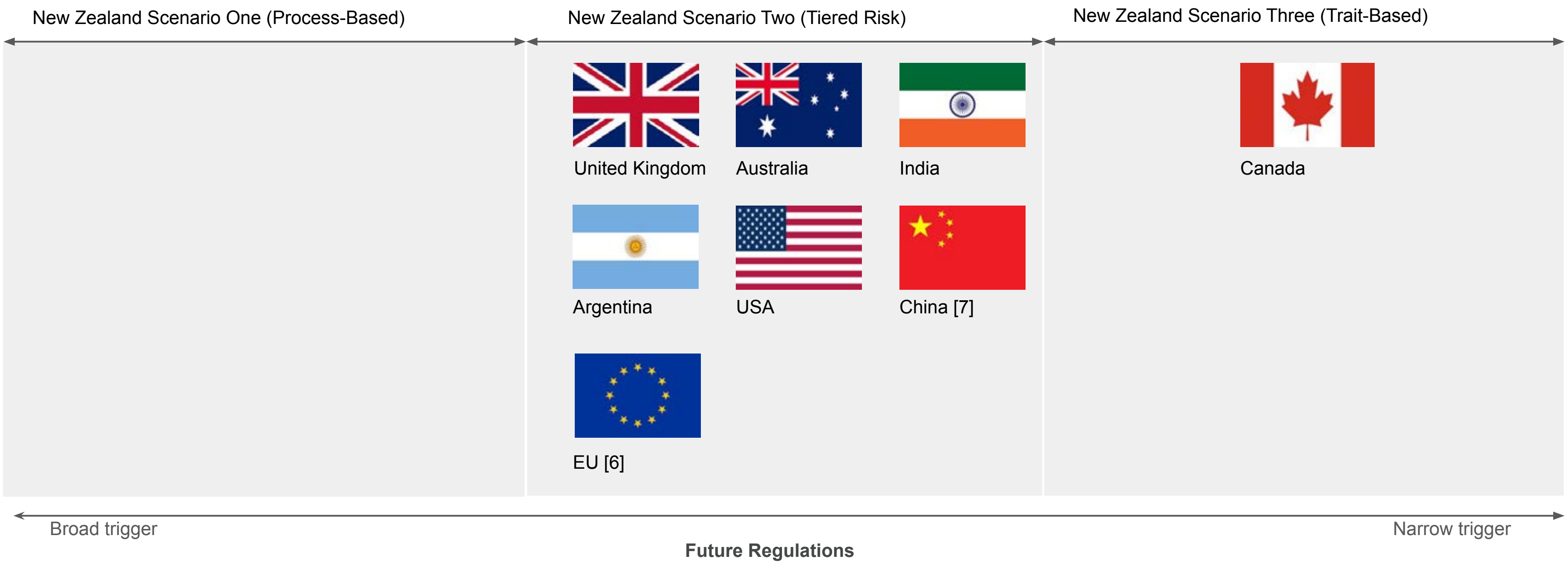
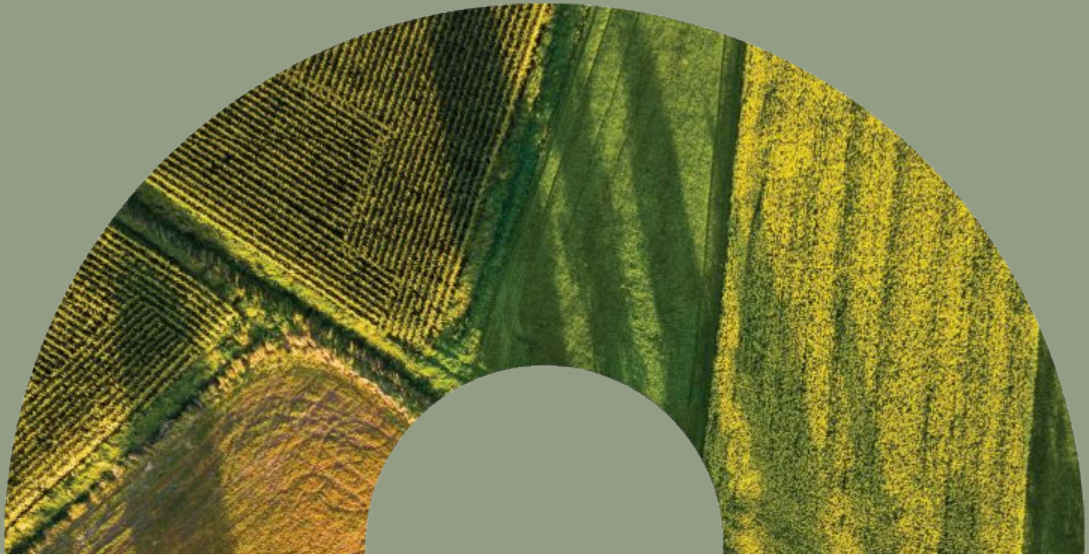


Figure 9: *Potential regulations of key markets in 2035*



Social and Economic Considerations of Changing Regulation

The Possible Socio-economic Impacts from Changing Genetic Technology Regulation are Diverse and Global

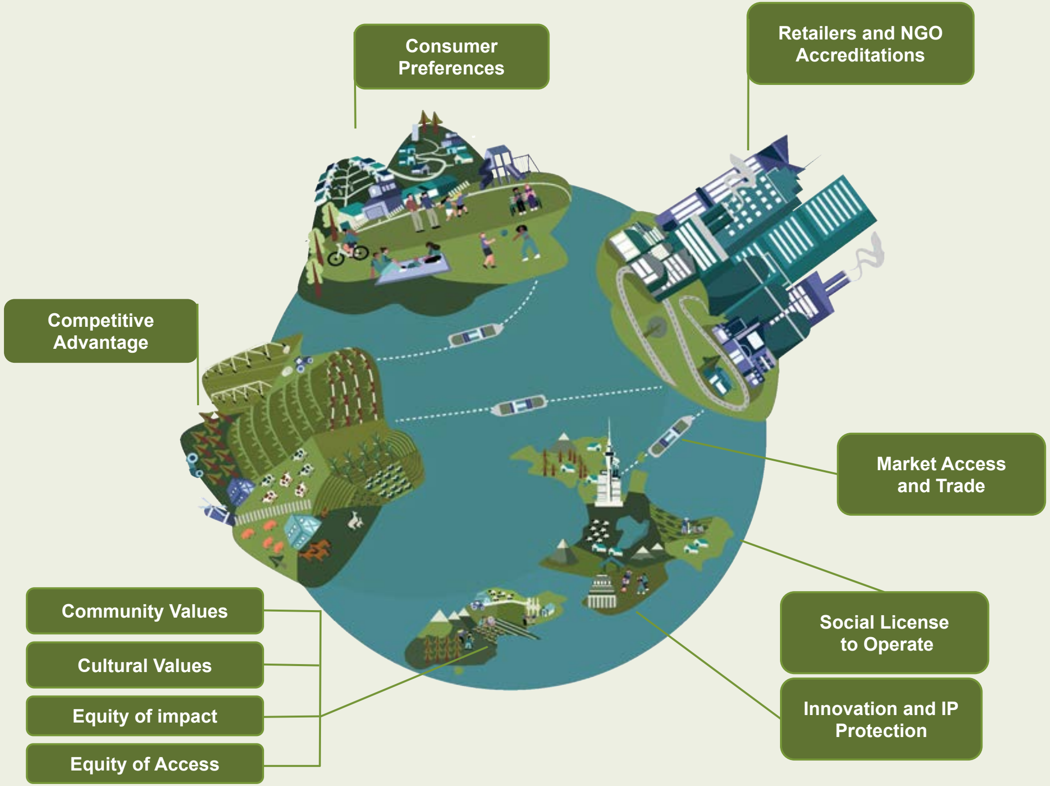
What socio-economic factors could be impacted by a change in regulation?

Looking forward to 2035, New Zealand and countries around the world may have a different approach to regulating the use of genetic technology.

While the focus of this work is exploring the possible environmental impacts of the use of genetic technology within food and fibre production systems, these production systems do not exist in a bubble.

The indirect impacts of genetic technology applications need to be considered by the reader as they explore each case study. The infographic to the right outlines a range of socio-economic factors that could be impacted through changing regulation. These impacts can be close to home, such as impacts on community values or social equity, or further abroad, such as market access or consumer preferences.

The following pages outline these potential social and economic impacts in the context of the case studies and regulatory scenarios detailed in this report.



Definitions of Socio-Economic Considerations (1 of 2)

Community Values

The values of community members in New Zealand as individuals, groups, and collectively that may be impacted by genetic technology use.
This considers the alignment (or not) of genetic technology and its use cases to the values of communities in New Zealand.

Cultural Values

The values of Māori in New Zealand, as individuals, hapu, iwi, and collectively may be impacted by genetic technology use.
Cultural values specifically relate to indigenous perspectives and values. An overview of the possible impact of the use of genetic technology on cultural values and the spectrum of indigenous perspectives is outlined on the next page (page 39).

Consumer Response

The reaction or behaviour of consumers towards the use of new genome techniques that could potentially significantly impact the sector.
This focuses on the acceptance, concerns and preferences of consumers that might, in aggregate, have a significant impact.

Producer Responsiveness

The ability of producers to decide whether or not they would like to engage with new genome techniques and their products.
This captures the supply side of regulation of new genome techniques, exploring the extent that producers can choose whether or not to opt in or out of use of new genome techniques and their products.

Competitive Advantage

The potential change in New Zealand's competitive advantage in international markets as a result of adopting new genome techniques.
This refers to the potential costs and benefits applications of new genome techniques may offer in areas such as productivity, product traits, or reduced environmental impacts and will be a significant consideration when assessing the economic impact of new genome techniques.

Retailer and NGO Accreditations

The non-regulatory mechanisms used by buyers and third parties on New Zealand products to ensure their obligations are met and consumers can be assured of claims made.
This focuses on how environmental, social and governance standards may impact New Zealand producers through non-regulatory mechanisms.

Definitions of Socio-Economic Considerations (2 of 2)

Equity

The fairness across groups and individuals of the costs and benefits associated with new genetic technology.
This considers who will front the costs of new genome techniques and who will receive the benefits, which will be critical to promote fairness and sustainable development.

Innovation

The ability to create and distribute new technology.
This focuses on the pace and pathway of bringing applications developed using new genetic techniques to market. This also includes considerations on intellectual property.

Trade and Market Access

The ability for New Zealand to export products to other countries and the associated requirements related to genetic technology to access these markets.
This considers international requirements on what needs to be disclosed regarding the development or use of products of new genome techniques in trade regulations, certification processes, and other potential limiters of trade.

Social License to Operate

The level of social legitimacy and permission granted by New Zealanders for the continued operation or use of a particular technology or practice by an industry/sector.
Gaining and maintaining social acceptance and trust will be crucial for the long-term viability of new genome techniques and their applications.

Cultural Values and Indigenous Perspectives on Genetic Modification

Presently, Māori exhibit a spectrum of viewpoints on genetic technology and its potential applications, ranging from strong opposition to support. Researchers have made substantial and ongoing contributions to the understanding of Māori values as they relate to genetic technology [8]. Understanding and integrating Māori perspectives into genetic modification discourse is critical for informed decision making and ethical practice in Aotearoa New Zealand.

Recent research [9] has explored the different indigenous perspectives on the use of gene editing. Interviews, literature reviews, and surveys were conducted to inform this analysis which found:

- Perspectives are not uniform and depend heavily on how the genetic technology is applied. The views on the use of genetic technology has the potential to be positive or negative, depending upon values and relationship management.
- There is skepticism about the claimed benefits and risks of the use of genetic technology. Many agreed that there were huge potential benefits to be gained from the use of genetic technology, but emphasised 'who stands to benefit should always be front of mind'. Concerns included potential cultural and environmental impacts as risks from 'unscrupulous human interests'.
- There was strong feedback around 'control'. Who owns and controls the use of the technology? Who owns and controls the genomic knowledge and data?
- There is willingness to engage if issues around benefits and control are addressed.

Maui Hudson et al. (2019) [8] examined Māori perspectives on genetic modification, including its cultural and ethical implications in the context of gene-editing. The publication highlighted the importance of Māori values and cultural concepts, such as whakapapa, mauri, mana, and kaitiakitanga, in shaping Māori perspectives on biotechnology regulation. These concepts were seen as providing a cultural foundation for ethical considerations of gene editing.

***Table 2*, to the right, shows these core values and details how they can be diminished or enhanced depending on how genetic technology is applied and used.**

Table 2: Key Māori cultural concepts and values relevant to biotechnology and genetic research

	Value enhancement	Value diminishment
Whakapapa (genealogy)	If the modification does not involve the transfer of genes between species—whakapapa can be maintained and enhanced through the continued wellbeing of the species.	If the modification introduces foreign DNA or involves changing the genome intergenerationally with negative consequences - whakapapa is diminished.
Mauri (life essence)	If genetic technology is used to support human or environmental health - mauri is enhanced.	If genetic technology is used for inappropriate purposes - mauri is diminished.
Mana (power/authority)	If Māori are able to choose how genetic technology is used or applied - mana is enhanced.	If Māori have no say in discussions about how genetic technology is used or applied - mana is diminished.
Kaitiakitanga (guardianship)	If applications of genetic technology enhance the resilience of ecosystems - kaitiakitanga is enhanced.	If applications of gene editing have unknown effects on the wellbeing of organisms and the ecosystems - kaitiakitanga is diminished.

Potential Socio-Economic Impacts in 2035 (1 of 5)

Socio-economic impacts will differ based on the regulatory approach New Zealand, and the rest of the world, chooses to adopt. The following table provides an informed prediction on what possible impacts may be in 2035, based on professional judgement derived from research and conversations conducted by the secretariat. There is a large degree of uncertainty for how these impacts play out in the future. **This section intends to promote thinking around the trade-offs of different regulatory approaches in a socio-economic context, not to prescribe future impacts.**

<table>
<tr><th></th><th>Table 3a: Socio-economic impacts: trade and market access and competitive advantage</th><th>New Zealand Scenario One (Process-Based)</th><th>New Zealand Scenario Two (Tiered Risk)</th><th>New Zealand Scenario Three (Trait-Based)</th></tr>
<tr><td>Trade and Market Access</td><td>In 2035 it is likely that:
● Countries will still be trading globally similarly to how they do now.
● Large economies will have likely progressed their regulation of new genome techniques to more liberal systems as outlined on page 34.
● Products resulting from new genome technique applications will likely have increased in proportion of the share of global trade.</td><td>Increasingly large trading partners would likely want reciprocal agreements on market access and trade of their own products that have are applications of new genome techniques.
Non-alignment may impact New Zealand through impacts on preferential trading agreements.</td><td colspan="2">If more liberal regulation aligns with key markets, potential trade and access issues may be minimal.
As outlined on page 34, it is unlikely that markets will become more conservative. However, if regulation does not align with desired markets, significant trade and market access challenges could arise, depending on the import regulations of those markets.</td></tr>
<tr><td>Competitive (Dis)Advantage</td><td>In 2035 it is likely that:
● The impacts of climate change will be greater and result in inconsistent yield and quality of production, increasing the cost of production in attempts to manage this.
● Consumers will continue to look for new food products that benefit them.</td><td>As competitors worldwide gain access to new genome techniques, they may adapt their production systems and products to their environments and market demands, potentially gaining a competitive advantage [10].
Major market buyers increasingly demand reduced environmental impacts from producers. Countries with the ability to utilise new genome techniques may have an advantage in meeting environmental production targets.
Competitive advantage through differentiation of non-GMO products is likely to remain feasible.</td><td colspan="2">Having similar access as competitors to new genome techniques and their applications could enable New Zealand to continue to compete on:
● Efficiency of production system.
● Impacts of production system.
● Resilience of production system.
● Innovation of products for consumers.
Competitive advantage through differentiation of non-GMO products is likely to remain feasible. Non-GMO products may cater to a specific market niche, allowing companies to target a segment of consumers who are willing to pay a premium for these products. Regulatory labelling requirements for GMO products may offer the opportunity for companies to verify non-GMO claims.</td></tr>
</table>

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Potential Socio-Economic Impacts in 2035 (2 of 5)

	Table 3b: *Socio-economic impacts: consumer response and retailer and NGO accreditations*	**New Zealand Scenario One (Process-Based)**	**New Zealand Scenario Two (Tiered Risk)**	**New Zealand Scenario Three (Trait-Based)**
Consumer Response	In **2035** it is likely that: • Consumers as a whole are more accepting of applications of new genome techniques. • Products of some new genome techniques need not be labelled in all markets. But it is likely that certain new genome techniques will still require labelling in most markets. • A premium would likely still be maintained for non-GMO and organic products. • A premium will exist for some GMO products.	Unless New Zealand's key export markets require labelling of products created with new genome techniques, it is unlikely consumers would be able to identify (and therefore assign any difference in value) between GM and non-GM products. For products labelled as GM, discounting could be expected, meaning non-GM products would enjoy a relative premium. New Zealand may be able to command market premiums with its predominantly non-GMO products with consumers who value products which are specifically non-GMO [11,12].	Products that are required to be labelled as genetically modified are likely to have lower demand and willingness to pay from some consumers [13]. Consumers may prefer genetically modified products when the benefit of that application is of direct value to them including for environmental benefit [14]. Products that are unlabelled are likely to experience no change in value perception.	Long-term use of GM plants in New Zealand for food production will likely have minimal negative effects on international markets and the New Zealand brand [15]. This could be challenged by an genetic application in New Zealand that has significant negative impact and associated publicity.
Retailer and NGO Accreditations	In **2035** it is likely that: • Large retailers will have higher standards for those in their supply-chains guided by requirements from the financial markets. • Accreditations by non-government organisations (such as for good agricultural practice) will align to retailer demands and be more progressive than regulations in most countries.	New Zealand producers may struggle to reach retailer and NGO standards for the environment and social practice particularly if other global suppliers have competitive advantage with genetic technologies that assist with this. Accreditations for non GM products/supply-chains may be more easily met by New Zealand.	New Zealand producers will have more options for technology that can support their ability to reach retailer and NGO accreditations. Some accreditations (such as organic) may require proof that the product has no genetic technology applications in its supply-chain. This could be a challenge if adventitious presence occurs above accepted tolerance levels between production sites however this has been shown to be manageable in other countries.	

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Potential Socio-Economic Impacts in 2035 (3 of 5)

<table>
<tr><th></th><th>Table 3c: Socio-economic impacts: social licence to operate and community value</th><th>New Zealand Scenario One (Process-Based)</th><th>New Zealand Scenario Two (Tiered Risk)</th><th>New Zealand Scenario Three (Trait-Based)</th></tr>
<tr><td>Social License to Operate</td><td>In 2035 it is likely that:
● For the food and fibre sector, social license in the communities they operate in is built through trust and behaviour over time, as well as the ability to tangibly see impact.
● The food and fibre sector’s social license will likely be driven by the mood of the day. However, as New Zealand urbanises and climate change impacts increase, and food and fibre continue to play a significant role in emissions, social license is likely to erode.</td><td>Without the ability to utilise genetic technology applications, the sector may not experience direct impacts on social acceptance, whether positive or negative.</td><td colspan="2">The initial applications of genetic technology could negatively impact social acceptance if they lack transparent communication and fail to demonstrate tangible community benefits, especially if perceived to have adverse effects.

Conversely, the social acceptance of the food and fibre sector could be positively influenced by early genetic technology applications, such as reducing negative environmental impacts (e.g., reducing GHG emissions). Improved environmental practices, including the use of genetic technology, could enhance the sector's social acceptance.</td></tr>
<tr><td>Community Values (Incl. Cultural Values)</td><td>In 2035 it is likely that:
● New Zealanders’ views (including Māori) remain diverse on genetic technology with Māori tending to continue to have stronger views either way.
● These views have likely become more accepting, on average, over time.

n.b. community values are likely to also reflect a culmination of the other factors</td><td>Those whose values do not align with genetic technology may not experience significant impacts, as applications contrary to their values could remain effectively prohibited under regulation.

Conversely, individuals and groups valuing environmental care, nutrition improvement, or protection of taonga species may find themselves constrained by the lack of tools for value-aligned actions.</td><td colspan="2">It's possible that various groups and individuals within the community may feel challenged by genetic technology applications, perceiving them as conflicting with their values.

Conversely, some groups may appreciate the expanded tool options in the food and fibre sector, which could lead to outcomes aligning with their values, such as enhanced environmental protection, species preservation, or improved nutrition.</td></tr>
</table>

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Potential Socio-Economic Impacts in 2035 (4 of 5)

<table>
<tr><th></th><th>Table 3d: Socio-economic impacts: innovation and equity of access</th><th>New Zealand Scenario One (Process-Based)</th><th>New Zealand Scenario Two (Tiered Risk)</th><th>New Zealand Scenario Three (Trait-Based)</th></tr>
<tr><td>Innovation</td><td>In 2035 it is likely that:
• The world will have advanced significantly in its understanding and use of genetic technology.
• Genetic technology will increase the pace of innovation.</td><td>Continued limited access to develop genetic technology could result in longer term loss in capability/capacity and funding relocation to countries with more liberal biotechnology regulatory frameworks.

Innovation in New Zealand would likely focus on areas other than biotechnology where competitive advantage can be secured.</td><td colspan="2">More liberal regulation will encourage investment in biotechnology innovation capability and capacity in New Zealand. This capacity and capability can likely secure markets in New Zealand and globally as a service. This innovation system will increase the ability for bespoke New Zealand genetic technology applications to be developed to meet New Zealand requirements. It will also support the generation of New Zealand owned intellectual property which will enable the creation of a range of new business models and the potential to export the technology as its own product.

Having access to genetic technology tools will:
• Increase the pace of innovation
• Increase the breadth of innovation possible</td></tr>
<tr><td>Equity of Access</td><td>In 2035 it is likely that:
• Inequities in New Zealand society will still exist.
• Access to develop new technology and intellectual property will require capital, partnerships, and a pipeline of capability which without a supportive system, minorities may struggle with [16].
• Access to use new technology will require a strong economic case and, depending on who holds the intellectual property, fees to access.</td><td>Access to develop new genetic technology will remain highly constrained with high barriers to entry. As this is an effective ban for all, this model results in equal access.</td><td>Moderately liberal regulations may encourage more players to develop genetic technology applications. The system may still provide barriers to entry particularly for higher risk cases which have more involved regulatory requirements which would limit participation by smaller entities/groups.

Ability to access genetic technology will largely depend on the intellectual property associated with new applications.</td><td>More liberal regulations are likely to increase equity of access to develop new technology as the barriers to entry are lower, enabling smaller enterprises to participate.</td></tr>
</table>

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Potential Socio-Economic Impacts in 2035 (5 of 5)

Table 3e: *Socio-economic impacts: equity of impact*		**New Zealand Scenario One (Process-Based)**	**New Zealand Scenario Two (Tiered Risk)** / **New Zealand Scenario Three (Trait-Based)**
Equity of Impact	In **2035** it is likely that: • The food and fibre sector is composed broadly of the existing sectors who have similar challenges to today. • The existing inequities in the sector particularly between Māori and non-Māori remain. • Māori continue to be over-represented in the sheep and beef, and aquaculture/fishing industries and underrepresented in dairy, horticulture, and arable industries. • Māori producers will likely still have fewer resources	Some sectors will likely be more affected by climate change. This will occur in regulatory, market pull, and direct production impacts. By 2035, agriculture will be included in the emissions trading scheme which will financially impact dairy and sheep + beef producers more relative to horticulture, arable, and aquaculture/fishing. The market will likely follow a similar trend, demanding reduced environmental impact from those currently contributing greater impact relatively. Production volatility will increase and affect sectors and regions differently. Industries clustered in regions such as horticulture and arable carry more risk of adverse events affecting the entire industry. Māori producers in particular will likely have fewer resources to manage increased production volatility and meet market demands due to historic barriers faced by Māori in the food and fibre sector.	Having increased access to genetic technology tools and subsequent applications may assist some sectors with the outlined impacts in the 2035 current state regulation scenario that will be disproportionately felt. It is likely that larger sectors globally and in New Zealand will be more able to develop useful applications due their increased cash flow compared with smaller or less profitable sectors. This could mean that industries such as dairy have more genetic technology application options than say sheep. There could, therefore, be inequity of impact between sectors if widespread adoption of favourable technologies to production output, environmental impact, or customer desirability are adopted. However, with increased access, there is likely to also be increased democratisation of the technology - making it cheaper and easier for smaller industries to engage with. While it is impossible to anticipate the equity of all impacts on the sector and the communities around it, given the existing inequities in the sector particularly between Māori and non-Māori, there is potential for exacerbation of inequity which should be considered carefully.

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Plant Case Studies

Case Studies Introduction

Purpose of section

This section outlines three applications of genetic technology in plants that address key issues in the food and fibre sector. These case studies aim to demonstrate the different environmental risks, benefits, and impacts of applications of genetic technology and outline how different regulatory approaches may address these risks.

Approach

Three case studies were selected to represent the range of primary production systems and to showcase the variation in the types of changes that can be made to a genome and the traits that these can produce. This differentiation creates a suite of products with a range of risk profiles enabling a thorough evaluation of regulatory settings, products that lie under nuanced classifications can be considered.

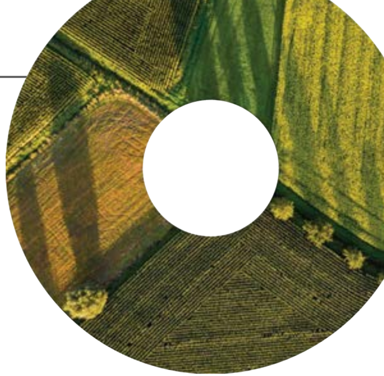
The selected case studies vary in the types of benefits they provide to the environment, the novelty of trait, the specific changes made to the organism's genome and the proximity of the application to being available for implementation, with some being currently developed in containment or field tested abroad.

To analyse these case studies, a systematic approach was employed to assess the qualitative and quantitative impacts. This is outlined in more detail below.

Methodology

To surface the environmental considerations for the three case studies, a high-level environmental impact screening and evaluation was completed. This is a high-level early-stage assessment of the potential positive and negative environmental impacts from each of the case study technologies. The assessment process involved the following activities:

- Identifying and reviewing pre-existing research in a detailed literature review.
- Conducting an initial screening to identify environmental impacts and interactions with the receiving environment.
- Modelling the potential impacts and benefits and how these might develop at scale for each case study application.
- Evaluating the impact type (positive, neutral, or negative) of each case study on a set of core environmental metrics.
- Describing the impacts using a combination of research and model outputs.
- Analysing the broader socio-economic risks associated with each application.
- Engaging in stakeholder interviews to ensure accuracy and inform the analysis.



Environmental Impact Screening and Evaluation Methodology

Under each case study, this report evaluates the possible environmental impacts of the application of genetic technology. The high-level evaluation considers the impacts to the following aspects of the receiving environment. Note, this is not a detailed 'Environmental Impact Assessment'. This analysis assumes that any regulatory system will require a thorough, case-specific, Environmental Impact Assessment similar to other activities regulated by the EPA.

Climate and Air Quality

Evaluating impacts on air quality, greenhouse gas emissions and carbon sequestration.

Biodiversity

Evaluating impacts on pest or predator control, and impacts on native plants and animals.

Land

Evaluating impacts on erosion, soil health and land use.

Animal welfare

Evaluating impacts on quality of life for animals, this includes natural life expectancy of an animal, as well as its state of comfort.

Resilience

Evaluating impacts on the resilience of the sector. This includes assessing change in the ability of the sector to withstand increased frequency of adverse weather events and disease.

Resource Use Efficiency

Evaluating impacts on the efficiency of production. Greater efficiency indicates less intensive resource use for a given level of production.

Water

Evaluating impacts on water quality. This includes nutrient loading and other pollutants.

Key

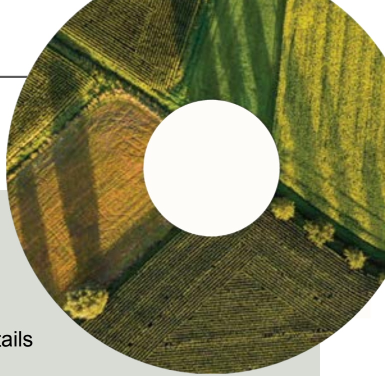
▲ Positive impact on aspect of receiving environment, relative to baseline

≈ Negligible change on aspect of receiving environment, relative to baseline

▼ Negative impact on aspect of receiving environment, relative to baseline

✖ Application of technology does not interact with aspect of receiving environment

● Limited evidence to support impact of application of technology



How to Read this Section

This section presents three plant case studies, including modelling and analysis of impacts and risks.

Rapid Flowering Apple Trees | Horticulture

Genetically modified apple tree with a reduced breeding cycle which can be used to achieve high-value traits on accelerated timeframes.

Page 50 - 64

High CT White Clover | Dairy

Genetically modified clover species which produces high condensed tannins in leaf tissue which may have impacts of increased productivity, lower emissions and increased animal welfare.

Page 65 - 74

Sterile Douglas-fir | Forestry

Genetically modified Douglas-fir trees which are sterile and can enable extension of plantation forestry without the risk of further contributing to New Zealand's wilding conifer problem.

Page 75 - 93

Structure of the case studies

Introduction

Introduction to the case study application, the challenge the application addresses and details around the techniques used to achieve the modification.

Modelled impacts

This part of the section details the modelled benefits of each application of genetic technology in their respective production systems. This sets out the outline of the modelling approach, the model narrative, any key assumptions and the key outputs from the model.

Environmental impacts

Describes the environmental impact of each application. This follows the methodology outlined on page 47. This report does not provide a detailed environmental impact assessment and only intends to surface environmental considerations. It is assumed specific and detailed impact assessments will be required for progressing through regulatory approvals.

Regulatory classification

Outlines how each case study would be classified under the three regulatory scenarios and rationale for this classification.

Road to implementation

Outlines the additional events that would need to occur before implementation of each application of genetic technology.

Considerations for decision-makers

A summary of considerations for decision-makers, including broader socio-economic factors and exploring alternative applications that employ analogous reasoning to those outlined in the case study.

Modelling Limitations

Modelling has been employed to support the analysis of each case study. Each model has its own appendix which contains the overarching logic of the model and lists all inputs and assumptions used in its construction. There are overarching limitations in the modelling approach that apply to all models and are important for the reader to note when interpreting the outputs. These are as follows:

- **The evidence base is limited in some areas.** We have used published research and literature where it is available. However, where there are gaps for data and inputs, we have engaged with stakeholders to get an informed estimate. We have attempted to engage with a broad range of stakeholders to avoid bias, however, inevitably there will be some bias in the inputs. We have used ranges in places where there are uncertainties in the inputs. Sources are detailed within the appendix.
- **The model has only captured the known or suspected environmental impacts.** The models have focused on capturing only environmental impacts, not economic or social impacts, these are discussed later in the section. Additionally, the estimates for the environmental impacts are limited to the current understanding of the application. None of the applications have been tested in a New Zealand environment, which means the assumptions can only be based on the best possible proxies. All of the assumptions have been taken from published literature or production system experts. Where there is no evidence to suggest otherwise, the model assumes that all else is equal outside of the known or suspected environmental impacts of the technology.
- **The model has only captured general impacts.** Specific impacts will vary in significance based on the scale of the activity and the sensitivity of the receiving environment. It is assumed that any regulatory system will require a thorough, case-specific, Environmental Impact Assessment similar to other activities regulated by the EPA.
- **Farm, orchard and plantation systems are complex.** The models have not attempted to capture the interactions within and between biotic and abiotic factors. The models are conservative in many assumptions however there is a risk that the multifaceted nature of the open environment may result in the model misrepresenting the impact of the technology in practice.
- **Societal perceptions on genetic modification have not been modelled.** In reality, there will be societal pressures at play, this is a complex issue and reliant on multiple factors, some of which are discussed later in this report. For the purpose of modelling possible environmental impacts, the models all assume that once allowed, uptake would be driven by individual incentives and not perceptions on genetic engineering.
- **It is assumed that the use of genetically modified products within a production system will not distort the market.** The model assumes that through using genetically modified products in a production system, or if the product is modified itself, that the market will maintain the same level of demand. This economic analysis has been determined as out of scope for the modelling. Additional factors involved in this topic are discussed in the macro section of the report.

Case Study 1:
Rapid Flowering Apple Trees

Genetic Technology Description

This case study examines Rapid Flowering Apple Trees and their null-segregant* offspring.

Rapid Flowering Apple Trees are created utilising a small targeted insertion of DNA from the same species which disrupts an apple gene that represses flowering [17].

*During the breeding process, not all offspring in a generation will inherit the edited DNA. Offspring that do not inherit the DNA are known as null-segregants for the gene of interest (see diagram on page 52). These null-segregant trees and their fruit do not have the original genetic modification anywhere in their genome and the trees will have a standard juvenile period. Null-segregants can be confirmed before having to wait to observe a tree's flowering patterns through genotyping of the tree or fruit.

Case Study 1: Rapid Flowering Apple Trees
Introduction

The apple and pear industry is expected to face challenges as climate change continues to make weather more extreme and unpredictable. Orchardists will face the challenge of altered growing conditions, severe weather events, increased pest and disease pressure, and impacts to pollinator species [18]. It will be important for the pipfruit industry, and the horticulture sector more generally, to be able to breed different varieties of plants to be able to combat these challenges.

Currently, apple trees must reach maturity before being able to reproduce. This period of juvenility is around 5 years [19].

Production of new traits requires multiple generations (or breeding cycles) through selective breeding. Roughly, it can be assumed that this will take at least seven breeding cycles.

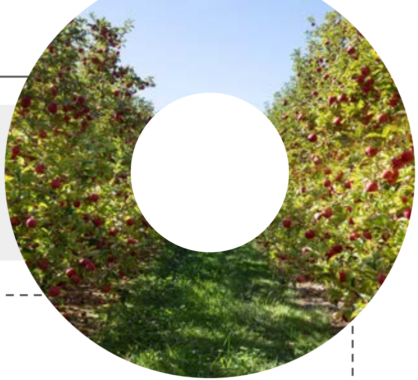
This means that it can take decades of lag time to produce a desired trait to market [20].

Current New Zealand breeding programmes factor this into their strategic development of new apple cultivars, however, the sector is limited in its ability to be dynamic to changing customer preferences or growing conditions.

Case Study Application

Rapid Flowering (RF) Apple Trees have a significantly shorter breeding cycle than a wild-type apple tree and therefore the time required to breed a high-value trait is also shorter. In this specific case study, the report looks at the use of RF apple trees to breed the high-value trait of black spot resistance (BSR) and the relative impact of adopting the BSR trait on a significantly closer time horizon than if the trait had been achieved with conventional breeding.

The case study explores two release pathways, one which releases a null-segregant with BSR trait, the other releases the RF trees to breeding centres. These release pathways are outlined in greater detail on subsequent pages in this section. The release pathway taken does not impact the modelled outcomes of this application of genetic technology, as the time to achieve the BSR trait is similar under both pathways. However, the release pathway does have implications for regulatory approach and the potential environmental impacts. These differences will be explored throughout this section.



What are Null-Segregants?

These organisms are descendants of genetically modified organisms, but do not have the genetic modification themselves.

Just as a brown eyed parent may have a blue-eyed child who did not inherit the gene for brown eyes, plants, animals or other organisms that are descended from genetically modified organisms may by chance not inherit the modified gene.

The diagram on this page details the process of using rapid flowering apple trees to attain a null-segregant with a high-value trait (in this case black spot resistance). This process could be repeated to accelerate the process of breeding other high-value traits, but, as stated previously, this case study will look specifically at black spot resistance.

Case Study 1: Rapid Flowering Apple Trees
Process of Developing Null-Segregants

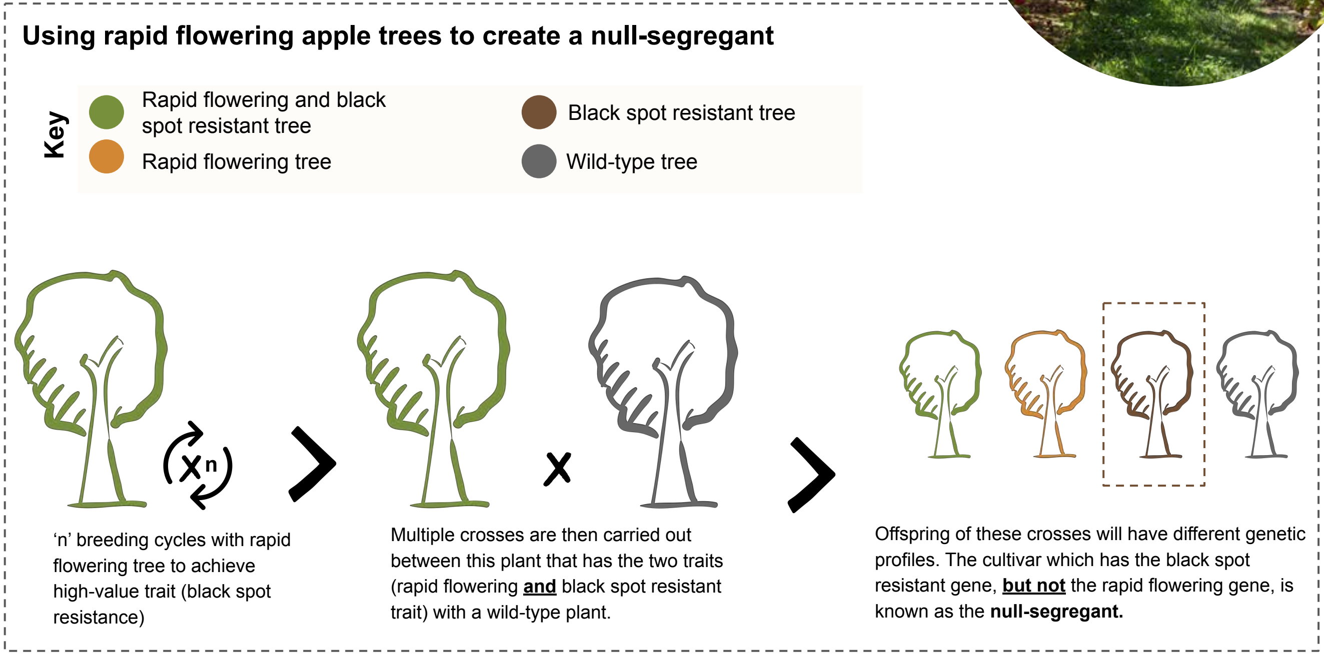


Figure 10: *Using rapid flowering apple trees to create a null-segregant*

Case Study 1: Rapid Flowering Apple Trees **Modelled Impact**

Modelling Approach

The model considers a single orchard, representative of an average non-organic apple orchard in New Zealand. From time n, the model explores two scenarios: in the first, where the black spot resistant trait has been bred using rapid flowering apple trees and is available for the model orchard to introduce immediately. The second uses conventional breeding to obtain the trait, meaning the process is longer than the first scenario. The precise length is determined by the difference in time required to breed the trait through both methods, calculated using the same number of breeding cycles but different breeding cycle lengths.

Adoption curves are then estimated for how this technology will diffuse among New Zealand orchardists, which when overlaid with the per-farm impact provides an estimate for the national impacts.

The core benefit for the use of rapid flowering apple trees is the accelerated timeline in achieving new, valuable traits. The aim of this model is to quantify the impact of an orchard being able to adopt trees with a new, highly valuable trait (BSR) on an accelerated timeline achieved using rapid flowering technology.

The model looks at a representative single apple orchard, its adoption of trees with the BSR trait, and how, as the orchard's collective resistance to black spot increases, the total apple yield and fungicide use changes.

Analysis is completed for three different breeding scenarios:

- The *low breeding scenario* reflects an increased time period to produce the trait and slower replacement from apple orchards.
- The *high breeding scenario* reflects a decreased time period to produce the trait and faster replacement from apple orchards.
- The *base breeding scenario* takes the midpoint of the range used in the high and low scenarios.

The outputs of this model are intended to support the analysis around the environmental impact of this application of technology. Alongside farm level impacts, the model also provides estimates for how these impacts may realistically scale if the application of genetic technology is adopted nationally. These values are outlined within the environmental impact analysis of this application of technology.

As outlined in the beginning of this section, there are two release pathways within this case study. Both eventuate in null-segregant cultivars with the BSR trait being released to orchards, but **Pathway A** involves rapid flowering apple trees remaining in containment, while **Pathway B** involves the rapid flowering apple trees being released to apple breeding centres. There is no difference between these two pathways in the model and model outputs, however, the possible environmental impacts, risks and benefits will differ. Analysis is segmented by pathway accordingly.

For a complete breakdown of the model assumptions, logic and inputs see Appendix A.

Case Study 1: Rapid Flowering Apple Trees
Modelled Impact

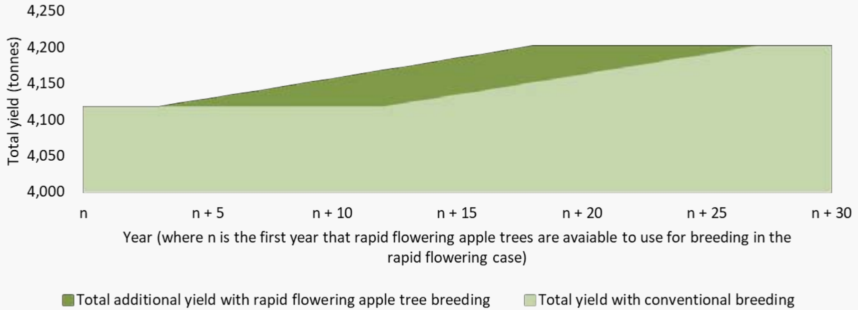
Total Yield

Rapid flowering apple trees enable black spot resistant trees to be available to orchards earlier. As a result, there is a period of time where one orchard is losing less apples to black spot and therefore has a higher overall yield assuming the same time and effort. The model estimates that this could result in a single orchard producing up to an additional 50 tonnes of apples per year when compared to an orchard that breeds the black spot resistant trait, without rapid flowering trees. On a national level, this equates to 7,000 tonnes of apples.

Figure 11 shows the per orchard impact, comparing the timelines of when a black spot resistant tree is available for the orchard through rapid flowering and conventional breeding. The gradual increase in yield is driven by the gradual replacement of apple trees to include the black spot resistant trait. In total, the net gain in apple yield through getting the trait earlier because of rapid flowering apple trees is 760 tonnes of apples. At a national level, this accounts to 105,000 tonnes of apples over time.

It should be noted that managing black spot is important for market access. This means that an orchard many only get a 1% yield increase in annual yield from the black spot trait, but there is likely to be a much greater increase in exportable yield for some high paying export markets.

Figure 11: *The total yield of apples (in tonnes) on a single orchard that chooses to adopt black spot resistant trees, illustrating the delay between when these trees will be available through rapid flower breeding and conventional breeding.*



Due to the impacts on access to export markets, controlling black spot is critical to orchard operations. Controlling black spot requires staff to be

on call 7 days per week, 12 hours per day

as spray windows for control are very tight [21].

For details on sources and evidence, see Appendix A.

Case Study 1: Rapid Flowering Apple Trees
Modelled Impact

Fungicide Use

Due to the significant impacts black spot can have on the final saleable yields, orchard owners invest in fungicide to prevent its damage. The amount of chemicals used by farmers is proportionate to the risk of disease. The modelling estimates that by using rapidly flowering trees to accelerate the timeline for producing a black spot resistant trait, orchard owners are able to adjust their fungicide use sooner.

At peak adoption of the black spot resistant trait obtained from rapid flowering trees, this could result in a single orchard requiring **25 fewer black spot prevention sprays per annum** when compared to an orchard that chooses to plant apple varieties that have bred the black spot trait conventionally.

See *Figure 12* for the modelled annual reduction in fungicide sprays in an apple orchard in the base case scenario. Note, currently, orchards use about 30 sprays per year and the extent of the reduction as a result of black spot resistant trees is uncertain. Some sensitivity analysis on this is conducted in Appendix A.

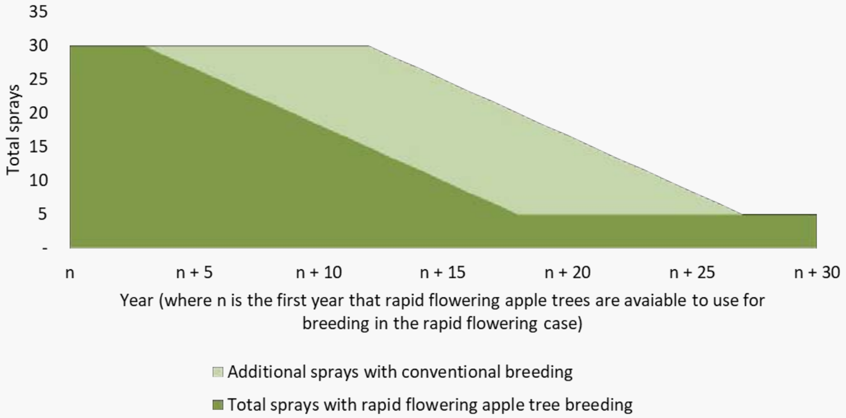


Figure 12: *The annual reduction in number of sprays on a single apple orchard comparing the case where a black spot resistant trait is achieved through breeding with rapid flowering apple trees to conventional breeding. This graph shows the base case reduction in fungicide sprays. For outputs from the low and high case reduction in fungicide sprays, see Appendix A.*

This modelled scenario indicates a farm that acquires the black spot resistant trait through rapid flowering may use a total of

225 fewer fungicide sprays

than a farm that acquires the trait through conventional breeding methods.

For details on sources and evidence, see Appendix A.

Case Study 1: Rapid Flowering Apple Trees
Release Pathways

For this case study, this report will examine two separate release pathways.

These pathways have different regulatory and environmental implications, which will be explored throughout the section. However, it is important to note that both pathways ultimately result in the cultivation of apple orchards that exclusively grow null-segregants. Similarly, consumers will only have access to null-segregants for consumption.

Release Pathway A

This pathway is defined by the black spot resistance being bred in complete containment, with only the null-segregant being released to open environment (apple orchard).

Release Pathway B

This pathway is defined by the release of the modified rapid flowering apple tree to breeding centres. The high-value trait (black spot resistance) is bred in these breeding centres (not in complete containment) but apple orchards are still only provided with null-segregant seed and only grow the null-segregant.

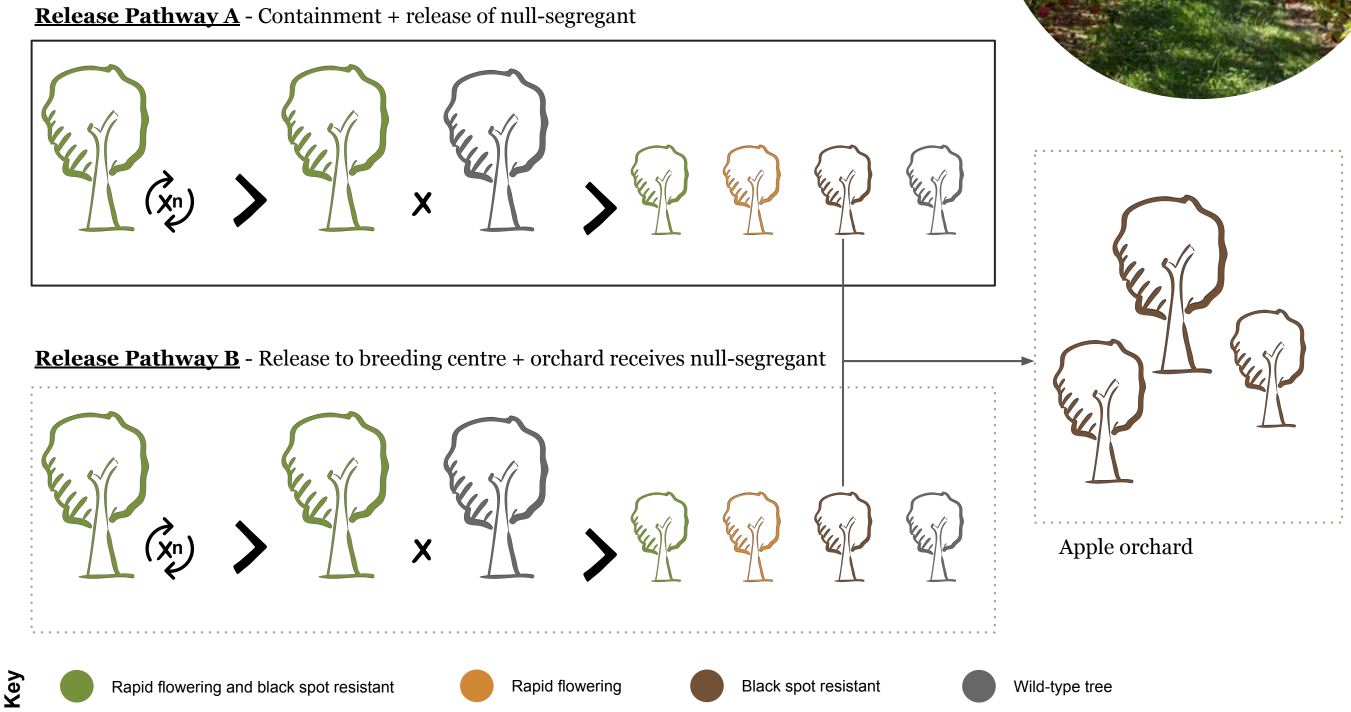


Figure 13: *Release pathways of rapid flowering apple trees*

Environmental Impacts Release Pathway A

Containability

In this release pathway, the rapid flowering apple trees are kept in containment and the cultivar, which has the black spot resistance and no fast flowering trait (making it the null-segregant) is released. As no genetically modified DNA leaves containment, there is minimal risk of the genetically modified genes spreading throughout the environment without human intervention.

Reversibility

As there is no risk to containment of the modified genetic material, reversibility is assumed to be straight forward.

Climate and Air Quality

Using RF to achieve the BSR trait is proposed to have a positive impact on the climate.

Nationally, using RF to achieve the BSR trait is modelled to result in 30,000 (15,000 - 80,000) fewer fungicide sprays over the time period before the black spot trait can be acquired through conventional breeding under the base breeding scenario.

modelling estimates 30,000 fewer fungicide sprays nationally

Fungicides can release volatile organic compounds (VOCs) into the air during application, which can contribute to air pollution. These VOCs can react with other pollutants and sunlight to form ground-level ozone, a harmful air pollutant that can negatively impact human health and vegetation.

Biodiversity

Using RF to achieve BSR trait is proposed to have a positive impact on biodiversity.

The significant decline in fungicide spraying associated with the accelerated adoption of the black spot resistant trait will likely have a positive benefit for biodiversity on land and in water.

Fungicides can have unintended impacts on non-target organisms, including beneficial insects, birds and other wildlife. Studies [22,23] have shown that exposure to fungicides is linked with increased infection and poor nutrition in pollinators, such as bees and butterflies, which are crucial for maintaining biodiversity and supporting crop production.

Animal Welfare

Using RF to achieve BSR trait is proposed to have a positive impact on animal welfare.

As above, the significant decline in fungicide spraying will likely have a positive benefit for insects, birds and other wildlife. The reduction in use of agri-chemicals decreases the risk of off-target effects.

Environmental Impacts Release Pathway A

Traceability

From a scientific perspective, there is no difference between null-segregant BSR apples achieved with RF and BSR apples achieved with conventional breeding. Therefore, if an apple is a null-segregant, it becomes indistinguishable from one selectively bred from wild-type parents to exhibit the same trait. To assure traceability, a strict reporting process would be required.

Water

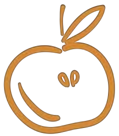
Using RF to achieve the BSR trait is proposed to have a positive impact on water quality.
The modelled significant decline in fungicide spraying associated with the accelerated adoption of the BSR trait would likely have a positive benefit on water quality. Fungicides can be carried off-site through runoff or leaching, contaminating nearby water bodies. This can lead to water pollution, affecting aquatic ecosystems and potentially harming fish, amphibians, and other aquatic organisms. Some fungicides may also persist in water bodies, posing long-term risks to water quality. Fungicide residues, which make their way into surface and ground waters, have the potential to cause adverse effects to the structure and functioning of aquatic ecosystems [24,25].

Resilience

Using RF to achieve the BSR trait is proposed to have a positive impact on sector resilience.
A Ministry for Primary Industries paper on climate change impacts on diseases impacting New Zealand Horticulture [26], found that the greater the predicted increase in temperature, the greater was the increase in black spot risk within a given region. A black spot resistant trait will help build sector resilience to greater disease incursion associated with a changing climate.

Resource Use Efficiency

Using RF to achieve the BSR trait is proposed to have a negligible impact on resource use efficiency.
Nationally, modelling suggests that at peak adoption of the black spot resistant trait obtained through from rapid flowering trees, there would be a peak national increase in yield of approximately 7,000 tonnes apples per annum relative to a counterfactual of no black spot resistant trait.



Land

Using RF to achieve BSR trait is proposed to have a positive impact on soil health.
The significant decline in fungicide spraying associated with the accelerated adoption of the BSR trait will likely have a positive benefit on soil health. Frequent and excessive use of fungicides can disrupt the natural balance of microorganisms in the soil, including beneficial bacteria and fungi. This can lead to a decrease in soil fertility, nutrient cycling and overall soil health. The presence and persistence of fungicides in agricultural soils can cause adverse effects to soil organisms, such as earthworms and microorganisms, and the crucial functions these organisms are responsible for [27].

Case Study 1: Rapid Flowering Apple Trees
Regulatory Classification - Release Pathway A

Regulatory Scenario 1: Process-Based

In Feb 2024, the New Zealand EPA ruled that organisms known as null-segregants are not considered genetically modified organisms and are therefore not subject to the Hazardous Substances and New Organisms Act 1996 [28]. While other regulations and standards may still apply to the introduction of a new variety of apples, this implies that null-segregants with high-value traits (e.g. BSR) can be introduced into the environment in a manner similar to any traditionally bred variety.

Null-segregant exempt from GM regulation

Regulatory Scenario 2: Tiered Risk Based

The null-segregant has no trace of the genetic modified gene in its genome. This classifies it as Risk Tier 0 - exempt from regulation under the hypothetical tiered risk classification framework outlined in this report. While other regulations and standards may still apply to the introduction of a new variety of apples, this implies that null-segregants bearing high-value traits (e.g. BSR) can be introduced into the environment in a manner similar to any traditionally bred variety.

Null-segregant exempt from GM regulation

Regulatory Scenario 3: Trait-Based

Black spot resistance may be considered to be a novel trait for apple varieties. Under this regulatory scenario, the null-segregant would be captured by the GM regulation and require further assessment prior to release.

Null-segregant subject to further assessment and approval prior to release

Under Regulatory Scenario 1 and 2, the null-segregant has been classified as exempt from GM regulation and there will be no requirement for an environmental impact or risk assessment before release into the environment. Noting that other regulations and standards may still apply. Under Regulatory Scenario 3, black spot resistance may be considered to be a novel trait, so may be subject to further assessment and approval before release.

Environmental Impacts Release Pathway B

Containability

In this scenario, the rapid flowering apple trees are released from containment to breeding centres around the country. Orchards still receive null-segregant cultivars. As the genetically modified apple tree is released into the open environment, there is risk of spread throughout the environment. The risk of uncontrolled spread could be mitigated by breeding centres implementing isolation measures, such as physical barriers or buffer zones.

Reversibility

Apple trees are not a weedy species. Removing RF trees from nurseries would be a relatively simple process.

Note: This section looks at the environmental impact of the release of the rapid flowering trait, not of any high-value trait (i.e. black spot resistance). The environmental impact of using rapid flowering to obtain black spot resistance can be found on the previous pages 56-58.

Climate and Air Quality

The release of RF apple trees is proposed to have a negligible effect on the climate.

Release of RF apple trees will likely not impact carbon sequestration, carbon dioxide emissions or air quality.

Biodiversity

It is unclear what the impact of RF apples trees would have on biodiversity.

RF trees will have altered flowering patterns, potentially impacting the availability of nectar and pollen resources for pollinators, however it is unclear whether this impact will be negative or positive. Additionally, noting that RF apple trees will only be bred in nurseries, it is unlikely that any impact will be significant to pollinators.

As it is unclear what the extent of the impact of this would be, this would be an area of further research for Release Pathway B.

Resilience

The release of RF apple trees is proposed to have a positive impact on sector resilience.

Under ‘Release Pathway A’, the rapid flowering technology remains in containment and in the hands of scientists. The release of RF apple trees to breeding centres under ‘Release Pathway B’ enables the technology to be used directly by plant breeders. It is likely that the release of RF apple trees would foster faster innovation and enable the sector to address and adapt to environmental or market stressors at scale. This will improve the resilience of the sector, as it will be able to rapidly adapt to challenges on multiple fronts.

Environmental Impacts Release Pathway B

Traceability

The rapid flowering trait can be readily identified both genomically and through observation of the tree. However, identifying whether an apple originates from a rapid flowering tree would necessitate genomic testing to ascertain the presence of the modification. Breeding centres employing this technology may still need to implement regular monitoring programmes, involving genetic testing or phenotypic analysis, to detect and track the rapid flowering trait in apple trees. It would also be crucial to establish a process to prevent apples from these trees being removed from breeding centres.

Resource Use Efficiency

The release of RF apple trees is proposed to have a negligible effect on resource use efficiency. RF trees are unlikely to directly impact production or resource use efficiency, however, the high-value traits that result from the use of the RF trait will likely positively impact this factor.

Land

The release of RF apple trees is proposed to have a negligible effect on soil health. RF trees are unlikely to directly impact on land or soil health, however, the high-value traits that result from the use of the RF trait will likely positively impact this factor.

Animal Welfare

This factor is not directly applicable to this case.

Water

The release of RF apple trees is proposed to have negligible impact on water quality. RF trees are unlikely to directly impact fungicide residue and therefore water quality.

Case Study 1: Rapid Flowering Apple Trees
Regulatory Classification - Release Pathway B

Regulatory Scenario 1: Process-Based

As rapid flowering apple trees are created using genetic technology, they are classified as genetically modified organisms and are prohibited from being field tested or released prior to regulatory approval. This regulatory approval process is extensive and has a large burden of proof.

Rapid flowering tree subject to further assessment and approval prior to release

Regulatory Scenario 2: Tiered Risk Based

The genetic technique used to create the rapid flowering trait results in new DNA in the apple tree genome. This DNA is from the same species and is a targeted insertion. This results in a risk classification of Tier 2 - expedited assessment and approval.

Rapid flowering tree subject to further assessment and approval prior to release

Regulatory Scenario 3: Trait-Based

Rapid flowering would be classified as a novel trait. Under this regulatory scenario, the null-segregant would be captured by the GM regulation and require further assessment and approval prior to release.

Rapid flowering tree subject to further assessment and approval prior to release

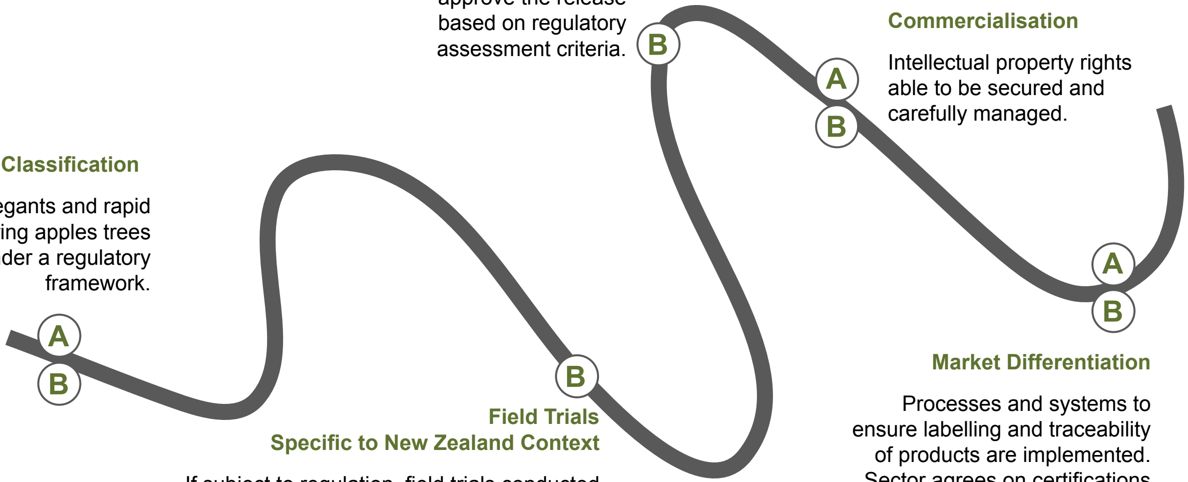
Under all Regulatory Scenarios, ‘Release Pathway B’ is captured by the regulation and would require further approvals. Regulatory scenario 1 assigns the highest burden of proof for the approval process, whereas it is hypothesised that Regulatory Scenario 2 and 3 would require an expedited and more streamlined approvals process. All three scenarios require assessment of the possible environmental impacts and risks.

Case Study 1: Rapid Flowering Apple Trees
Road to Implementation

Scientists in New Zealand have already created a Rapid Flowering Apple Tree in a secure lab setting [29]. **This page outlines the additional events that would need to occur before implementation of this application of genetic technology.**

This roadmap to implementation differs between Release Pathway A and Release Pathway B. Relevant steps to implementation are highlighted for each release pathway with *A* or *B*.

Note that time to implementation will differ by regulatory scenario and by release pathway. For instance, regulatory scenarios which exempt or allocate lower risk to the null-segregant/RF apple tree will result in a shorter time to implementation.



Regulatory Classification

Null-segregants and rapid flowering apples trees classified under a regulatory framework.

Field Trials Specific to New Zealand Context

If subject to regulation, field trials conducted to demonstrate if the benefits exist in a New Zealand context and understand the specific risks. In particular, exploring if there are any unintended consequences and that it can achieve its desired impact.

Regulatory Assessment

Regulatory authority approve the release based on regulatory assessment criteria.

Commercialisation

Intellectual property rights able to be secured and carefully managed.

Market Differentiation

Processes and systems to ensure labelling and traceability of products are implemented. Sector agrees on certifications and standards.

Figure 14: *Rapid flowering apple trees road to implementation*

Case Study 1: Rapid Flowering Apple Trees
Considerations for Decision-Makers

Application Effectiveness

Releasing the rapid flowering technology to nurseries comes with higher risks, but increased potential for innovation. Limiting use of rapid flowering technology to containment presents fewer environmental risks, but may limit innovation and equitable access to high-value traits. If rapid flowering technology is only accessible to a select few or restricted to specific applications, it may hinder the potential for widespread adoption and utilisation of beneficial traits.

Other Potential Applications

Conceptually, this application could be applied to other fruiting plants to more rapidly create high-value varieties across the horticulture sector. For plants, such as trees and vines, that have a long juvenile phase before fruiting, exploration of a similar pathway could have significant benefits to reduce breeding cycle times. Industries where this could be beneficial to explore faster breeding and development of variants include, but are not limited to, winegrowing, olives, kiwifruit, berries and summer fruit.

Key Socio-Economic Impacts

Consumer Response: There is anecdotal evidence that some consumers would discount fresh apples produced using genetic technology [30]. This would only be relevant in markets where the apple is labelled as GMO or produced using genetic technology.

Competitive Advantage: New Zealand is currently a market leader in the apple industry, partly due to the success of its breeding programme, which produces new varieties. This technology would extend New Zealand's competitive advantage through enabling a more productive and responsive industry.

Social License to Operate: The rapid flowering tree can be used to attain high-value traits, which limit environmental impact of production. The case of black spot resistance explored how this could reduce fungicide and pesticide use, something that would likely be favourable to communities.

Community Values: Hastings, which holds a significant proportion of the apple production in New Zealand, has a strong anti-genetic modification position. However, the Central Hawke's Bay District Council has recently reviewed their district plan, and stated that GMO are to be controlled by the EPA.

Case Study 2:
High Condensed Tannin White Clover

Genetic Technology Description

This case study examines High Condensed Tannin (Hi-CT) White Clover which is a genetically modified commercial White Clover which produces condensed tannins in its leaves.

A gene from a closely related clover species is inserted.
This inserted sequence acts as a 'master switch' that can essentially switch on a condensed tannin pathway which is already present in the white clover genome.
This switching on allows for biologically significant levels of condensed tannin expression in leaf tissue. The insertion of this transgene is non-targeted, meaning the exact location of changes in the genome needs to be confirmed after the change is made [31,32].

Case Study 2: Hi-CT White Clover
Introduction

Dairy farming is New Zealand's largest export earner and a significant contributor to the economy. However, it is also one of New Zealand's leading contributors to global climate change through enteric methane and nitrous oxide emissions [33].

New Zealand has an ideal climate for pasture-based farming systems, making it efficient and competitive to farm ruminant livestock on pasture. New Zealand has grown its dairy sector and improved its production efficiency through innovation and pasture-based farming. However, a different set of tools are required to address the environmental challenges that are now facing the sector.

Dairy production and emissions intensity of production are driven primarily by levers, such as dry matter intake and the nutritional value of feed, which correspond to quality and composition of a farms' pasture.

Overseas, methane inhibitors are being developed, which, when constantly fed to livestock, can significantly reduce methane emissions.

These are well suited to intensive barn-systems, but do not work well in pasture-based systems due to their extensive nature. New Zealand farmers currently have limited tools available to influence the quantity of emissions associated with production.

Case Study Application

Traditional breeding methods have shown limited success in achieving desired traits in pasture plants [34]. Pasture plays a critical role in New Zealand pastoral farming sectors and gains in the quality of pasture can address environmental and productivity challenges effectively.

Hi-CT White Clover is a pasture forage which may improve the nutritional quality of a pasture. Implementing Hi-CT White Clover within a pasture sward, in replacement of standard White Clover, has the potential to produce a range of benefits on a dairy farm. These include increasing production, reducing methane and nitrous oxide emissions, reducing nitrogen leaching and reducing the incidence of bloating in cows.

Modelling Approach

The aim of the model is to quantify the expected impact of the adoption of Hi-CT White Clover. The outputs consider a model farm, assumed to represent the average farm, in each of the five dairy farm systems (table 4).

The transition away from conventional white clover to Hi-CT White Clover is modelled on individual farms. This is assumed to occur as farmers naturally resow their pasture.

The impacts of the Hi-CT White Clover are scaled by the proportion of the cow's diet that is home-grown and the percentage of pasture area that is planted with at least 25% Hi-CT White Clover.

Adoption curves are then estimated for how this technology will diffuse among New Zealand dairy farmers, which, when overlaid with the per-farm impact, provides an estimate for the national impacts.

Case Study 2: Hi-CT White Clover **Modelled Impacts**

Trials of Hi-CT White Clover have been completed in containment in New Zealand suggesting a suite of environmental outcomes are potentially achievable. Three years of field trials have been completed in the United States, which showed the levels of condensed tannins expressed in field conditions were consistent with what was seen in the plants grown in containment in New Zealand [35]. Permission has now been granted for further field trials in Victoria, Australia. The supporting evidence from lab and overseas field trials is promising, although it has not been tested in a New Zealand dairy farming context. It is possible that cows consuming Hi-CT White Clover will experience lower methane emissions, higher milk production, lower urinary nitrogen and are less likely to suffer from bloat.

All of these outcomes are quantified within the model in an attempt to illustrate the potential scale of these benefits on a farm level. Alongside farm level impacts, the model also provides estimates for how these impacts may realistically scale if the genetic technology is adopted nationally. The outputs of modelling the adoption of Hi-CT White Clover on a single farm depends on the farm system employed (see *Table 4).* This is driven by the different average size of the dairy farms and the varying proportion of the cow's diet that is home-grown and therefore how much Hi-CT White Clover they consume.

Note, this model assumes Hi-CT White Clover comprises at least 25% of the pasture sward, as the impacts detailed in the literature are consistent with this concentration. In farm systems, white clover's contribution to total pasture yield has been estimated at around 20% [36]. Further research is required to quantify the impact of Hi-CT White Clover at different pasture concentrations. This limitation should be considered when evaluating the modelled outputs in this report. For a complete breakdown of the model assumptions, logic, and inputs, see Appendix B.

Table 4: *The descriptions and representations of the different farm systems in New Zealand's dairy production.*

Farm System	Description	% farms
System 1	All grass system, 100% home-grown feed with all adult stock on the dairy platform year round	14%
System 2	90-99% of total feed is home-grown. 1-10% of feed imported (i.e. supplement or winter grazing)	14%
System 3	80-89% of total feed is home-grown. 11-20% of total feed imported to extend lactation (e.g. autumn) and for wintering dry cows	48%
System 4	70-79% of total feed is home-grown feed. 21-30% of feed imported and used at both ends of lactation and for wintering dry cows	13%
System 5	50-69% of total feed is home-grown. >31% of feed imported and used throughout lactation	13%

Case Study 2: Hi-CT White Clover **Modelled Impacts**

Productivity

The literature claims a milk production increase of up to 10% is possible in cow milk production, based on a diet of 100% pasture, with at least 25% Hi-CT White Clover. Other field trials have shown a 10 - 32% increase in milk production levels in sheep and goat dairy production. Figure 15 below shows how this translates into the different farm systems after fully integrating this forage into their pasture systems. Considering the range of potential milk production increase (8 - 10% increase), the absolute change in production levels ranges from 6,000 KgMS to 20,000 KgMS depending on the farm system.

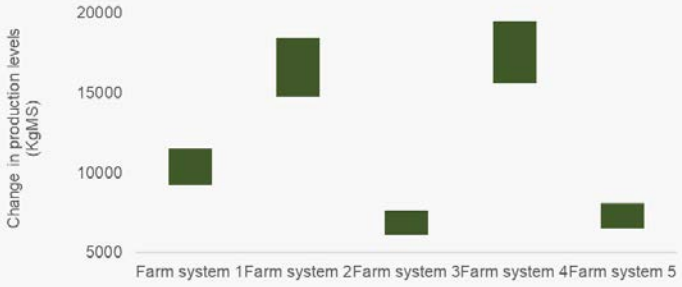


Figure 15: *Range in potential increases in production level by farm system through the full integration of Hi-CT White Clover into the farm system.*

6k - 20k KgMS

potential increase in milk production p/a per farm

Urinary Nitrogen

Increased condensed tannins have been shown to reduce urinary nitrogen. Once fully integrated into farm systems, the modelling estimates that farms could expect to reduce their total urinary nitrogen by 2 - 18 tonnes per annum. This is based on a 10 - 50% decrease if a cow consumes 100% pasture with at least 25% Hi-CT White Clover.

This will have downstream implications for nitrous oxide emissions and nitrogen leaching. However, it is hard to quantify what the reduction in both byproducts will be due to the systems complexities associated. Some research shows that 2% of urinary nitrogen is converted to nitrous oxide, implying that Hi-CT White Clover could reduce nitrous oxide emissions by 40 - 360 kg nitrous oxide per annum per farm - equivalent to 12 - 110 tCO_2e of nitrous oxide reduced per annum per farm [37].

12 - 110 tCO_2e

potential decrease in nitrous oxide emissions p/a per farm

For details on sources and evidence, see Appendix B.

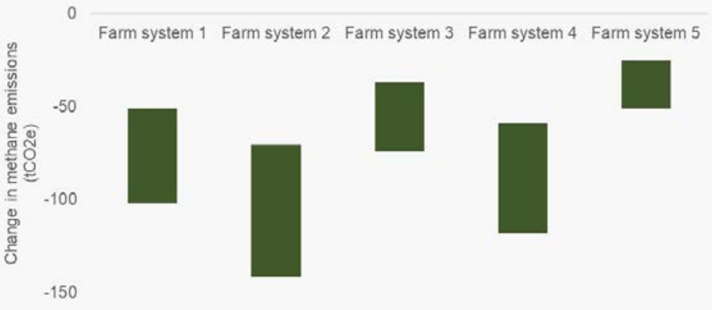
Case Study 2: Hi-CT White Clover **Modelled Impacts**

Methane Emissions

The literature supports a decrease in methane emissions of 5% - 10% per cow, based on a diet of 100% pasture with at least 25% Hi-CT White Clover. Fully integrating Hi-CT White Clover into a farm system could reduce methane emissions by 25 - 140 tCO_2e per farm per annum, depending on the farm system. The potential impact could be the highest on farm system 2 due to the higher herd size on average and a relatively high proportion of the cow's diet being from home-grown feed.

See *Figure 16* for the modelled range of potential changes in methane emissions per model farm system.

Figure 16: *Range in potential changes in methane emissions by farm system through the full integration of Hi-CT White Clover into the farm system.*



25 - 140 tCO_2e
methane reduction per farm p/a

Bloat Mortality

Hi-CT White Clover is assumed to reduce the incidence of bloat and therefore the number of mortalities from bloat. The extent of this impact is unknown, but is theorised by experts to have the potential to range from a 50% reduction through to complete elimination of bloat. Note, while there is a body of evidence to support this theory, it has not yet been proven scientifically. Based on this assumption, the model shows that farms could avoid the mortality of anywhere **from 0.5 - 2.5 cows per year** averaged over time**.** The extent of this depends on the farm system and ultimately the size of their herd.

0.5 - 2.5
avoided bloat mortalities p/a per farm

For details on sources and evidence, see Appendix B.

Environmental Impacts

Containability

Wild-type White Clover can disperse pollen and seeds over large distances. If Hi-CT White Clover was released outside of containment, it would be expected to spread throughout the environment.

Reversibility

Wild-type White Clover is persistent and can be found in most of New Zealand. Identifying Hi-CT white clover would require genomic or biochemical testing as it is otherwise indistinguishable from wild-type white clover. Removing all clover effectively once it has spread throughout a natural environment is extremely difficult. Given these factors it would be expected, depending on its competitive advantage, that low levels of Hi-CT White Clover would persist where clover is currently present and full reversal would prove exceedingly difficult.

Climate and Air Quality

Introducing Hi-CT White Clover into pasture is proposed to have a positive impact on climate.

If national adoption began in the next 10 years, the modelling suggests that by 2050 methane emissions could be reduced by 220 - 440 ktCO_2e per annum. This would contribute 3 - 5% towards the lower end of the 2050 Zero Carbon Act target of a 24% reduction from 2017 levels. See Appendix B for more details on the model.

Condensed tannins have also been shown to reduce urinary nitrogen, which will have implications for nitrous oxide emissions. At a national level, by 2040, a decline in total urinary nitrogen of 10,000 - 60,000 tonnes could be seen per annum. Based on the research that 2% of this is converted to nitrous oxide emissions, this would result in a reduction of 70 - 350 ktCO_2e nitrous oxide emissions per annum [37].

In total, this would result in a 290 - 790 ktCO_2e reduction in greenhouse gas emissions per annum, contributing to

4 - 10% of 2050 Zero Carbon Act target

Biodiversity

It is uncertain what impact Hi-CT White Clover will have on biodiversity.

More research is required to understand what impacts Hi-CT White Clover could have on biodiversity and what the extent of those impacts would be. Containing or removing/reversing Hi-CT White Clover once it is within a farm system will present similar challenges to containing or removing any non-GM clover cultivar and will depend on the farming system employed such as cultivation or oversowing.

However, two factors may mitigate the significance of the impact on the biodiversity of the ecosystem. Firstly, the trait of high condensed tannins is already present in the wild type (only in the clover flower) and the genetic modification acts to switch on a pre-existing pathway to also generate tannins in the leaves of the forage. Further, Hi-CT White Clover is unlikely to outcompete wild-type white clover in the environment, as the modification has been shown to decrease the yield, making it a less weedy version than the wild-type white clover.

Environmental Impacts

Traceability
The Hi-CT trait is not visually distinguishable from wild-type white clover and would require genomic testing to ascertain the presence of the modification. Tracing the spread of Hi-CT White Clover would be exceptionally difficult, given the inability to visually identify the modified species, the persistence and survival of white clover and the range of seed dispersal.

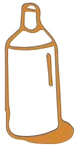
It is also impossible to determine from dairy products whether the cow that produced them had consumed genetically modified organisms. This would require significant documentation and labelling processes to ensure traceability.

Water

Introducing Hi-CT White Clover into pasture is proposed to have a positive impact on water quality. The reduced urinary nitrogen as a result of the introduction of Hi-CT white clover implies that incidences of nitrate leaching will reduce, increasing the quality of groundwater. As outlined in the modelled impacts, understanding the impact on nitrogen leaching would require further research.

Productivity

Introducing Hi-CT White Clover into pasture is proposed to result in an increase in milk production. The impact of Hi-CT White Clover on production levels is assumed to range from a 8% to a 10% increase. Nationally, based on the assumed adoption curve of this technology across all dairy farms and the assumed base case for change in production levels, using Hi-CT White Clover could generate an additional 50 million KgMS per annum in the base case.



+ 50 million kg milk solids p.a.

Land

It is uncertain what impact Hi-CT White Clover would have on soil health or land. More research is required to understand if Hi-CT White Clover would impact soil health. Based on the genetic modification of the organism, it is unlikely that Hi-CT White Clover would have a different impact from wild-type White Clover.

Animal Welfare

Introducing Hi-CT White Clover into pasture is proposed to result in an increase in animal welfare due to a reduction in bloat incidence and bloat mortality. On a national level, by 2040, the model estimates that New Zealand could expect to reduce bloat mortality by 4,000 to 7,500 cows per annum.

Resilience

Introducing Hi-CT White Clover into pasture is unlikely to improve the resilience of pasture swards to a changing and more unpredictable climate. Improved pasture resilience is likely to be attained through diversification of pasture species and further exploration of forage genetics (genetic modification or conventional breeding programmes).

Case Study 2: Hi-CT White Clover **Regulatory Classification**

Regulatory Scenario 1: Process-Based

As Hi-CT White Clover is created using genetic technology, it is classified as a genetically modified organism and is prohibited from being field tested or released prior to regulatory approval. This regulatory approval process is extensive and has a large burden of proof.

Hi-CT White Clover subject to further assessment and approval prior to release

Regulatory Scenario 2: Tiered Risk Based

The genetic technique used to create Hi-CT White Clover results in new DNA in the white clover genome. This new DNA is from a different but closely related same species, but is a non-targeted insertion. This results in a risk classification of Tier 3 - standard assessment and approval.

Hi-CT White Clover subject to further assessment and approval prior to release

Regulatory Scenario 3: Trait-Based

High condensed tannins are present in wild-type White Clover, but only in the flower. This modification acts as a master switch to turn on an existing pathway that causes the production of tannins in the leaf matter of white clover as well. As this trait is already present in the plant, this would be classified as a non-novel trait and would be exempt from GM regulation.

Hi-CT White Clover exempt from GM regulation

Under Regulatory Scenario 3, Hi-CT White Clover would be exempt from GM regulation and could be released into the environment if other regulations and standards did not prohibit its release. Hi-CT White Clover is captured by GM regulation under Regulatory Scenario 1 and 2 and would require further assessment and approvals by a regulatory body before it could be released. In this case, Regulatory Scenario 1 would involve a more onerous assessment process than scenario 2. Scenario 1 and 2 require a detailed assessment of the possible environmental impacts and risks.

Hi-CT White Clover already exists. It has been tested in field trials overseas, which have demonstrated its potential benefits. **This page outlines the additional events that would need to occur before implementation of this application of genetic technology.**

Case Study 2: Hi-CT White Clover
Road to Implementation

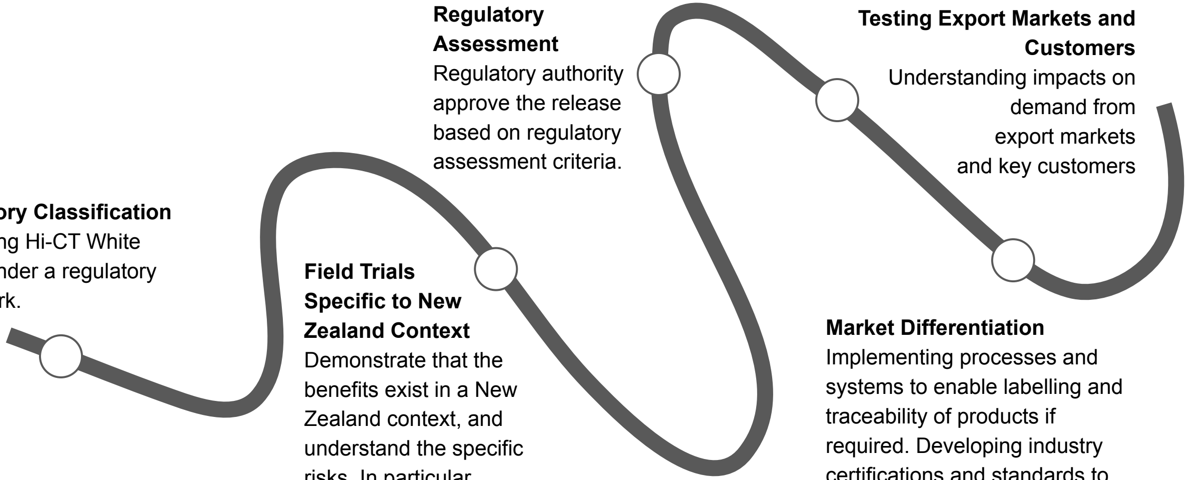


Figure 17: *Hi CT White Clover road to implementation*

Case Study 2: Hi-CT White Clover
Considerations for Decision-Makers

Application Effectiveness

This application of technology may contribute to lowering greenhouse gas emissions. Based on the modelling outlined in this report, Hi-CT White Clover could have the ability to reduce gross greenhouse emissions by 290 - 790 ktCO_2e per annum by 2050. This reduction may contribute 4 - 10% of the lower end (24%) of New Zealand's 2050 Zero Carbon Act methane targets. While this is by no means a trivial reduction of greenhouse gas emissions, it is not a 'silver bullet' for the emission reduction challenges the sector is facing.

Alternative methods to achieve the same or additive impacts could also be explored.
Through conversations with stakeholders, alternative ways forward, such as alternative farming practices, vaccines and other forages were mentioned. The use of Hi-CT White Clover as another tool in the toolbox should be weighed up in balance with the benefits and risks. For example, researchers at Lincoln University have found that providing diverse pasture forages can deliver environmental benefits such as reductions in methane emissions and urinary nitrogen.

Other Potential Applications

Broader Pastoral Sector Applications: Hi-CT White Clover could also be utilised in sheep and beef pasture systems, delivering similar benefits.

Other Modified Pasture Species: The concept of genetically modifying forage species for environmental and economic gain has multiple possible applications, notably research relating to genetically modified HME ryegrass is currently in the field testing state overseas. Other modified pasture species will have similar considerations regarding risks from spreading through the environment, but environment impacts will be organism specific.

Key Socio-Economic Considerations

Producer Responsiveness: The ability of Hi-CT White Clover seed and pollen to disperse means that once adopted by some farmers, Hi-CT White Clover may be detected in surrounding farms, even if the respective farmer wants their pasture to remain free of genetically modified forage. This may increase compliance relating to achieving accreditation standards. However, globally, accreditation bodies have built in GM tolerance levels to account for this and enable co-existence of production systems. For example, the non-GMO project will still provide non-GMO accreditation to products with up to 5% GMO presence in feed and supplements for livestock, poultry, bee and seafood and 0.9% tolerance for wholesale goods approved for human ingestion [38].

Retailer and NGO Accreditations: Organic pasture-based farmers' organic certification may be compromised if they detect GM clover in their pasture above tolerance limits and they take no mitigating actions.

Case Study 3: Sterile Douglas-fir

Genetic Technology Description

Sterile trees are produced through making disruptive point mutations to a specific gene which is essential for cone initiation and development rendering the tree sterile [39].

Case Study 3: Sterile Douglas-fir Trees
Introduction (1 of 2)

Wilding conifers have a number of negative impacts, such as overwhelming native species, ecosystems, extensive pastoral farmland, altering water surface water flows and increasing fire risks, among others [40,41,42].

The impact of wilding conifer invasion can be seen across New Zealand. As of 2022, it was estimated that over 2 million hectares were infested with wilding conifers [43]. Left unchecked, these wilding populations will continue to spread and invade landscapes. Manaaki Whenua modelling shows that over the next fifty years wildings could spread to a further 500,000 hectares and 1.8 million hectares of already infested land could become dense forest.

The origins of the current wilding problem can be traced back decades. The majority of wilding populations originated from the New Zealand forestry service and catchment boards in the 1950s. Soil engineers looked to manage slips in the New Zealand high country with exotic trees, due to their effectiveness at erosion control. Pinus Contorta was their first choice - by 1955, they'd planted 8000 hectares of it - but they also planted Douglas-fir and Corsican, Scots and Ponderosa pines, among a dozen others [44].

Presently due to their planted density Pinus contorta are the most prolific invasive species in New Zealand. Other prolific and high wilding risk species include Douglas-fir, Pinus radiata and Corsican pine.

Douglas-fir trees are an exotic species introduced to New Zealand for commercial forestry purposes and have proved to be a highly valuable production species. However, Douglas-fir trees have an extremely high spreading vigour, with only Pinus contorta exceeding their risk of wilding [45]. Due to this spreading vigour, experts estimate that Douglas-fir comprise approximately 40% of all existing wilding forests [46].

Wilding spread is exponential, meaning what is now a significant area of invasive exotic forestry species, may have once been only a few thousand hectares planted for erosion control. Due to the exponential growth, wilding control efforts are of vital importance. However, these efforts will always be limited if commercial forestry of Douglas-fir (or other invasive exotic forest species) continue to provide an active seed source for wilding spread.

Plantation forestry plays an important role in New Zealand's economy, as a high quality source of wood fibre, and in meeting New Zealand's carbon reduction targets. It is not an attractive option to limit or reduce plantation forestry in New Zealand, therefore, considering how new plantations can minimise, or even eliminate, their contribution to the wilding problem is critical.

Case Study Application

Genetic technology can be used to create sterile Douglas-fir trees. Sterile conifers would enable existing plantations to harvest and replant with sterile trees to stop their seed source contribution to wilding populations. This technology would also enable new plantation forests to be established with no risk to generating new wilding populations that damage local ecosystems. This can be achieved through the prevention of cone development, potentially resulting in an increased growth rate, as energy is not diverted to cone production.

Case Study 3: Sterile Douglas-fir Trees **Introduction (2 of 2)**

Under current regulatory settings, new plantations of Douglas-fir are significantly constrained, particularly in dry, high country areas. The National Environmental Standard for Commercial Forestry (NES-CF) stipulates that foresters must assess the risk of wilding conifers before being permitted to plant or to replant after harvest [44]. As Douglas-fir have extremely high spreading vigour, this has significantly limited the ability of the sector to maintain or increase the number of Douglas-fir plantations, and may limit the ability for existing plantations to re-establish plantations after harvest . As shown in *Figure 18*, the age profile for Douglas-fir are predominately between 16 and 30 (a total of roughly 68,000 ha). Due to regulatory restrictions under the NES-CF, there has been a significant decline in the number of new area planting Douglas-fir, with only ~2,000 ha planted in the last 5 years.

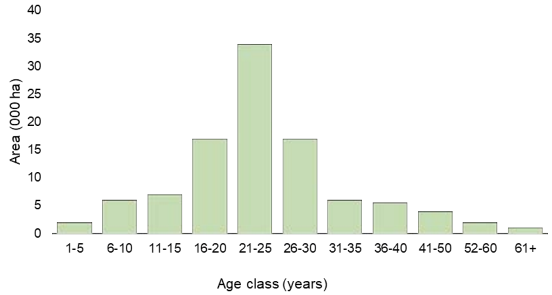
The availability of sterile Douglas-fir trees in New Zealand's fibre production could potentially unlock new opportunities for forestry plantations. This would lead to an increase in Douglas-fir timber production volume and carbon sequestration. However, it is important to note that these new plantations may replace pastoral-based farming, rather than other tree-species plantations. This means that, when compared to the counterfactual of farmland remaining unchanged, there would not be a significant impact on wilding area from new plantations.

The introduction of sterile Douglas-fir trees also offers the option for existing plantations to transition their stock, which would have implications for managing the spread of wildings.

'Turning off the tap' and stopping the spread of Douglas-fir seed from plantation forestry could potentially contribute to more effective wilding conifer control efforts

The use of sterile Douglas-fir trees in plantation forestry may enable the forestry sector to enhance timber production, carbon sequestration and potentially contribute to the control of wilding conifers in a sustainable manner.

Figure 18*: The total number of hectares planted of Douglas-fir by age class as at 1 April 2022, data sourced from Wilding Pine Network nz.*



Modelling Approach - Application One

The model considers the existing area of Douglas-fir planted within plantations in New Zealand and the age profile. Based on the assumption that Douglas-fir is harvested at 40 years, it then considers two scenarios once the trees are harvested: they are replaced with sterile Douglas-fir and they are replaced with non-sterile Douglas-fir.

Any area of non-Sterile Douglas-fir will contribute wilding area each year at a rate of 5% per annum. Once invasive trees have reached maturity (12 years), they will contribute to further wilding at the same rate of 5% per annum. Sterile Douglas-fir trees will not contribute at all to wilding area.

Case Study 3: Sterile Douglas-fir Trees
Modelled Impacts - Application One

As discussed in the introduction, sterile Douglas-fir trees can be applied in new or existing plantation forests post harvest. These two applications result in different environmental impacts. The modelling and analysis for this case study is separated accordingly based on application of technology.

The model for the first application (**Application One**) explores if **current Douglas-fir plantation owners harvest their trees and replace them with sterile Douglas-fir instead of standard Douglas-fir.** The model shows the possible implications for plantation forestries transitioning to sterile Douglas-fir and the impact on its ongoing contribution to the wilding problem in New Zealand.
The model will measure this impact as the area of wildings. This model does not take into account the density of impacted areas. It is important to note that density is a key metric when trying to control wilding populations. Density of infested areas varies, with the majority (~80%) of land classified as sparsely infested. Left unmanaged, sparse wilding infested areas can become dense forests. In some cases this process can happen in as little as 14-21 years, such as with Pinus contorta forests.

An example of this can be seen in the pictures to the right, showing the spread of Pinus Contorta between 2004 and 2014. The images highlight how aggressive the spread of wildling populations is, if left unchecked. This spread and increase in density will have implications for the impacts on the environment and the removal costs.

Photo source: Ministry for Primary Industries

For a complete breakdown of the model assumptions (including assumptions around spread of wildlings through environment), logic and inputs, see Appendix C.

Case Study 3: Sterile Douglas-fir Trees
Modelled Impacts - Application One

Hectares Impacted

Sterile Douglas-fir trees can reduce the future impact of wilding infested areas caused by existing plantations. Assuming plantations transition their trees following harvest cycles, around 80,000 ha of non-sterile Douglas-fir trees will be replaced with sterile ones in the next 24 years. This would result in a decrease of 4,000 ha per year in the spread of wildings, assuming a 5% spread rate. Although this may seem small compared to the current 800,000 ha of Douglas-fir wildings, these 4,000 ha could expand to cover 300,000 ha in 100 years without intervention.

Figure 19 illustrates how any decrease or increase in wilding impact accumulates over time due to exponential growth. For instance, after 50 years, the sterile case shows a significant 50% reduction in the total area of wildings contributed by plantations compared to the non-sterile case. However, it is important to note that even if all plantations transition to sterile trees, the exponential expansion of wildings will continue. This illustrates that whilst sterile technology is useful to reduce the impact, wilding control programmes are vital to get this problem under control.

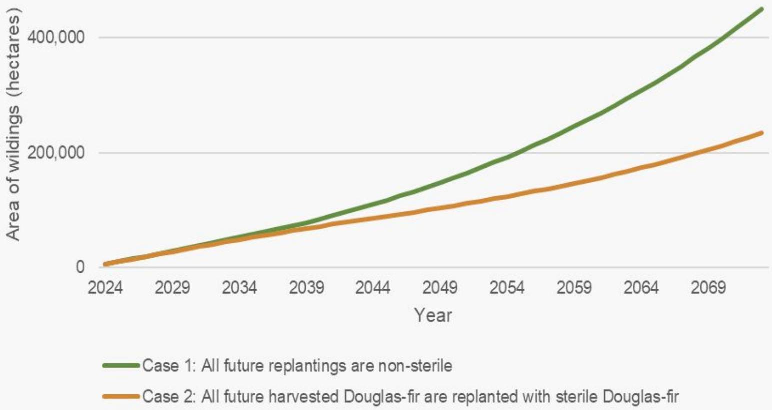


Figure 19: *The total number of additional hectares of wildings contributed to by Douglas-fir plantations from 2024 in the cases where they replant with non-sterile and sterile Douglas-fir trees.*

Without other intervention, transitioning existing plantations to sterile Douglas-fir trees may result in a

200,000 ha difference in total area impacted by wildings after 50 years

For details on sources and evidence, see Appendix C.

Case Study 3: Sterile Douglas-fir Trees
Modelled Impacts - Application One

Hectares Impacted (cont)

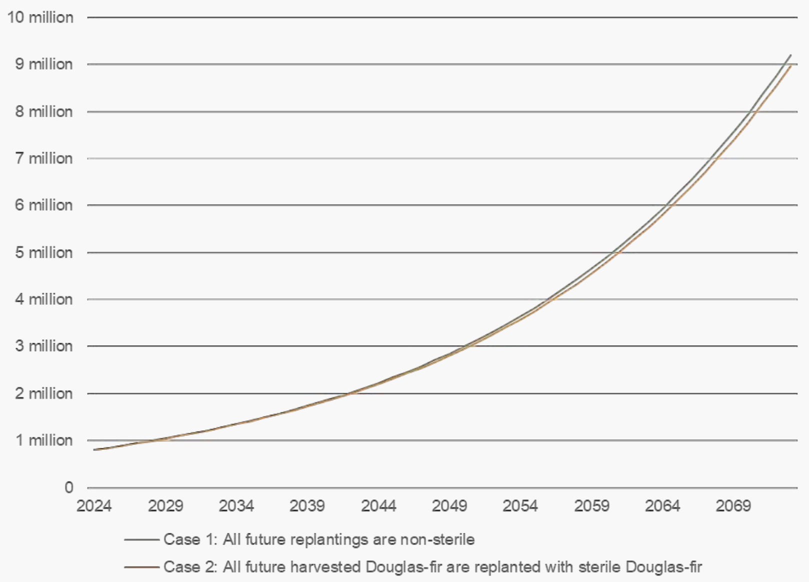


Figure 20: *The total number of hectares of wildings contributed to by Douglas-fir plantations from 2024 in the cases where they replant with non-sterile and sterile Douglas-fir trees.*

To put this in context, *Figure 20* illustrates the impact of plantation sterile Douglas-fir on the total number of hectares impacted by Douglas-fir wildings in New Zealand. Based on the assumption that there are currently about 800,000 ha of Douglas-fir wildings that will continue to spread at a rate of 5%*, the plantations on-going contribution to the problem is minimal in comparison to the existing issue.

If all plantations transition to sterile trees at harvest, it would result in a 200,000 ha reduction in impacted area after 50 years, which is only a 2.4% difference. This model assumes that there is no further intervention to control the wilding populations. In reality, there are currently wilding programmes working towards controlling spread and removing wilding areas. These are effective and large scale. As of 2022, wilding programmes have funding to control 2,311,844 hectares of infestation [48]. **The exponential growth from existing wilding populations shown in this model reinforces the important role that wilding control programmes currently play in controlling the problem.**

**The absolute result in terms of the total hectares impacted is incredibly sensitive to the estimated rate of spread. This is tested in the appendix.*

In this modelled scenario, transitioning existing plantations to sterile Douglas-fir trees results in

2.4% difference in the area impacted by wildings after 50 years

assuming no control of existing wilding populations.

For details on sources and evidence, see Appendix C.

Case Study 3: Sterile Douglas-fir Trees
Modelled Impacts - Application Two

The model for the second application (**Application Two**) explores the impact of new sterile Douglas-fir plantations. As discussed in the introduction, the NES-PF prevents new plantations of Douglas-fir due to its high wilding risk. If sterile Douglas-fir are available to the sector, the sector would be able to expand and establish new plantations, subject to planning rules.

This model assumes that sterile Douglas-fir results in an additional 1,000 hectares of forestry established per year. Sector experts indicated that this growth rate aligns with the demand level now and over time. The model assumes that the demand for Douglas-fir forestry will not be influenced by sterile technology, but the technology will help overcome regulatory obstacles to meet forecast demand levels.

Douglas-fir is a high-value tree that can grow in areas, such as high-country, that other high-value commercial forestry trees species cannot. In the counterfactual, it is likely that land used for new plantations would have otherwise been used for pastoral-based farming. This is the point of comparison for the modelled impacts. Because pastoral-based farming will not contribute to wildings, and sterile Douglas-fir plantations will also not contribute to wildings, there will not be a net benefit in terms of the area of New Zealand impacted by wildings. It will, however, have implications for the total production volume of timber that New Zealand produces and the total amount of carbon sequestered through forestry. These are the two impacts that will be modelled in this application.

The modelling also adopts the theory that sterile Douglas-fir trees will grow faster than standard trees. This is based on the idea that sterility will be achieved through the removal of cones, redirecting the energy that would have gone into cone generation into tree growth. As a consequence, the proportional increase in growth rate is assumed to equate to the same proportional increase in carbon sequestration per annum. The model also assumes that harvesting will occur at the same production volume, therefore shortening the harvesting lifecycle of Douglas-fir trees.

For a complete breakdown of the model assumptions (including assumptions around spread of wildlings through environment), logic, and inputs see Appendix C.

Modelling Approach - Application Two

In the new plantation model, it is assumed the annual planting of 1,000 ha of Douglas-fir indefinitely. Carbon sequestration is modeled based on the New Zealand Forest Service's average accounting system, which considers the average carbon sequestered over time for forestry plantations. For Douglas-fir, this occurs when the tree is 26 years old. The model uses official carbon tables to model the growth in carbon sequestration each year until the new plantings reach 26 years old, after which the amount of carbon sequestered per year remains constant.

For production volume, timber volume at the time of harvest is calculated. It is assumed the harvest lifecycle of sterile Douglas-fir is shorter, at 35 years, rather than 40 years, due to the increased growth rate from energy otherwise used for cone production. Once harvested, it is assumed the land is replanted with more sterile Douglas-fir.

Case Study 3: Sterile Douglas-fir Trees
Modelled Impacts - Application Two

Carbon Sequestration

Sterile Douglas-fir may enable new Douglas-fir plantations. This model assumes that these new plantations will be in the place of pasture-based farming, which has a negligible carbon sequestration profile. This model assumes that the transition from pastoral land to forestry will result in a net gain in carbon sequestered. This is shown in *Figure 21,* where the annual carbon sequestered per annum reaches 1,000 ktCO_2e after 45 years of 1,000 ha planted per annum from year 0.

New Zealand is aiming for net zero carbon emissions by 2050 [49]. In 2021, forecasts predicted around 55,000 ktCO_2e gross emissions, which could be partially offset by sequestration. If year ‘n’ represents 2024, additional sterile Douglas-fir plantations would contribute to an additional reduction of about 400 ktCO_2e by 2050, offsetting around 0.7% of emissions. While seemingly small, this contribution is important alongside other efforts to reduce emissions

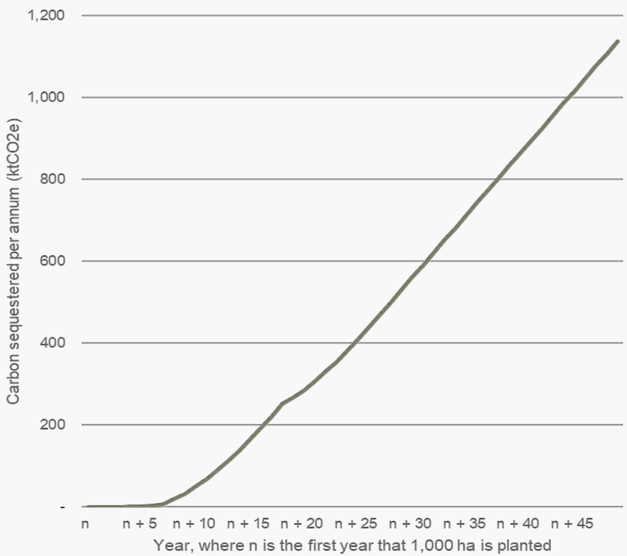


Figure 21: *The total carbon sequestered through the addition of Douglas-fir plantations (1,000 ha planted each year from year n).*

New sterile Douglas-fir plantations, planted at 1,000 ha per annum may **offset 0.7% of New Zealand’s total carbon emissions by 2050**

For details on sources and evidence, see Appendix C.

Case Study 3: Sterile Douglas-fir Trees
Modelled Impacts - Application Two

Production Volume

Additional sterile Douglas-fir plantations may lead to a gradual and incremental increase in the volume of available Douglas-fir timber for harvesting and sale, as shown in *Figure 22*.

Starting in year n, 1,000 ha of Douglas-fir is planted. The assumed harvesting lifecycle for sterile Douglas-fir is 35 years, shorter than the standard 40 years. After 35 years, the first 1,000 ha is ready for harvest and replanting. This process continues, with the second 1,000 ha harvested and replanted after 36 years, and so on. After 70 years, the first 1,000 ha planted will be ready for a second harvest, along with the 1,000 ha planted after 35 years, resulting in a doubling of total timber harvested. This pattern repeats every 35 years, increasing annual timber harvest by over 400,000 m3.

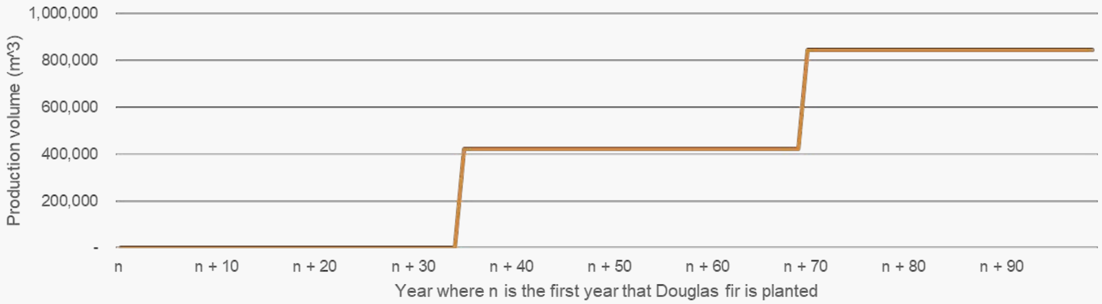


Figure 22: *The total production volume arising from only future planting of Douglas-fir in the case where all are sterile.*

With the ability to plant sterile Douglas-fir, there may be a 400,000 m³ increase in annual production volume every harvesting lifecycle

For details on sources and evidence, see Appendix C.

Ability to Control the Spread of Sterile Douglas-fir

Containability

As a sterile tree, the modified Douglas-fir is unable to reproduce through conventional means. It is highly unlikely that they would pose containability risk outside of human intervention.

Reversibility

As sterile Douglas-firs have low containability risk, their reversal or removal from the environment would be relatively straightforward. Reversibility would also be influenced by the scale and extent of the introduction of sterile Douglas-firs. If they are widely planted across large areas, the task of removing or reversing their presence may be more challenging and costly.

Traceability

It would be possible to visually distinguish wild type from modified ones once the trees have reached reproductive age (i.e., absence of cones). Genomic testing could be used to confirm the complete absence of ability to reproduce. However, given that this modification is a deletion (which results in no detectable trace of genetic modification), it would be impossible to determine whether this event had occurred naturally or was a result of genetic modification.

While it can reasonably be expected that the trees themselves would remain traceable, their wood products would currently require significant documentation and labelling processes to ensure traceability.

Photo source: Ministry for Primary Industries

Environmental Impacts

Application One:
Transitioning Plantations

Climate and Air Quality

Transitioning existing plantations to sterile Douglas-fir may result in less total carbon sequestration.

Transitioning existing plantations to sterile Douglas-fir could avoid a wilding impact of approximately 200,000 ha, which would also result in avoided carbon sequestration. However, according to carbon accounting standards, this sequestration cannot be used to offset domestic targets. Therefore, while this technology may result in a decline in sequestration, it will not impact New Zealand's climate targets.

Biodiversity

Transitioning existing plantations to sterile Douglas-fir is proposed to have a positive impact on biodiversity.

The model assesses the difference in the hectares impacted if plantations transition to sterile trees, and illustrates that in 50 years time there is an avoided wilding impact of 200,000 ha.

an avoided wilding impact of 200,000 hectares after 50 years

Wilding conifers, including Douglas-fir, have been shown to have negative effects on existing biodiversity. Native flora and fauna, finely attuned to their local habitats, may face displacement or negative repercussions due to the intrusion of wilding conifers. This disruption can impede the provision of crucial ecosystem services like pollination, soil stability, and water regulation.

Water

Transitioning existing plantations to sterile Douglas-fir is proposed to have a positive impact on water supply

Preventing wilding conifer spread positively impacts catchment water supply by conserving water resources. Wilding conifers can hold water within the soil which may reduce the flow of water into rivers. Wilding conifers in heavily affect catchments have been shown to reduce water that flows into rivers by 30% to 40% [50]. This technology may reduce the spread of wildings and therefore improve water use within affected catchments.

Environmental Impacts

Application One:
Transitioning Plantations

Resilience	**Sterile Douglas-fir may lead to a decrease in sector resilience due to lower genetic diversity as a result of increased clone use.**
Resource Use Efficiency	**Transitioning existing plantations to sterile Douglas-fir is likely to have a positive impact on resource use efficiency.** It is theorised that Sterile Douglas-fir will have a faster growth rate than wild-type Douglas-fir due to energy that would have otherwise been used for cone production. This may result in plantations with sterile Douglas-fir having shorter harvest rotations.
Land	**Transitioning existing plantations to sterile Douglas-fir is likely to have a positive impact on land use.** The application of this technology supports efforts to stop wilding spread, and therefore supports the prevention of productive land and significant landscapes being locked up in wilding conifers. Wilding conifers can also increase the risk of wildfires in affected areas. They tend to have higher flammability compared to native vegetation, and their dense growth can create a continuous fuel source.
Animal Welfare	**This factor is not directly applicable to this case study.**

Environmental Impacts

Application Two: Expansion, new sterile Douglas-fir plantations

These impacts are not specific to sterile Douglas-fir (i.e., they would also occur with wild-type Douglas-fir). However, this application of genetic technology enables new exotic forestry plantations where current regulations would otherwise prevent it. Managing these impacts is not linked to managing the use of genetic technology. Consideration may need to be given to policy instruments, such as regional/district plans, to ensure appropriate land use (right tree, right place).

Note: This section looks at the environmental impact of new sterile Douglas-fir plantations. These environmental impacts are evaluated against the counterfactual of prior land use being pastoral farmland.

Climate and Air Quality

Additional sterile Douglas-fir plantations are likely to have positive impact on climate. Sterile Douglas-fir trees would enable new plantations to exist, increasing the total number of trees sequestering carbon. The modelling estimates that there will be an additional 1,000 ktCO_2e of carbon sequestered after 45 years, or offset ~1% of New Zealand's 2050 emissions profile.

Biodiversity

The biodiversity impact will be dependent on previous land use and forest management practices. Plantation forests can serve as new habitats for a variety of plant and animal species. The establishment of plantations can provide shelter, nesting sites, and food resources for a range of wildlife, including birds, mammals and insects. A 2010 paper found that over 50 threatened species have been recorded in New Zealand exotic forests plantations [51]. However, the same paper found that exotic forests have lower biodiversity outcomes than indigenous forests, and can become ecological traps if the harvest and replant cycle is not managed to best practice standards. Further, exotic forests can also provide habitat for introduced species and pests, which could negatively impact biodiversity.

Resilience

Additional Douglas-fir plantations may have a negative impact on climate resilience, if established in the wrong place. The impact of additional Douglas-fir plantations on climate resilience may vary depending on forest management practices and the specific geographical location. While recent severe storm events in Gisborne/Tārawhiti and Wairoa, such as Cyclone Gabrielle (2023), resulted in destructive woody debris from plantation forestry causing significant damage to key infrastructure and waterways, it is important to note that the severity of these impacts is strongly influenced by geographical factors.

If established in the wrong location, additional exotic forestry plantations may decrease our resilience to these storm events and our ability to mitigate the resulting damage.The impact on climate resilience will ultimately be determined by forest management practices and the geographical location of additional forestry plantations.

Environmental Impacts

Application Two: Expansion, new sterile Douglas-fir plantations

These impacts are not specific to sterile Douglas-fir (i.e., they would also occur with wild-type Douglas-fir). However, this application of genetic technology enables new exotic forestry plantations where current regulations would otherwise prevent it. Managing these impacts is not linked to managing the use of genetic technology. Consideration may need to be given to policy instruments, such as regional/district plans, to ensure appropriate land use (right tree, right place).

Water

It is uncertain what impact additional sterile Douglas-fir plantations will have on water. The impact on water use and quality will depend on the geographical location and previous land use. Exotic forests hold water within the soil and release water into the atmosphere through the trees' leaves. This reduces the flow of water into rivers and decreases water refilling underground aquifers.

Additional sterile Douglas-fir plantations are likely to be established in dry high-country areas, and may result in a decrease in water harvest for catchments.

However, plantation forests can stabilise soil, preventing nutrient and sediment runoff into water bodies, thus improving water quality, relative to the counterfactual of pastoral farmland, which can have negative impacts water quality through nitrogen leaching and effluent runoff.

Resource Use Efficiency

It is uncertain what impact additional sterile Douglas-fir plantations will have on resource use efficiency, relative to the counterfactual of pastoral farming.
The impact on resource use efficiency from land use change of pastoral farming to plantation forestry will depend on the class of land, and the productivity of the previous land use. This will need to be assessed on a case-by-case basis.

Animal Welfare

This factor is not directly applicable to this case.

Environmental Impacts

Application Two: Expansion, new sterile Douglas-fir plantations

These impacts are not specific to sterile Douglas-fir (i.e., they would also occur with wild-type Douglas-fir). However, this application of genetic technology enables new exotic forestry plantations where current regulations would otherwise prevent it. Managing these impacts is not linked to managing the use of genetic technology. Consideration may need to be given to policy instruments, such as regional/district plans, to ensure appropriate land use (right tree, right place).

Land

Geographical factors and forest management will influence the impact of additional Douglas-fir plantations. It is difficult to quantify the degree of impact of additional Douglas-fir forestry on the land and soil without taking a case-by-case approach.

Te Uru Rākau (The New Zealand Forest Service) research has found that plantation forestry on erodible land can potentially reduce soil erosion by up to 95% [52]. However, inadequate management between harvest and replanting of plantation forests can result in sediment losses. Studies completed in Hawke's Bay and Waikato catchments have shown that despite sediment losses following harvest, when averaged over harvest cycles, afforestation provided up to 78% reduction in catchment sediment yield [53, 54]. This impact on soil erosion / conservation will be dependent on the baseline of soil health prior to the land being converted to plantation forestry and the forestry management practices undertaken by foresters.

Douglas-firs are primarily grown in dry high-country areas. As our climate changes, extreme temperatures will become more common and the risk of vegetation fires will increase. Additional Douglas-fir plantations may provide more fuel for forest fires and lead to a heightened risk of large and significant forest fires. Fire risk is a landscape issue, considerations may need to be given to the spatial planning of additional forestry plantations within the broader landscape.

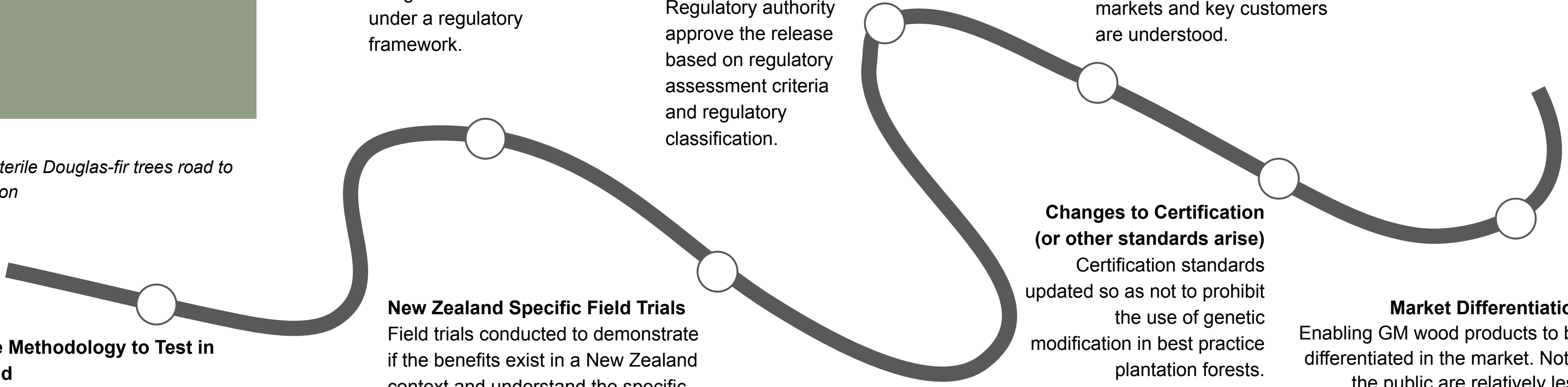
There is likely to be increased risk of larger and more significant forest fires with additional plantations.

Further, it is worth assessing how additional Douglas-fir plantations may impact the aesthetic value of the land. New plantations can drastically change how some of New Zealand's iconic landscapes look.

Case Study 3: Sterile Douglas-fir Trees
Road to Implementation

This technology already exists, but is not available for development and release in the New Zealand environment. **This page outlines the additional events that would need to occur before implementation of this application of genetic technology.**

Figure 23: *Sterile Douglas-fir trees road to implementation*



Confirm the Methodology to Test in New Zealand
In this case study, it is assumed the technique will seek to create sterile trees that target prevention of cone development. Alternative methods include allowing cone development but preventing seed creation/dispersal.

Regulatory Classification
Douglas-fir classified under a regulatory framework.

New Zealand Specific Field Trials
Field trials conducted to demonstrate if the benefits exist in a New Zealand context and understand the specific risks. In particular, exploring if there are any unintended consequences and that it can achieve its desired impact.

Regulatory Assessment
Regulatory authority approve the release based on regulatory assessment criteria and regulatory classification.

Testing Export Markets and Customers
Demand impacts from export markets and key customers are understood.

Changes to Certification (or other standards arise)
Certification standards updated so as not to prohibit the use of genetic modification in best practice plantation forests.

Market Differentiation
Enabling GM wood products to be differentiated in the market. Note, the public are relatively less interested in genetic modification of trees than modified food or animals. Therefore, the need for market differentiation may not be as significant as in other case studies.

Case Study 3: Sterile Douglas-fir Trees **Regulatory Classification**

Regulatory Scenario 1: Process-Based

Sterile Douglas-firs are created using genetic technology and therefore are classified as a genetically modified organism both in scientific and legal definition. This means they are prohibited from being field tested or released prior to regulatory approval. This regulatory approval process is extensive and has a large burden of proof resulting in an assumed effective ban under this scenario.

Sterile Douglas-fir trees subject to further assessment and approval prior to release

Regulatory Scenario 2: Tiered Risk Based

The genetic technique used to create sterile Douglas-fir results in no new DNA in the end product, but changes (point mutations) are permanent. This results in a Risk Tier 1 classification which requires notification to the regulator before release, assuming alignment with other existing regulation not specific to genetic modification, but no assessment or approval is required based on the application's genetic modification.

Sterile Douglas-fir trees notification of release required

Regulatory Scenario 3: Trait-Based

Spontaneous sterility is moderately prevalent in wild population of conifers [55]. Therefore this is a non-novel trait, which poses no greater threat than that currently existing in the environment. This application is therefore exempt from regulation assuming alignment with other existing regulation not specific to genetic modification.

Sterile Douglas-fir trees exempt from GM regulation

Under Regulatory Scenario 2 and 3, no assessment or approval is required before release of sterile Douglas-firs. Regulatory Scenario 2 still requires a notification of release to the regulator, whereas Regulatory Scenario 3 is completely exempt from regulation. Under Regulatory Scenario 1, an extensive assessment and approval process is required before release into the open environment.

Case Study 3: Sterile Douglas-fir Trees
Considerations for Decision-Makers (1 of 2)

Application Effectiveness

Wilding control programmes are critical to managing the wilding problem. While the use of sterile Douglas-fir is a valuable tool in addressing the wilding problem, it is important to recognise that it alone is not sufficient. The majority of the wilding issue stems from existing wilding populations, highlighting the need for comprehensive wilding control programs that work in tandem with the implementation of sterile Douglas-fir to effectively manage and mitigate the spread of wildings. Note, the relative importance of sterile technology increases as wilding control efforts increase. Complete management of invasive forest species cannot be achieved without sterility in commercial plantations.

Sterility provides opportunities for the sector given the restrictions posed by the National Environmental Standard for Commercial Forestry. Sterile trees would be very effective in enabling the planting of economically desirable species as the risk of adding to the wilding problem would be removed.

Other Potential Applications

Sterility: Conceptually, exploring using genetic technology to achieve sterility in tree species could provide similar benefits in reducing wilding spread or, with trees that are otherwise genetically modified, prevent the transfer of transgenes to other wild-type individuals.

Other Applications of Douglas-fir: This application of genetic technology could potentially provide other land users access to a high value tree species for other purposes (e.g., wind breaks or erosion control) without risk of contributing to the wilding problem.

Case Study 3: Sterile Douglas-fir Trees
Considerations for Decision-Makers (2 of 2)

Key Socio- Economic Considerations

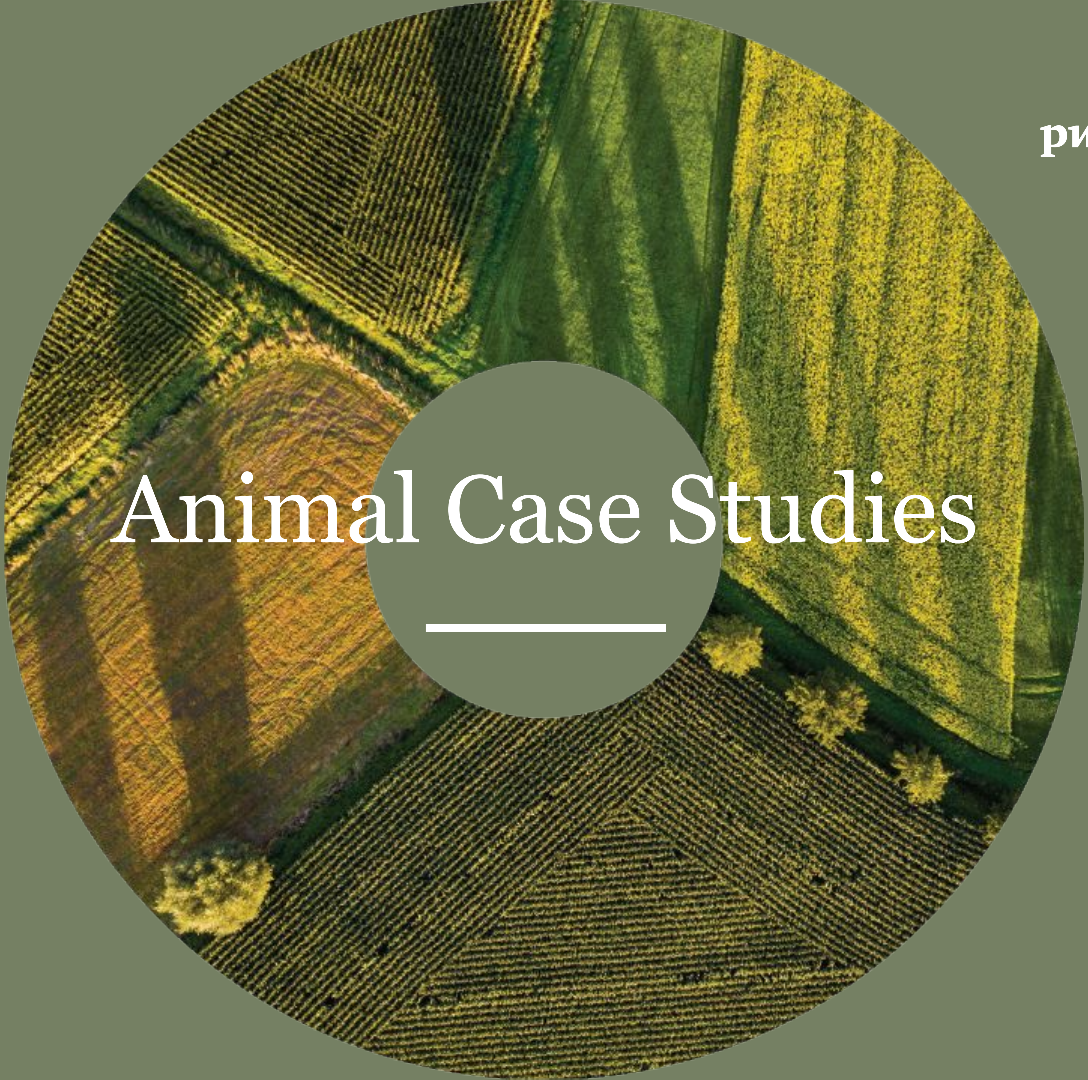
Competitive Advantage: This application of genetic technology enables the establishment of new plantations, therefore increasing New Zealand's competitive advantage.

Accreditations: The Forest Stewardship Council (FSC) has currently banned genetically modified trees. The FSC is one of the world's largest certifiers of 'sustainably harvested timber' [56]. This position could be reevaluated in the context of the sustainability benefits, noting it will be a full harvest lifecycle (roughly 35 - 45 years) before any modified Douglas-fir wood would be available to export.

Social License: Sterile Douglas-fir trees may help restore social license that has been lost due to the environmental impacts of wildings associated with forestry. However, there are still social license issues within the sector that need to be addressed, such as the perception of plantation forest's impact on rural communities from woody debris.

Community Values: Consideration may need to be given to supporting policy around 'the right tree in the right place'. This application of genetic technology unlocks the possibility of additional Douglas-fir plantations. Community impacts (positive or negative) of land use change should be considered when undergoing spatial planning and resource management consents.

Animal Case Studies



Introduction

Purpose of section

This section outlines important considerations for applications of genetic technology in animals in different production systems. These applications are categorised based on their relevance to marine-based production systems, terrestrial-based production systems, and pest species that impact multiple production systems. The report discusses the possibilities and implications of genetic technology in these contexts, without focusing on specific case studies.

Methodology

Given the speculative nature of these applications, a conceptual analysis approach was employed to explore the potential environmental risks, benefits and impacts associated with each type of application. This involved desktop analysis, stakeholder discussions and conceptualising potential scenarios and their implications within marine-based, terrestrial-based and cross-system pest contexts.

Approach

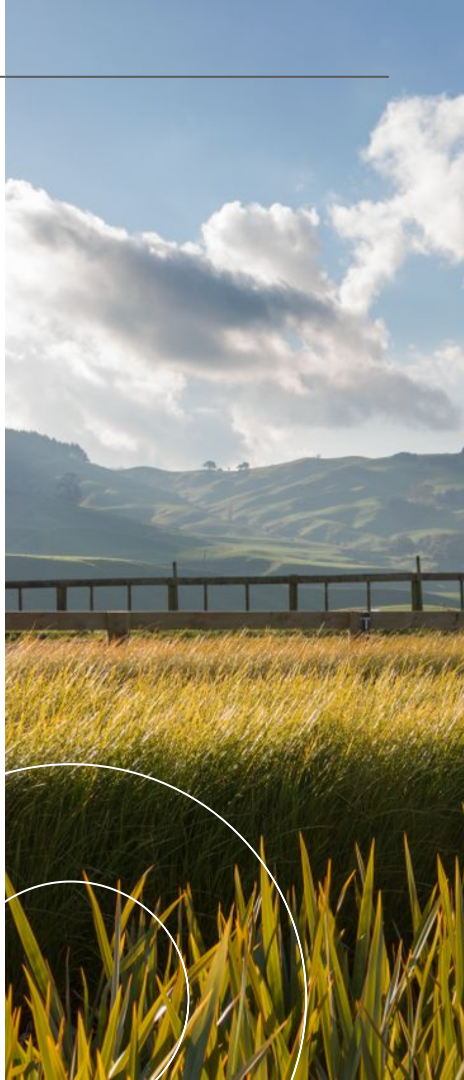
The three types of applications discussed in this section are not based on specific case studies, but rather represent broad categories of potential genetic technology applications in different production systems.

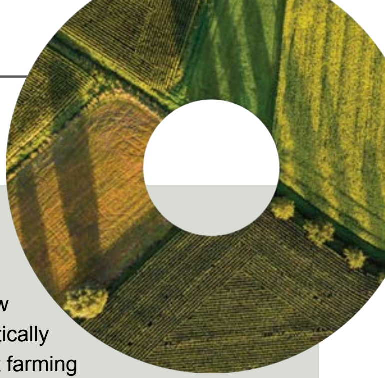
Marine-Based Production Systems: This category explores the possibilities of genetic technology applications in marine-based industries, such as aquaculture farming. It considers how genetic modifications could enhance traits like disease resistance, growth rates or nutritional content in marine organisms.

Terrestrial-Based Production Systems: This category focuses on the potential applications of genetic technology in terrestrial-based production systems, including agriculture and livestock farming. It examines how genetic modifications could improve product yields, enhance animal health and resilience or increase resistance to pests and diseases.

Cross-Systems Pest Control: This category addresses the challenges posed by pest species that impact multiple production systems, such as invasive species or pests that affect both marine and terrestrial environments. It explores how genetic technology could be used to control or mitigate the negative impacts of these pests, potentially through genetic modification or targeted population management strategies.

A speculative approach was taken to analyse these types of applications, considering the potential environmental, economic, and social impacts that could arise from their implementation. It is important to note that these discussions are hypothetical and intended to stimulate further exploration and discussion around the possibilities and considerations of genetic technology in marine-based, terrestrial-based and cross-system pest contexts.





How to Read this Section

Structure of this section

This section first presents a high-level overview of how different jurisdictions have regulated the use of existing applications of genetic modification in animals.

This is followed by a summary of general considerations for decision makers regarding the use of genetic modification in animals.

The section then explores different applications of genetic technology in animals across three different environments (marine, terrestrial, and ecosystem). This includes:

- Overview of existing modified organisms or research areas,
- Assessment of ability to control spread of organisms throughout the different environments,
- Environmental impact screening,
- Environment specific considerations for decision makers.

Structure of the case studies

Introduction

An introduction to environment (i.e. marine, terrestrial, ecosystem) specific challenges and how those challenges may impact food and fibre production systems, an overview of existing genetically modified organisms and research, and a description of how genetic modification could support farming systems through the specified environmental challenges.

Assessment of the ability to control spread of organisms throughout the environment

A generic assessment of containability, reversibility, and traceability of genetically modified animals throughout the environment.

Environmental impact screening

An evaluation of the likelihood of an application of genetic technology impacting an aspect of the receiving environment. Note this does not indicate whether there will be a positive or negative impact, but the likelihood of an impact occurring.

Considerations for decision-makers

A summary of considerations for decision makers, including broader socio-economic factors.

Overview of Regulatory Classification

It is not possible to assign a regulatory classification of hypothetical genetic modifications if the science enabling the genetic modification has not been fully developed. This is due to classification being dependent on specific traits and/or changes. For this reason, this section does not examine specific New Zealand animal case study examples - the research is currently not mature enough to begin to make assertions about their classification or impacts. In place of this, the examples below show a range of close-to-market examples from overseas and their indicative classifications.

Table 5: *Overview of regulatory classification for animal research*

Overseas case	Regulatory Scenario 1: Process-Based	Regulatory Scenario 2: Tiered Risk Based	Regulatory Scenario 3: Trait-Based
Sterile fast growing Atlantic Salmon *(Marine)*	As animals have all been produced using new genome techniques all animals subject to an effective ban.	Targeted insertion of DNA from a similar species - Risk Tier 2	Novel trait - subject to further assessment and approval prior to release
Sterile disease resistant catfish *(Marine)*		Targeted insertion of foreign DNA to interrupt gene expression - Risk Tier 3	Novel trait - subject to further assessment and approval prior to release
Slick Coat (heat tolerant) Cattle™ *(Terrestrial)*		Substitution of gene variant - Risk Tier 1 requirement for notification only	Non-novel trait - exempt from GM regulation
Disease resistant pigs *(Terrestrial)*		Small Deletion - Risk Tier 1 requirement for notification only	Non-novel trait - exempt from GM regulation
Gene drive mosquitoes *(Ecosystem)*		Targeted insertion of foreign DNA to interrupt gene expression - Risk Tier 3	Non-novel trait - exempt from GM regulation

These five examples have all been approved for field trials in their local territories and some are even approved as safe for food products in these same territories (e.g. Slick Coat Cattle in the USA). These cases highlight the difference between the three regulatory scenarios explored in the previous sections and the steps being taken by overseas regulators and markets.

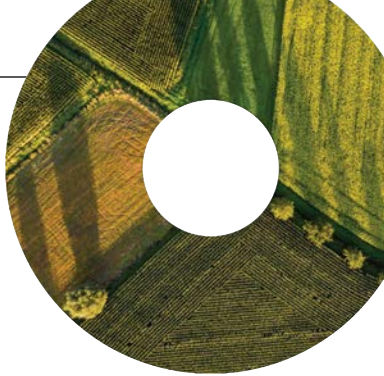
General Considerations for Decision-Makers

Key Socio- Economic Impacts

Innovation: Presently, research into genetically modified plants surpasses that of animals, primarily due to stricter regulatory processes, ethical concerns and the intricate complexities of animal biology. This discrepancy in research focus leads to limited funding and expertise in genetically modified animals, perpetuating a cycle of slower innovation in this field. Some countries with less stringent regulations regarding the genetic modification of animals have shown progress in producing genetically modified products and have used them to demonstrate benefit. However, these advancements often prioritise commercial factors over environmental considerations. Addressing these challenges could involve exploring incentives that promote research directly aligned with achieving outcomes conducive to New Zealand's interests and environmental sustainability and being a leader in this area.

Cultural Values: Although the majority of New Zealand’s farmed species are not considered taonga, current farming practices can still significantly impact taonga species, prompting concerns regarding environmental harm and cultural heritage. Consequently, the discussion around genetic modification for taonga species preservation has gained traction. However, views within Māori communities on genetic modification for taonga species preservation vary, with some viewing it as a potential solution to farming impacts and to climate adaptation, while others express reservations about its consequences and clash with traditional knowledge systems.

Trade and Market Access: Compared to plants, genetically modified animal products face greater scrutiny from consumers and regulators. This stems from the fact that genetic modifications in animals tend to be more complex than those made in plants due to the relative increase in complexity of animal systems and because of animal welfare and ethics considerations. Due to these factors, regulation around genetically modified animals can differ from the regulation of plants within a territory, which may be important to consider when assessing alignment with foreign trade partners.



Genetic Modification vs Conventional Breeding

Another key consideration for decision makers is the role of conventional breeding versus the role of genetic modification to achieve desirable traits in animals. In some cases, it may be more effective to invest in conventional breeding programmes to achieve highly valuable traits than using genetic modification.

Mono- and polygenic traits affect the potential effectiveness of genetic modification.

Monogenic traits are traits that are controlled by a single gene. These traits typically exhibit a clear cut pattern of inheritance, where the presence or absence of a specific allele determines the expression of the trait. Polygenic traits, also known as complex traits, are traits that are influenced by multiple genes. These traits do not follow a simple inheritance pattern.

Animals, mammals in particular, are more likely to have polygenic traits. The polygenic nature of traits in animals makes them more complex to study and understand compared to traits controlled by a single gene. It requires the analysis of multiple genetic markers and statistical methods to determine the contribution of each gene to the trait. This can make genetic modification more challenging.

Conventional breeding vs Genetic modification

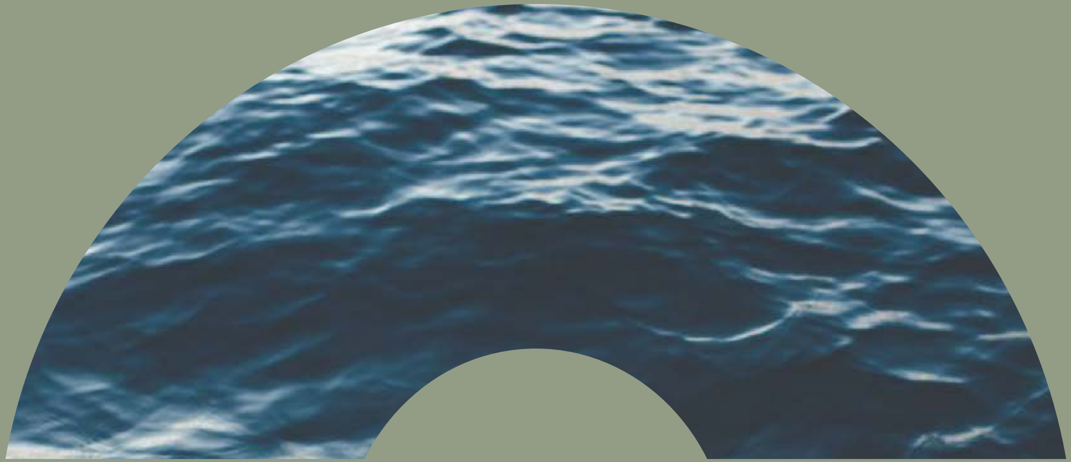
There is not a prescriptive way to determine which is the more appropriate technology, but conventional breeding and genetic modification have slightly different use cases and resulting effectiveness that may make the approach more or less appropriate to try to achieve target traits.

Conventional or selective breeding tends to be best suited for polygenic traits (traits controlled by multiple genes). This is because it allows you to not have to know the exact gene you are trying to influence and instead results in the accumulation of small genetic changes over generations as observed by changes to the traits expressed. This makes it most effective for traits that are influenced by complex interactions between multiple genes. An example of a current selective breeding programme in New Zealand to naturally breed low methane livestock is shown in the panel to the right.

New genomic techniques are best suited for monogenic traits (traits controlled by a single gene) with high levels of equilibrium expression (a sufficient proportion of the population displayed the trait). New genome techniques can be used to change expression of polygenic (multi-gene) traits, however this is more challenging due to the increased complexity of the biological system and associated gene architecture.

Selective Breeding: Low Methane Sheep [57]

AgResearch’s Low Methane Sheep Breeding Team has developed a successful program to select sheep emitting less methane. Over 12 years, they identified genetic and microbiological markers, creating two research flocks. After three generations, these sheep emit 13% less methane per kilogram of feed. Scaling up this approach could reduce New Zealand's sheep flock methane emissions by 0.5 to 1% annually. Support has been received to identify low methane rams and incorporate their credentials into on-farm greenhouse gas calculators.



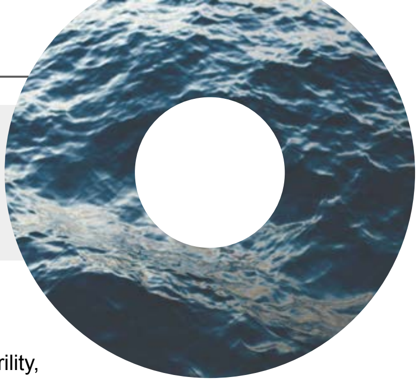
Marine-Based Production Systems

Example Applications of Genetic Technology Abroad

The following applications of genetic technology are currently being researched, developed or implemented in overseas countries.

- Red sea bream with 20% increased meat yield. *Available for sale in Japan [59]*
- Sterile, disease resistant catfish. Transgenic modification with an alligator gene. *Developed, but not available for commercial production. [60]*
- Disease resistant shellfish (e.g. oysters and mussels). Scientists are exploring genes related to immune response to create shellfish that are more resilient to diseases. *Area of research in genomic technologies. [61]*
- Coral reef resilience. Scientists are investigating genetic modification techniques to enhance the resilience of corals to environmental stressors. *Resilient genes have been identified, further research required [62]*

Marine Environment **Introduction**



The marine environment tends to feel the impacts of climate change more severely when compared to terrestrial environments. Oceans possess a higher heat capacity than land, enabling them to absorb and retain more heat. Consequently, as the atmosphere warms due to climate change, much of this heat is absorbed by the oceans. Additionally, oceans absorb a significant portion of the carbon dioxide emitted into the atmosphere leading to ocean acidification.

The New Zealand aquaculture industry is confronted with significant challenges due to climate change and environmental concerns. These include:

- rising sea temperatures and ocean acidification posing threats to the growth and resilience of species
- extreme weather events which damage infrastructure and disrupt operations
- changes in water quality, driven by altered rainfall patterns negatively impacting the health and growth of aquaculture species.
- biosecurity risks associated with the spread of invasive species and diseases.

Some applications of genetic technology have emerged as possibilities to support aquaculture farming in addressing some of these environmental challenges globally.

Some notable advances being developed in several fish species outside of New Zealand include sterility, disease resistance and improved growth (see panel).

In the New Zealand context, traditional selective breeding programmes have shown success in addressing some of these sector challenges. These programmes are in their infancy in the domestic marine farming sector relative to established terrestrial farming programmes. However, the programmes show significant potential in the marine environment where gains can be scaled across production systems faster due to broadcast spawning reproduction dynamics. There is substantial potential in traditional selective breeding programmes for the aquaculture industry.

The use of modern genetic technology could be considered in aquaculture production to bolster sustainability and competitiveness further. However, at this point, several companies within the aquaculture sector and the aquaculture industry body have indicated that they are not interested in the use of genetic modified organisms in aquaculture production systems. This is due to a lack of domestic social and cultural acceptance of GM, as well as consumer demands and market access requiring GM-free production. **New Zealand aquaculture targets high-value markets and consumers, which currently have no tolerance for genetically modified products.**

Ability to Control the Spread of Genetically Modified Organisms Throughout the Marine Environment

Containability

New Zealand primarily farms shellfish, salmon, kingfish and freshwater crayfish in aquaculture production systems. Containing organisms and their gene flow in aquaculture production systems is difficult due to the vastness of marine environments, the dynamic nature of water currents and the challenges of monitoring and controlling organisms in an open and interconnected ecosystem.

- Farmed fish have a moderate risk of spreading throughout the environment. It is not unusual for a small number of escapes of fish from open net pens during normal operations. Some aquaculture certification standards, such as the Global Seafood Alliance Best Aquaculture Practices, currently applied by New Zealand aquaculture companies, require the recording and reporting of any escape incidents.
- Farmed shellfish, such as mussels and oysters, have a moderate-high risk of spreading throughout the environment. While they are attached to substrates, at times, farmed shellfish will drop off lines and can potentially spread throughout the marine environment. Further, farmed shellfish can also undergo spawning events. The larvae of shellfish are planktonic and can be carried by water currents over varying distances. The duration of the larval stage and the dispersal potential depend on species-specific factors and environmental conditions.

Consideration could be given to also using genetic modification techniques to create sterile organisms to prevent any gene flow into the broader environment. Additionally, sterility could have additional benefits in shellfish production as spawning events are often unpredictable and result in lower shellfish meat yield and flesh becoming less palatable for a period of approximately 3 months post spawning [63]. These spawning events make harvesting and processing post-spawn uneconomic.

Reversibility

Once a marine organism has escaped from an aquaculture farm, they have the potential to disperse over large distances due to water currents, migration patterns and their own movement capabilities. However, in many cases, if a fish escapes, it would stay circling the pen. Tracking and removing these escaped individuals may be very difficult, especially in vast marine environments or with organisms that can interbreed with wild populations.

Traceability

It is likely that any modification made to aquaculture farmed organisms would be visually indistinguishable from the wild-type and would require genomic testing to confirm the presence of the genetic modification. This would be able to be detected at any point during the supply chain of intentional distribution of an organisms, however, this is unlikely to be conducted during private or small scale fishing in regions where a modified organism may have spread to. Without tracking mechanisms for aquaculture farmed organisms, it would be effectively impossible to trace the spread throughout the environment.

Screening of Environmental Impacts in the Marine Environment

NB:
Depending on the genetic modification chosen, there may be significant impacts to the receiving environment that have not been outlined.

Climate and Air Quality
There may be some indirect effects from introducing genetically modified organisms into the marine environment, such as a change to greenhouse gas emissions from production or altered carbon cycles. However, it is likely that impact on climate and air quality would be minimal.

Biodiversity
If an organism is non-sterile and can spread throughout the environment, there may be an impact on biodiversity. It will be important to assess the potential for competition with native species, disruption of food chains or genetic contamination.

Water
As water is the immediate receiving environment for marine organisms, it is highly likely that there will be an impact to water quality (positive or negative). It will be important to consider if a modified marine organism results in changes to inputs in aquaculture farming and any changes to waste production.

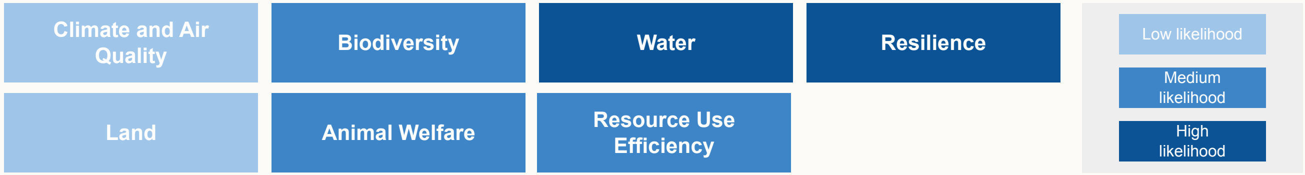
Land
Modified animals in the marine environment are unlikely to directly impact land, but there may be potential indirect effects, such as changes in land use for feed production or waste disposal.

Resilience
The strongest value proposition for modification of marine organisms is for increasing resilience to environmental stressors. It is likely that a modified organism may have a different tolerance to changing environmental conditions.

Animal Welfare
A marine organism that has been modified to be better suited to the environment may have better welfare. Conversely, due to the complexities of animal biology, there may be unintended impacts to a modified organism. It is important to consider whether the modifications may cause harm or distress to the organisms.

Resource Use Efficiency
A marine organism that has been modified to be better suited to its environment may have better resource utilisation, such as more efficient feed conversion. It will be important to consider any flow on impacts to water quality or resilience.

Likelihood of an application of genetic technology in the marine environment impacting an aspect of the receiving environment.
Note this does not indicate whether there will be a positive or negative impact, but the likelihood of an impact occurring.



Marine Environments
Considerations for Decision-Makers

Key Socio- Economic Impacts

Cultural Values: Taonga species are central to the identity and wellbeing of many Māori. Genetic modification of these species may not be culturally appropriate. Within New Zealand's marine environment, several taonga species are commercially fished. However, when it comes to commercial farming, kūtai (green-lipped mussels) and koura (freshwater crayfish) are among the few that are actively farmed in the country.

In order to ensure responsible and respectful practices, it is crucial to engage with Māori communities and seek their input to fully understand the implications of modifying taonga species in this manner. It is worth noting that the modification of taonga species could potentially contribute to their protection, restoration and economic development. Additionally, modifications may arise as secondary impacts resulting from the modification of introduced species. However, careful consideration and consultation with Māori are necessary to determine the appropriateness and potential consequences of such modifications, while respecting the cultural significance of these species.

Consumer Response: Certain New Zealand produced seafood products are recognised globally as premium products. A positive perception of New Zealand’s aquaculture brand is critical to its acceptance in high-value markets. The introduction of genetically modified organisms could result in a complete boycott of New Zealand aquaculture products by these premium consumers and markets. This has been seen to a lesser extent with the willingness to pay for frozen salmon significantly decreasing, as it challenges the perception of the ‘premium product’ [64]. It will be important to consider labelling requirements and accreditation schemes to allow for effective and trusted market differentiation to ensure the sector can maintain its premium brand.

Terrestrial-Based Production Systems

Example Applications of Genetic Technology Abroad

The following applications of genetic technology are currently being researched, developed or implemented in overseas countries:

- Slick cows - Cows with short and sleek hair coat have increased thermoregulation. *Gene editing deemed low-risk by the FDA, not available to general consumers yet. [65]*
- Sexed offspring in beef - altering the sex determining region Y protein 'SRY' to skew sex ratios of offspring. *Area of research but further development required [66]*
- Sheep born without tails. *Proof of concept demonstrated in mice [67].*
- Low methane cattle. *Heritability of phenotype documented but genetic technologies in this area are in early stage of development [68]*
- Mastitis resistance in cattle. *Gene for mastitis resistance currently being researched* [69]

Terrestrial Environment **Introduction**

Agricultural producers in New Zealand, particularly in the pastoral sector, are facing increasing challenges due to the variability in weather patterns. The frequency and intensity of extreme weather events, such as droughts, floods and storms, are disrupting farming operations and requiring adaptive measures to ensure industry resilience. Furthermore, changes in temperature and rainfall patterns are affecting the distribution and prevalence of pests and diseases, posing challenges for disease management and necessitating adaptive strategies.

In addition to these adaptive challenges, the New Zealand pastoral farming industry is also confronted with significant issues related to climate change and the environment. Greenhouse gas emissions, particularly methane and nitrous oxide, are a concern for the industry in terms of reducing its carbon footprint and meeting emission reduction targets. Additionally, nutrient runoff from intensive farming practices contributes to water pollution and degradation of freshwater ecosystems, necessitating improved water quality management. Soil erosion and degradation resulting from intensive grazing practices also require attention to maintain soil health and prevent sedimentation in waterways.

To address these challenges, some applications of genetic technology have emerged as possibilities for supporting the sector in adapting to environmental challenges and limiting its impact on biodiversity, climate and animal welfare. These technologies are currently being researched, developed or implemented in overseas countries (see panel).

It is worth noting that while genetic technology holds promise for addressing these challenges, conventional breeding methods also play a crucial role. Specific initiatives (see panel) are currently underway focusing on breeding animals with traits that contribute to environmental sustainability, climate resilience and improved animal welfare. These initiatives aim to find innovative solutions to reduce greenhouse gas emissions, manage pests and diseases, improve water quality and maintain soil health. While some of these research projects are still in the early stages, they hold great potential for supporting the agricultural sector in New Zealand.

Genetic modification, conventional breeding and the integration of genetic technology and conventional breeding methods may have the potential to help the New Zealand pastoral farming industry navigate the challenges posed by climate variability, environmental concerns and the need for sustainable practices.

Ability to Control the Spread of Genetically Modified Organisms Throughout the Terrestrial Environment

Containability

Terrestrial animal farm systems in New Zealand are predominantly based on pasture and are primarily livestock such as sheep, beef and dairy cattle, and deer. These animals can generally be contained within the farm boundaries with appropriate fencing and infrastructure. While there is a small risk of escape which may be impacted by the geographical location and rurality of a farm, farmers take proactive measures to prevent it and promptly address any breaches. The establishment of feral herds from escaped livestock without human intervention is relatively uncommon.

Reversibility

The ability to remove livestock with a specific gene from a pastoral farm depends on several factors. If the gene is easily identifiable and there are reliable genetic testing methods, it could be relatively manageable. If the gene is difficult to detect, it may pose challenges. Removing genetically modified products or products of genetically modified livestock from the supply chain would depend on the traceability of the genomic change. Additionally, while it may be plausible, the economic implications of reversing the presence of genetically modified livestock may also need to be considered, this includes potential impacts on productivity, market access and profitability.

Traceability

The ability to trace genetically modified livestock is influenced by the ability to visually distinguish between wild-type livestock and genetically modified livestock, however, as many traits will be not visually distinguishable, it is likely that identification requires genomic testing to confirm the presence of the genetic modification. The same genomic change would be able to be detected at any point during the supply chain of intentional distribution of the product in the same way as confirming the trait in the live animal. Additionally, all livestock are also tagged and traced through the NAIT system.

However, if the product was slightly removed in 'distance from human consumption', i.e. milk from genetically modified cows, this would be harder, if not impossible, to test for, and would require tracking mechanisms and documentation. Additionally, if the specific genetic change in the animal is undetectable, such as a change that could and does occur naturally in a specific species, it may indeed be impossible to identify any given animal or animal product as genetically modified.

This scenario highlights the challenges in traceability when the genetic modification is indistinguishable from natural variations, further emphasising the importance of robust identification and labelling systems to ensure transparency and consumer confidence.

Screening of Environmental Impacts in the Terrestrial Environment

NB:
Depending on the genetic modification chosen, there may be significant impacts to the receiving environment that have not been outlined.

Climate and Air Quality

Some research for modification of terrestrial organisms is focused on reducing the climate impact of terrestrial farming. If this is the intention of the modification, it is likely that climate and air quality will be impacted. With other modifications it will be important to assessing the potential for altered carbon cycling, greenhouse gas emissions or changes in air quality.

Biodiversity

Genetically modified organisms will interact with other organisms in the receiving environment. Their introduction may also result in a change in management practices that may impact biodiversity. However, terrestrial farming systems are relatively contained, so any impact may be able to be managed. It would be important to assess the potential changes in competition with native species, disruption of food chains or genetic contamination.

Water

It unlikely that there will be a direct impact to water quality from genetically modified animals in the terrestrial environment. However, there may be indirect impacts from their waste products or changes to farm management practices that result in changes to nutrient run-off.

Resilience

Modified animals in a terrestrial environment would likely be selected on the basis of contributing to the sector's overall sustainability and resilience. Genetically modified organisms may impact the environmental sustainability of the sector and hence its resilience.

Land

Genetically modified animals could potentially impact land use through changes in grazing patterns. It will also be important to assess the potential for increased or decreased land use, as well as the associated impacts on ecosystems and biodiversity.

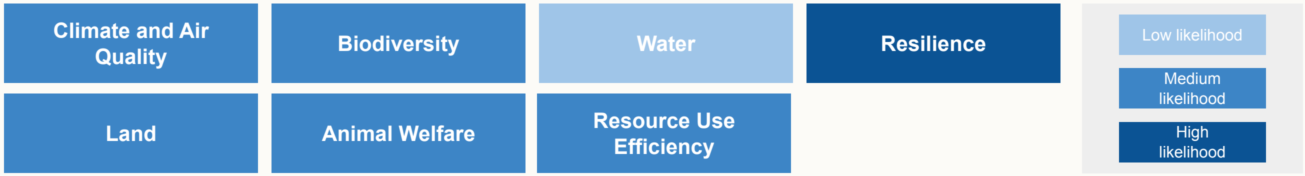
Animal Welfare

Terrestrial organisms that have been modified to be better suited to the environment are likely have better welfare. Conversely, due to the complexities of animal biology, there may be unintended impacts to a modified organism. It is important to consider whether the modifications may cause harm or distress to animal.

Resource Use Efficiency

A modified terrestrial animal may result in changes to resource utilisation, such as changes to feed conversion efficiency and final yield.

Likelihood of an application of genetic technology in the terrestrial environment impacting an aspect of the receiving environment. *Note this does not indicate whether there will be a positive or negative impact, but the likelihood of an impact occurring.*



Terrestrial Environment
Considerations for Decision-Makers

Other Potential Applications

Biomedical applications: Genetic technology can be used for biomedical applications, such as modifying livestock to produce therapeutic proteins or pharmaceuticals in their milk or eggs, which can be used for the treatment of various diseases in humans. For example, Scientists from AgResearch in New Zealand have developed transgenic goats that produce monoclonal antibodies or mAbs, a known candidate for anti-cancer therapy. With further research, the transgenic goats may prove to produce large volumes of the protein through their milk without the expensive production costs of the same protein in lab-controlled environment [70].

Key Socio- Economic Impacts

Innovation: The only Ministry for Primary Industry approved containment facility for genetically modified livestock is set to close June 2025. This will limit the ability for New Zealand to conduct further research on applications of genetic technology in animals. New Zealand researchers are currently looking to partner with other countries to meet their research needs, however, this upcoming lack of critical infrastructure will significantly impede innovation.

Equity: The costs associated with accessing genetic modification technologies can be significant. If these costs are high, it may create barriers for certain groups or individuals to access and benefit from these technologies. This could lead to inequitable distribution of the benefits associated with genetic modification. Further, if the ownership and control of these technologies are concentrated in the hands of a few entities, it may limit access and control for others, particularly marginalised communities. This can lead to inequitable distribution of benefits and power imbalances, significantly impeding local innovation. Decision-makers may need to consider regulatory frameworks and policies to safeguard against inequitable distribution of costs and benefits and to promote fairness and sustainable development.

Cross-Systems Pest Control

Example Applications of Genetic Technology

The following applications of genetic technology are currently being researched, developed or implemented in overseas countries.

- Gene drive in mosquito populations. *Proof of concept to generate total population collapse identified in laboratories [71].*
- Gene drive in common wasps. *Identified potential for gene drive for population suppression for wasps and other haplodiploid pests [72].*
- Gene drive in mice to induce female infertility. *Proof of concept for use of t-CRISPR technology in mice [73].*
- Gene drive in possums. A potential area of research. *Work is underway to sequence the genome of possums. If this occurs, many hurdles remain including requiring a huge breeding programme of altered possums to be released [74].*

Cross-Systems Pest Control
Introduction

Invasive predators, such as stoats, weasels, ferrets, rats, wasps, deer and goats are a distinct threat to New Zealand biodiversity. Their consumption of native plants and habitats disrupts ecological processes that leads to ecological imbalances and habitat degradation, disrupting reproductive cycles, competing with native species and hindering natural regeneration.

Various conventional techniques, such as trapping, poisoning and fencing have been employed to control these invasive species. However, despite these efforts, the impact of predators persists and their populations continue to pose a threat to native biodiversity and the New Zealand environment.

A gene drive for pest control has emerged as a potential solution. This a genetic engineering technique that aims to spread a specific gene throughout a population rapidly that will lead to sterile offspring (either male or female) for the pest, halting and reversing population growth in pests. Gene drives are being developed and tested with high levels of success in mosquito populations in laboratories and there is a lot of excitement surrounding their potential application in combating invasive predators in New Zealand (see panel).

Invasive wasps, such as the German and common species, have inflicted significant damage to New Zealand's ecosystem and primary sector, resulting in an estimated annual cost of $133 million [75].

Traditional pest control methods have proven inadequate in managing their populations. Recently New Zealand researchers have proven the potential for a gene drive to offer large scale control for these wasps.

While the success with wasps is promising, it's crucial to acknowledge the inherent differences between wasps and other predators in New Zealand, particularly mammals like rats, mice, possums and stoats. Unlike invasive wasps, mammalian pests possess distinct biological functions and reproductive mechanisms, complicating the application of a gene drive. Currently, there is limited evidence regarding the feasibility and effectiveness of employing a gene drive for mammalian pests. Ethical considerations, potential unintended consequences and ecological impacts also add complexity to exploring these possible applications.

Ability to Control the Spread of Genetically Modified Organisms Throughout the Ecosystem Environment

Containability

While animals and insects tend to stick to certain habitats over others, pests have high survivability in many different types of terrain and habitat, which means that they can cross geological borders and survive in forest, alpine and urban environments. This results in extremely low containability. However, for a successful gene drive to occur, the goal is to have as many of the modified organisms spread and breed with as many other wild-type organisms as possible in order to increase transmission of this gene to subsequent generations. Therefore, in this case, the lower the containability of an organism, the more effective it is.

Note, if this application was employed on an island and organisms could not fly or swim to leave the island, then this application could be considered ‘containable’.

Reversibility

The ability to remove pests with a specific gene from an ecosystem depends on several factors, including containability and the ability to identify the modified animals through genetic testing. As mentioned above, it is highly likely that modified organisms will disperse over large distances. As uncontained spread is the intended outcome of this scenario, reversing this activity would be near impossible, with the exception that the organism is released on a ‘containable’ island, which even then, would likely require a high degree of tracking, from point of release and would be resource intensive.

Traceability

It is likely that any modification made to ecosystem organisms would be visually indistinguishable from the wild-type and therefore would require genomic testing to confirm the presence of the genetic modification. Due to the inherent desire for a gene drive species to rapidly spread, it would be a challenge to trace modified organisms. If used on mammals, microchips or digital collars could be used to track organisms, but this also introduces a cost that may not be economically viable.

Screening of Environmental Impacts in Ecosystems

Climate and Air Quality
Animals, including pests and predators have been known to affect ecosystems, influencing native plant health, the composition of ecosystems, and forest regeneration and subsequent carbon sequestration.

Biodiversity
Introducing a pest control gene drive is proposed to have a high likelihood of impacting biodiversity. Changes to pest populations in ecosystems will change the composition and therefore biodiversity of these ecosystems.

Water
There is a low likelihood that introducing a pest control gene drive is proposed to have an impact on water. There may be marginal effects on water depending on the ability to conserve plants and forestry that would otherwise be destroyed by pests.

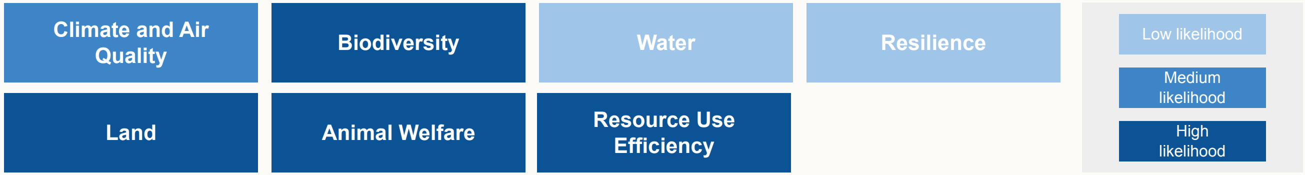
Resilience
There is low likelihood that introducing a modified animal in ecosystems would affect resilience.

Land
Modified animals in the ecosystems are highly likely to have an impact. Pest presence can change the type and number of plants present in an ecosystem, influencing forest regeneration and susceptibility to slips and erosion.

Animal Welfare
Modified animals in the ecosystem's environment are highly likely to impact animal welfare, as animals are highly interdependent on other species that share the ecosystem. Animals will experience fewer mortalities directly and indirectly from pests and predators. Modified animals in the ecosystem, such as a gene drive, is also a more humane way of managing pest and predator populations - intervention prevents birth instead of inflicting a painful death.

Resource Use Efficiency
An ecosystem organism that has been modified is likely to have better resource utilisation. Pest control requires a huge amount of labour and spend to keep pest populations under control. Changes in the pest population will affect the resource use in this sector.

Likelihood of an application of genetic technology in the ecosystem environment impacting an aspect of the receiving environment. *Note this does not indicate whether there will be a positive or negative impact, but the likelihood of an impact occurring.*



NB:
Depending on the genetic modification chosen, there may be significant impacts to the receiving environment that have not been outlined.

Pest Control
Considerations for Decision-Makers

Application Effectiveness	**Wasp Gene Drive:** There is evidence to support the potential for a gene drive application to provide widespread and cost-efficient control of wasps in New Zealand [70]. **Mammalian Predators:** The application's effectiveness for mammals is currently not feasible. There are significant proposed potential issues, which limit the use of this technique in mammals due to their more complex biological processes and population dynamics. While a successful gene drive for coat color has recently been demonstrated in mice, achieving the same level of success in terms of sterility is considerably distant, making it premature to generate excitement or promises about its applicability in mammals.
Other Potential Applications	**Further Research into Gene Drives in Insects:** Conceptually, while mammals may not be appropriate candidates, similar pathways for gene drive mediated control in other invasive insect species could be explored, e.g. the great white butterfly, which poses a threat to brassica crops and native cresses.
Key Socio- Economic Impacts	**Community Values:** Pests and predators are a commonly known and publicly understood problem. This is highlighted by high levels of engagement with initiatives, such as 'Bird of the Year', which raises awareness of conservation threats to native birds. Predator Free 2050 is also widely known and supported policy strategy and many members of the public volunteer with DOC to track and trap pests in their communities. However, in order to provide social comfort, there may need to be serious consideration of how this weighs against with the inability to contain, reverse or trace the genetically modified organisms released. **Cultural Values:** The unwanted introduction of invasive animals, plants and pathogens directly endanger how tikanga Māori and te ao tūroa (the natural world) continuously interplay. A 2017 survey found that Māori feel strongly about biosecurity and its role in keeping Aotearoa free from pests, diseases and invasive predators, and thereby preserving (and developing) tikanga Māori [76]. However, when exploring the use of gene-editing for pest control, it is important to consider various Māori values such as whakapapa (organism relationships), tika (what is right or correct), manaakitanga (cultural and social responsibility), mana (justice and equity), tapu (restrictions), kaitiaki (guardianship), and whanaungatanga (valuing and supporting whānau).

Synthesis

Conclusion

This report thoroughly examines the risks and potential impacts of modern genetic technology in the food and fibre sector, with a particular focus on its environmental impact. It investigates how three different regulatory approaches can alter the observed effects and considers the socio-economic factors associated with various applications and the sector at large.

While it does not predict the exact outcome of a change in regulatory approach by New Zealand, this report presents a range of potential impacts, both positive and negative, on the environment, and to a lesser degree society and the economy.

The aim of this evaluation is to encourage decision makers involved in shaping and responding to future changes in the regulation of modern genetic technology to consider the potential consequences of their actions on the food and fibre sector, the communities and environments it operates in, its intersection with cultural outcomes and Māori perspectives, and the markets and consumers who benefit from its products and services.

This analysis provides decision makers with evidence to question the appropriateness of different applications of this technology, to differentiate between those that offer sufficient benefits and to consider those that may be best avoided. Together with the exploration of regulatory scenarios, this will facilitate more informed decision making regarding both regulations themselves and how the food and fibre sector adapts to different regulatory scenarios in the future.

A Framework of Considerations

To further assist decision makers, a framework has been developed that consolidates the specific aspects identified throughout the analysis. This framework does not provide predetermined actions or recommendations. It serves as a tool to encourage critical thinking and informed decision making regarding the integration (or not) of genetic technology into New Zealand's food and fibre production system. This supports decision makers to navigate the complexities and uncertainties of genetic technology more effectively and make informed decisions that align with their objectives.

The framework is provided on the following page.

Key Considerations for Assessing Environmental Risk of Genetic Technology

1 What are the environmental challenges New Zealand is facing? What is the potential for genetic technology in addressing these challenges?

- What is driving environmental degradation? How will food and fibre sectors be impacted by environmental degradation?
- How can decision makers incentivise research and development of mitigative or adaptive solutions to environmental challenges? Particularly including research into the potential of modern genetic technology in a New Zealand context.
- What role can genetic technology play in adapting and managing the impact of these environmental stressors?
- Are there any alternative solutions that could address the impact of these environmental stressors (i.e. selective breeding programmes)?

2 What are the environmental risks and impacts associated with applications of modern genetic technology?

- What infrastructure and expertise is required to understand the environmental impacts and risks of modern genetic technology?
- How can regulation enable science and research to create a strong evidence base of efficacy, risks and impacts of modern genetic technologies?
- How could the use of genetic technology change production systems? Do these system changes have the potential to impact climate, water or biodiversity outcomes?

3 How might the use of modern genetic technology impact New Zealand society and the economy?

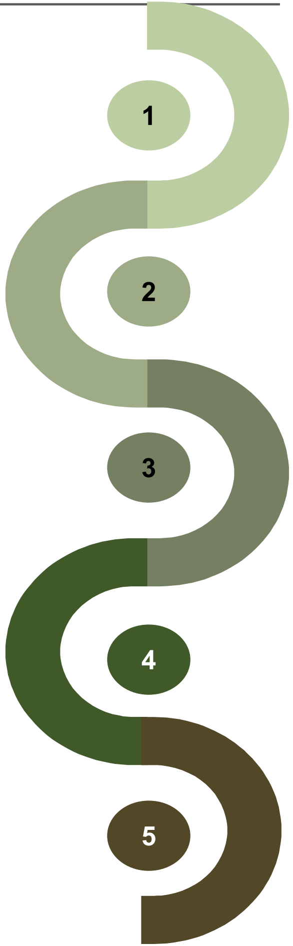
- How might the type of genomic technique impact community, cultural and consumer views?
- How might the purpose of an application of genetic technology impact community, cultural, and consumer views?
- What approach are New Zealand's major trading partners taking to the use of genetic technology?
- How might different approaches to the use of genetic technology impact New Zealand as an exporter of food and fibre products?

4 How can environmental and societal risks and impacts associated with the use of modern genetic technology be mitigated?

- Is it possible to contain, reverse or trace the spread of an application of genetic technology through the environment?
- What processes, accreditation schemes and regulation are required to protect industry's ability to differentiate in the market?
- How can government and industry uphold equity of access and impact with new technologies?

5 What regulatory and adaptive governance approaches result in the best outcomes for New Zealand?

- How can regulations related to genetic technology encourage innovation and experimentation while maintaining risk management and accountability?
- What adaptive governance approaches can be employed to continuously update regulations regarding genetic technology based on evolving scientific knowledge, technological advancements and societal priorities?



Appendix A: Rapid Flowering Apple Tree Model

Model Logic

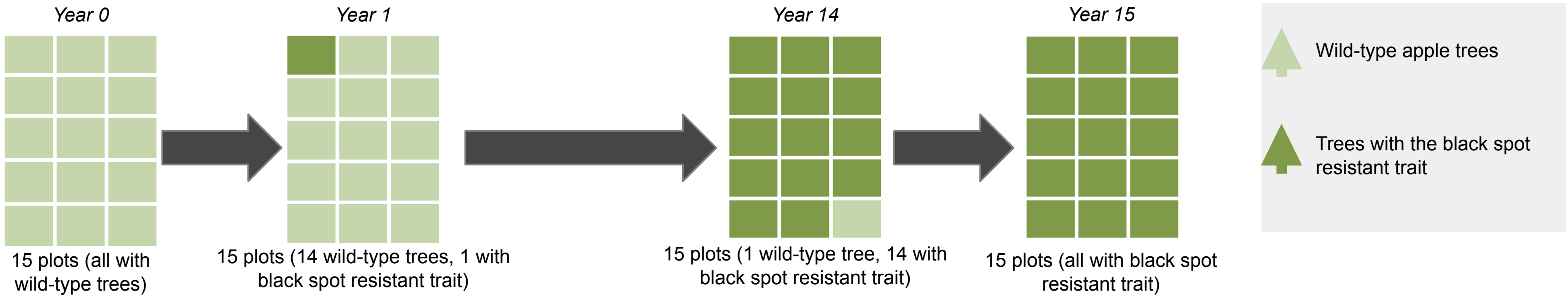
(1) Time to achieve blackspot trait in modelled scenario and counterfactual scenario.

The model first and foremost models the timelines for when a black spot resistant apple tree would be available to orchards. This is achieved through maintaining a constant total number of breeding cycles required to breed for this trait, whilst using two scenarios for the length of these breeding cycles: the first being through rapid flowering apple trees and the second using conventional breeding methods. The benefits measured are then representative of the time saved by orchards from adopting the trait achieved through rapid flowering vs breeding the trait naturally. *Figure 24* below provides a high-level visual of this benefit period.

(2) Once the trait is available, the model then looks at the impacts on a single representative apple orchard.

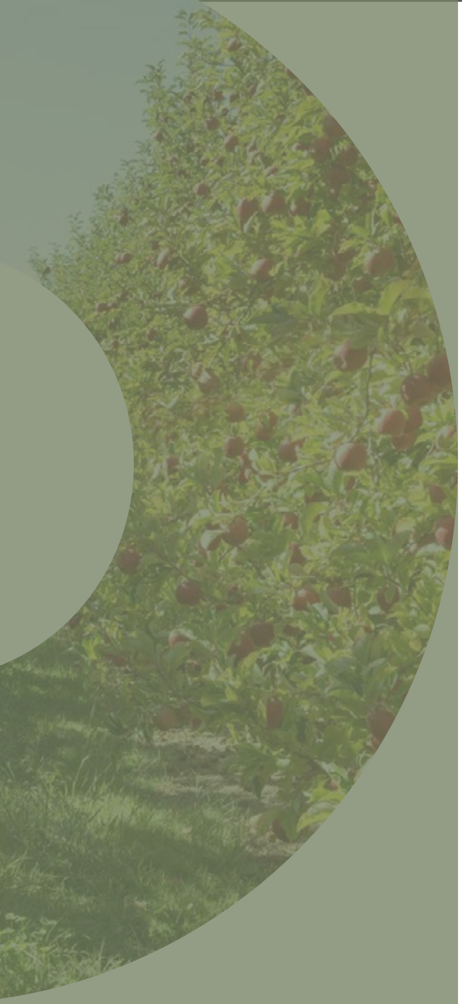
The orchard is defined by its size, the total number of apple trees, its annual apple yield, including how many are lost to black spot, and its current number of sprays used to try and prevent fungi. Once a black spot resistant apple tree is available the orchard begins to transition its current stock of apple trees to this new black spot resistant apple tree. This is based on the input for the timeframe it would take the orchard to completely transition, and assumes that they would undergo an equal fraction of this transition each year. The diagram below provides a visual representation of this replacement process. As the orchard transitions, their yield lost to black spot and chemical use will decline.

Figure 24: Transition logic of an orchard adopting cultivars with black spot resistant trait.



(3) Adoption of null-segregated black spot resistant apple trees among all apple orchard owners in New Zealand.

This considers how many apple orchards might choose to adopt this (peak adoption rate) and how long this transition will take. Using an adoption curve, the model begins transitioning individual orchards to adopt black spot resistant apple trees breed through rapid flowering in the year that they begin their adoption. This gives us the nationwide impact of this technology.



Model Outputs

Rapid flowering apple trees enable an accelerated time frame to breed desirable traits in apple trees. This model explores how using this technique could achieve a black spot resistant trait in apple trees quicker than conventional breeding. Specific to this trait, orchards would expect to have a reduction in the number of apples lost to black spot (outcome one) and reduce the chemicals used on orchards to prevent black spot (outcome two).

Our analysis is completed for three different breeding scenarios.

- The *low breeding scenario* reflects an increased time period to produce the trait and slower replacement from apple orchards.
- The *high breeding scenario* reflects a decreased time period to produce the trait and faster replacement from apple orchards.
- The *base breeding scenario* takes the midpoint of our range used in the high and low scenarios.

Through scenario analysis the variability in time to achieve the black spot resistant trait is tested between using a rapid flowering tree and conventional breeding. Under the low scenario there is a longer time period to obtain the trait and therefore orchards receive greater benefit from the accelerated breeding of the desirable trait. The inverse is true for the high scenario.

The analysis has also been completed assuming the apples are 100% resistant to black spot with the new trait, but additionally the report includes sensitivity testing where it has been assumed the black spot resistant trait is effective only 75% of the time. **The results of this analysis are found on the following pages.**

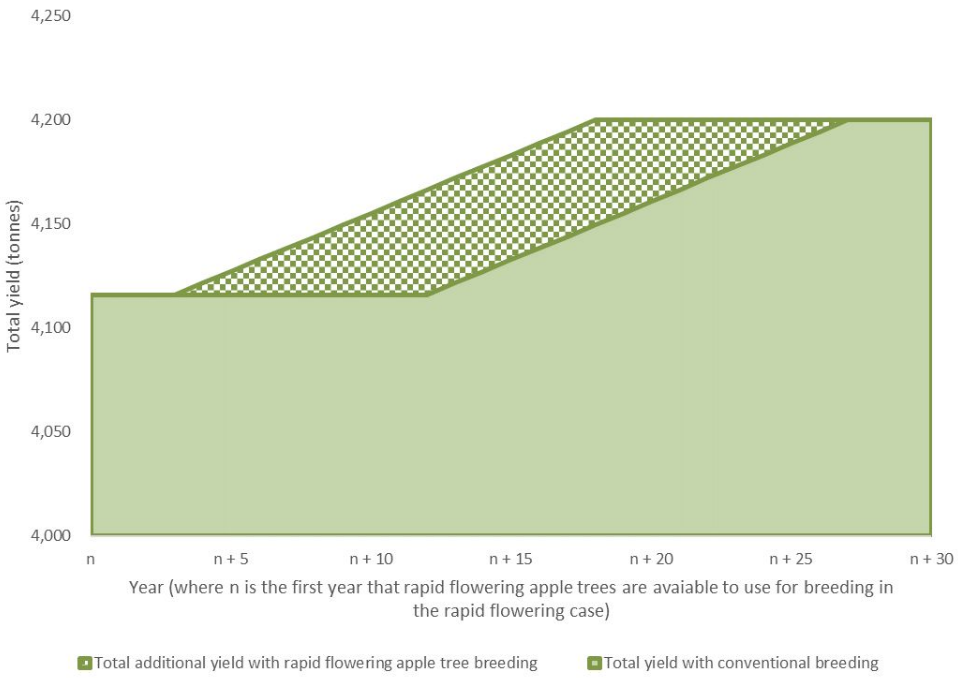
Outcome One: Total yield (1 of 2)

The model looks at a single orchard, representative of an average non-organic apple orchard in New Zealand. From time 0, the model then begins to explore two scenarios: the first is where black spot resistant trait has been bred using rapid flowering apple trees and is available for the model orchard to introduce, and the second uses conventional breeding to obtain the trait. As discussed within the assumptions table below, both scenarios have the same number of breeding cycles, however the length of these breeding cycles is significantly reduced through using rapid flowering apple trees. In the base case, this results in the trait being available after 2 years using rapid flowering apple trees, and 12 years using conventional breeding (given there has already been 30 years worth of progress made to date (equivalent to 5 breeding cycles).

Once the trait is available, the model orchard will then begin to adopt the tree over a period of 15 years. The trait could be available at time n, through rapid flowering apple tree breeding, or delayed (at n+10) through conventional breeding. Once the trees reach maturity and produce apples, the total apple yield will increase due to less being lost to black spot. This is all shown in *Figure 25*, illustrating the additional apples (in the checkered area) that will be able to be sold as a result of shorter breeding cycles. This accounts for 760 tonnes of apples in total.

n.b. Due to current farm management practices, black spot only impacts a small proportion of trees within an orchard, so the total yield change is small. However, overseas regulation in large export markets like China does not allow imports of apples from orchards where black spot is present. This means that an orchard many only get a 1% yield increase in annual yield from the black spot trait, but there is likely to be a much greater increase in exportable yield for some high paying export markets.

Figure 25: The total yield of apples on a single orchard that chooses to adopt black spot resistant trees, illustrating the delay between when these trees will be available through rapid flower breeding and conventional breeding.

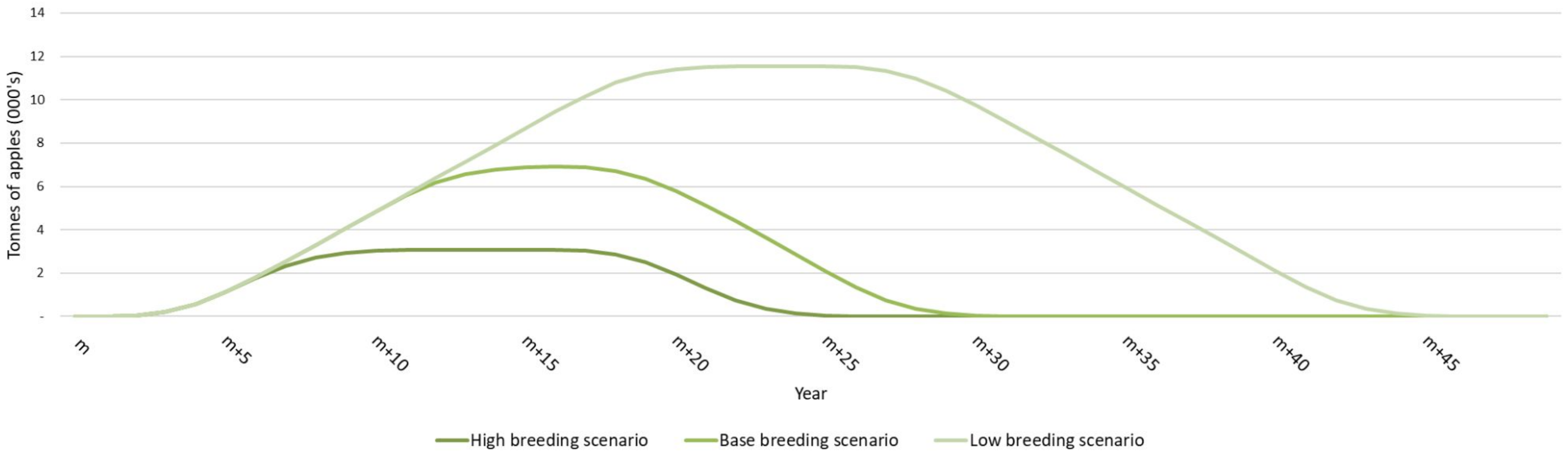


Outcome One: Total yield (2 of 2)

The model then explores, if this technology diffused across the apple industry, the potential implications for all of New Zealand. Drawing on the ADOPT model outputs (as noted in the assumptions table below), 98% of all apple orchards nationally will adopt this technology over 7 years, starting from time 'm' - beginning their individual transition to having black spot resistant apple trees from the null-segregant. The ADOPT model considers the natural diffusion of technology, given the incentives for individual orchard owners.

Figure 26 below looks at the change in total yield, when comparing orchards that adopt the fast flowering obtained trait vs orchards that breed the black spot resistant trait conventionally in three breeding scenarios. The high breeding scenario captures the case where it takes less time to breed the trait in both the rapid flowering case and the conventional case, whereas the low breeding scenario is where it takes longer. The model predicts that over the forecast period there will be **an increase in total yield of 105,000 tonnes of apples** with the adoption of this technology nationally, under our base scenario this peaks at an annual increase in yield of 7,000 tonnes of apples.

Figure 26: Annual increase in yield (tonnes of apples) when scaled up nationally comparing the case where a black spot resistant trait is achieved through breeding with rapid flowering apple trees to conventional breeding.

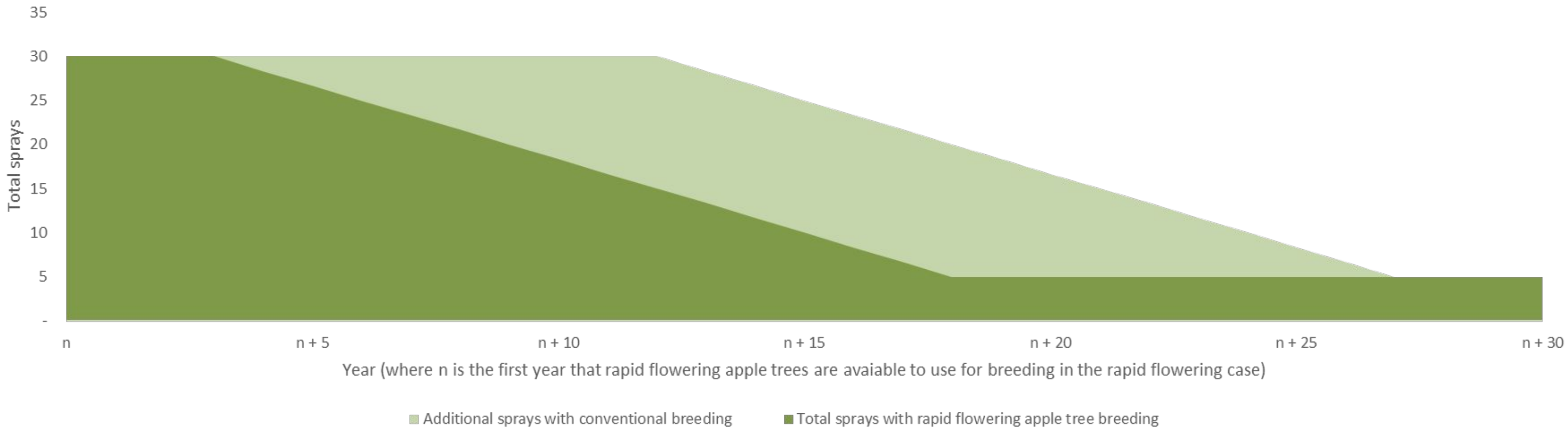


Outcome Two: Fungi prevention (1 of 2)

Alongside an increase in apple yield, orchards can expect to reduce the total number of sprays they complete in a single year to prevent black spot. Currently, an orchard conducts about 30 sprays a year, and with all their trees containing a black spot resistant trait, they could expect to reduce these sprays down to 3 to 10 sprays a year (depending on other fungi present). We consider a base case of a reduction to 5 sprays.

The reduction in the number of sprays, as seen in *Figure 27*, captures the decrease in the total number of black spot prevention sprays used on a single model orchard due to the adoption of a black spot resistant tree. The timeline in reducing this is accelerated by the use of rapid flowering apple trees saves a total of 225 sprays. With all else constant, changing the total number of sprays from 5 to 10 will save 180 sprays in total, whilst changing to 3 would save 243 sprays in total.

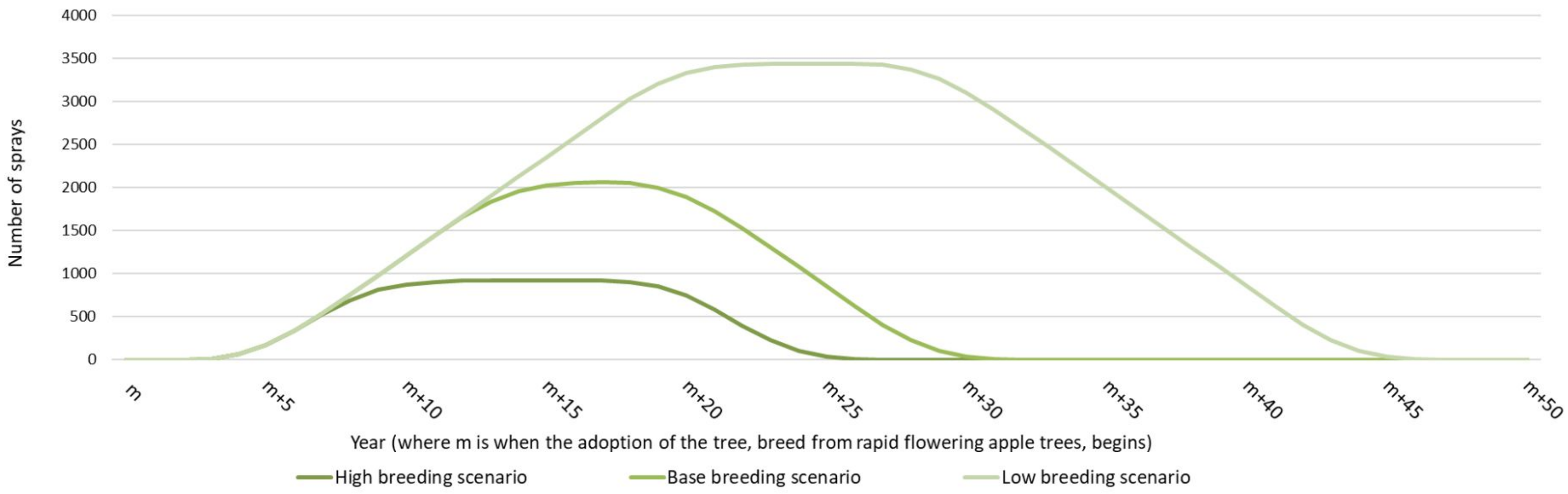
Figure 27: The total number of sprays on an orchard that adopts black spot resistant apple trees, illustrating a delayed timeline between when the trait is available between rapid flowering apple tree breeding and conventional breeding.



Outcome Two: Fungi prevention (2 of 2)

We once again draw on the ADOPT model outputs to better understand how the use of fungicide sprays may change with the adoption of this technology at a national level. *Figure 28* uses the same three breeding scenarios, and looks at the reduction in the total number of black spot prevention sprays, when comparing an orchard that adopts black spot resistant traits on different timelines, depending on when the trait is available. The model predicts that over the forecast period there will be a total reduction of 30,000 sprays with the adoption of this technology nationally, under our base scenario (15,000 - 80,000 in the high and low breeding case respectively).

Figure 28: The annual reduction in number of sprays on a single apple orchard comparing the case where a black spot resistant trait is achieved through breeding with rapid flowering apple trees to conventional breeding.



Model Inputs, Assumptions and Sources (1 of 4)

Input	Unit	Justification / other assumptions / notes	Source	Value (base case)	Low case (if applied)	High case (if applied)
Average orchard inputs						
Average size of an apple orchard	ha	Based on the commercial scale requirements of 25 ha of land and an additional orchard manager being required when an orchard surpass 60 ha in size.	n.d. (2024). *Commercial apple and pear (pipfruit) growing NZ: statistics and guidance*. Tupu.nz. Retrieved February 23, 2024, from https://www.tupu.nz/en/fact-sheets/apples-and-pears	70		
Yield	Tonnes / ha	The average NZ production per hectare is 60 tonnes. Our range is based on MPI model orchards and high density orchards.	n.d. (2024). *Commercial apple and pear (pipfruit) growing NZ: statistics and guidance*. Tupu.nz. Retrieved February 23, 2024, from https://www.tupu.nz/en/fact-sheets/apples-and-pears	60		
Impact of rapid flowering inputs						
Incidence of black spot	% / year	This low range has been based on an orchard where disease is managed and is profitable. If the rate of black spot gets too high then orchards will not be profitable. Orchards cannot also sell to large export partners like China if they experience any black spot.	Discussed with stakeholders.	2%	1%	3%
Number of sprays annually used to prevent fungi	# / year	N/A	Discussed with stakeholders.	30		
Number of sprays annually used to prevent fungi **after** an orchard transitions to black spot resistant trees	# / year	N/A	Discussed with stakeholders.	5	10	3
We have assumed that the model apple orchard will introduce rapid flowering trees at the same rate annually, until 100% of the farm is using rapid flowering trees. This is known as the age of replacement	Years	Based on discussions with SMEs we expect orchards to replace their current apple trees at a rate of 5-10%.	Discussed with stakeholders.	15	10	20

Model Inputs, Assumptions and Sources (2 of 4)

Input	Unit	Justification / other assumptions / notes	Source	Value (base case)	Low case (if applied)	High case (if applied)
Impact of rapid flowering inputs (cont)						
Number of breeding cycles until trait is produced	#	This is assumed to vary between 8 and 10 breeding cycles to breed a new targeted trait.	Discussed with stakeholders.	7	10	6
Current breeding cycle of status quo apple trees	Years		Discussed with stakeholders.	6		
Breeding cycle of rapid flowering apple trees	Years		Discussed with stakeholders.	1		
Total amount of time taken to a breed black spot resistant trait conventionally	Years	Based on the breeding cycle inputs	Discussed with stakeholders.	42	60	36
Total amount of time taken to breed a black spot resistant trait using rapid flowering apple trees	Years	Based on the black spot breeding cycle inputs	Discussed with stakeholders.	7	10	6
Current time spent working towards breeding the black spot resistance trait naturally	Years	NZ apple farmers have spent the last 30 years working towards producing apple trees with the black spot resistant path.	Discussed with stakeholders.	30		
The stand down time for new GE trees (assumed to be the null-segregant)	Years	Apple trees start producing sellable apples around 3 years after being planted. By five years they are producing significant amounts of apples. Therefore we have taken a midpoint of 4 years for our stand down period as this smoothes the growth period from 3 to 5 years.	Discussed with stakeholders.	4		

Model Inputs, Assumptions and Sources (3 of 4)

National adoption inputs (without intervention)						
Total land area planted with apples	ha	The source provides an estimated for the total land area in 2022. We assume that there has not been significant growth from this.	https://figure.nz/chart/KUrywEnAVzQynaJQ-ecDwlsUU455YxAMK	9,811		
Number of orchards	#	This is a calculation based on the average number of hectares per apple orchard, and the total land area allocated to apple orchards.		140		
Peak adoption rate	%	Value derived from the ADOPT model. This derived an estimate for the input based on the responses to 22 questions about the target market and the innovation. These 22 questions and the responses are attached below, along with some discussion on the results. The responses assumed that there would be a financial gain for the plantation owners through adopting the technology.	Kuehne G, Llewellyn R, Pannell D, Wilkinson R, Dolling P, Ouzman J, Ewing M (2017) Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy, Agricultural Systems 156:115-125 https://doi.org/10.1016/j.agsy.2017.06.007	29		
Time to peak adoption	Years	Value derived from the ADOPT model. This derived an estimate for the input based on the responses to 22 questions about the target market and the innovation. These 22 questions and the responses are attached below, along with some discussion on the results. The responses assumed that there would be a financial gain for the plantation owners through adopting the technology.	Kuehne G, Llewellyn R, Pannell D, Wilkinson R, Dolling P, Ouzman J, Ewing M (2017) Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy, Agricultural Systems 156:115-125 https://doi.org/10.1016/j.agsy.2017.06.007	12		

Model Inputs, Assumptions and Sources (4 of 4)

#	ADOPT question	ADOPT response
1	Profit orientation	All most all have maximising profit as a strong motivation
2	Environmental orientation	A minority have protection of the environment as a strong motivation
3	Risk orientation	About half have risk minimisation as a strong motivation
4	Enterprise scale	Almost all of the target farms have a major enterprise that could benefit from this innovation
5	Management horizon	All most all have a long-term management horizon
6	Short term constraints	A minority currently have a severe short-term financial constraint
7	Trialable	Easily trialable
8	Innovation complexity	Moderately difficult to evaluate effects of use due to complexity
9	Observability	Easily observable
10	Advisory support	About half use a relevant advisor
11	Group involvement	A majority are involved with a group that discusses farming

#	ADOPT question	ADOPT response
12	Relevant existing skills and knowledge	Almost none will need new skills or knowledge
13	Innovation awareness	It has never been used or trialled in their district(s)
14	Relative upfront cost of the project	Minor initial investment
15	Reversibility of the innovation	Difficult to reverse
16	Profit benefit in years that it is used	Very large profit advantage in years that it is used
17	Future profit benefit	Large profit advantage in the future
18	Time until any future profit benefits are likely to be realised	6 - 10 years
19	Environmental costs and benefits	Moderate environmental advantage
20	Time to environmental benefit	6 - 10 years
21	Risk exposure	Small increase in risk
22	Ease and convenience	No change in ease and convenience

Questions and responses provided using the ADOPT model for sterile Douglas-fir trees to get the peak adoption rate and time to peak adoption among Douglas-fir plantation owners.

Appendix B: Hi-CT White Clover Model

Model Logic (1 of 2)

Adoption of Hi-CT White Clover into the dairy farming system and effective consumption of white clover

We initiate our analysis by constructing a model of a representative farm within each of the five dairy farm systems (ranging from System 1 -100% home-grown feed to System 5 - 50-69% home-grown feed) . This model takes into account factors such as the total pasture area of the farm and the yearly transition of pasture to include the targeted area of Hi-CT White Clover. Subsequently, we determine the "effective number of cows consuming Hi-CT White Clover," accounting for the percentage of feed that is home-grown and the proportion of the sward composed of Hi-CT White Clover. The following diagram outlines the transition logic of a case study ‘system 3’ dairy farm, where it takes on average a farmer 8 years to resow his paddocks with Hi-CT White Clover.

Year 0 *Year 4* *Year 8*

130 ha (8 plots)

WC is 25% of the sward, and 85% of feed is home-grown. Therefore WC is 17% of total diet for cows.

130 ha (8 plots)

WC is 25% of the sward, and 85% of feed is home-grown. Therefore WC is 17% of total diet for cows.
50% of WC consumed is Hi-CT. As 17% of total diet for cows is WC, Assuming a linear relationship, cows receive 50% x 17% of total benefit from Hi-CT WC

130 ha (8 plots)

WC is 25% of the sward, and 85% of feed is home-grown. Therefore WC is 17% of total diet for cows.
100% of WC consumed is Hi-CT. As 17% of total diet for cows is WC, Assuming a linear relationship, cows receive 100% x 17% of total benefit from Hi-CT WC

Model Logic (2 of 2)

Impact of Hi-CT White Clover

Using the effective number of cows consuming white clover as a basis, we then compute the total changes in milk production, methane emissions, nitrous oxide emissions, ammonia production, and bloat incidence.

National impact of Hi-CT White Clover

Subsequently, we simulate the adoption of Hi-CT White Clover across the entire dairy farming population, following an adoption curve for each of the farm systems. This gives us the nationwide impact of this technology.

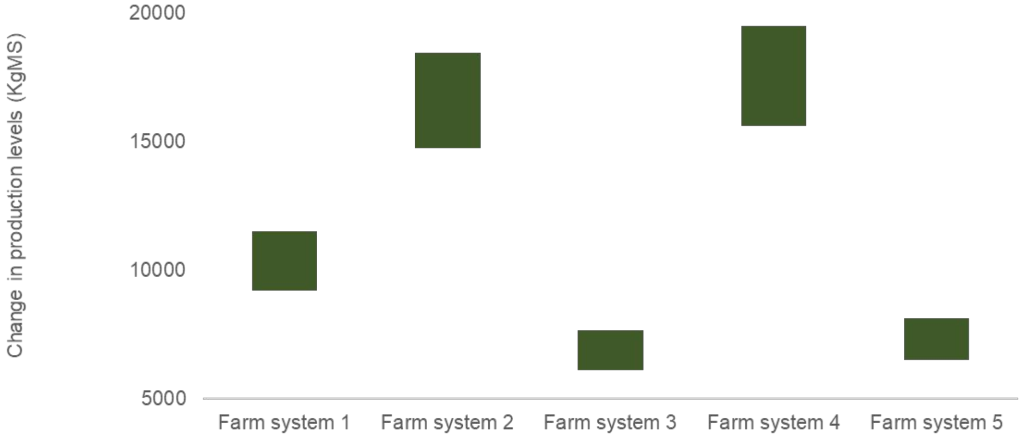
Model Outputs

Hi-CT White Clover could produce a suite of benefits for dairy systems that use it. The evidence to support the existence of these benefits is strong, however, the extent of these benefits in the context of New Zealand dairy farming has not been tested. As mentioned in the assumptions table from page 137, the potential percentage change in a variety of outcomes will have an estimated range. This section will explore, based on these ranges, what the hypothetical reach of these benefits could be on a single dairy farm and on a national level. The outcomes that will be explored are productivity gains, methane emission reduction, urinary nitrogen reduction and a decrease in the loss of cow life due to bloat.

Outcome One: Productivity Gains

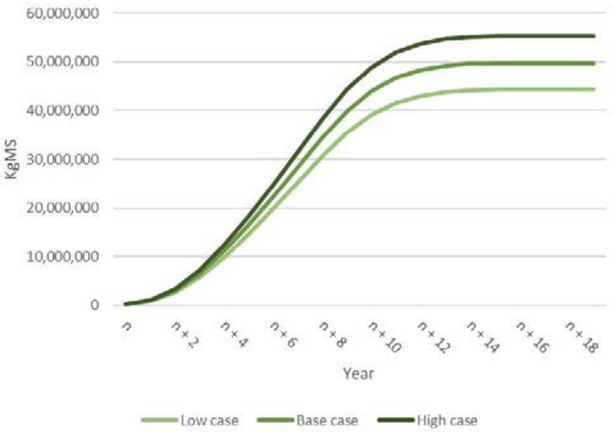
The proportional impact per cow of introducing Hi-CT White Clover is not uniform across the farm systems. This is driven by the varying proportion of the cow's diet that is home-grown and the original production levels. The overall on-farm impact is also influenced by average herd size of each farm system. As noted in the assumptions table from page 137, the impact of Hi-CT White Clover on production levels is assumed to range from a 8% to a 10% increase. In the base case (a 9% increase), the absolute change in production levels after a complete transition to using Hi-CT White Clover (in KgMS) ranges from up to 6,000KgMS on a farm system 3 farm to up to 20,000KgMS on a farm system 4 farm. *Figure 29* below shows the potential range for a production increase as a result of fully integrating this forage into their pasture systems.

Figure 29: Range in potential increases in production level by farm system through the full integration of Hi-CT White Clover into the farm system.



Nationally, based on the assumed adoption curve of this technology across all dairy farms, using Hi-CT White Clover could generate an additional 50 million KgMS per annum in the base case. This is based on the assumption that using Hi-CT White Clover can generate up to 9% more production. In the low case, of a 8% increase, the production levels would be closer to a 45 million KgMS increase, whilst in the high case with a 10% increase in production levels, the increase could be as high as 55 million KgMS.

Figure 30: Increase in production nationally in the low, base and high case.



Outcome Two: Methane Emissions

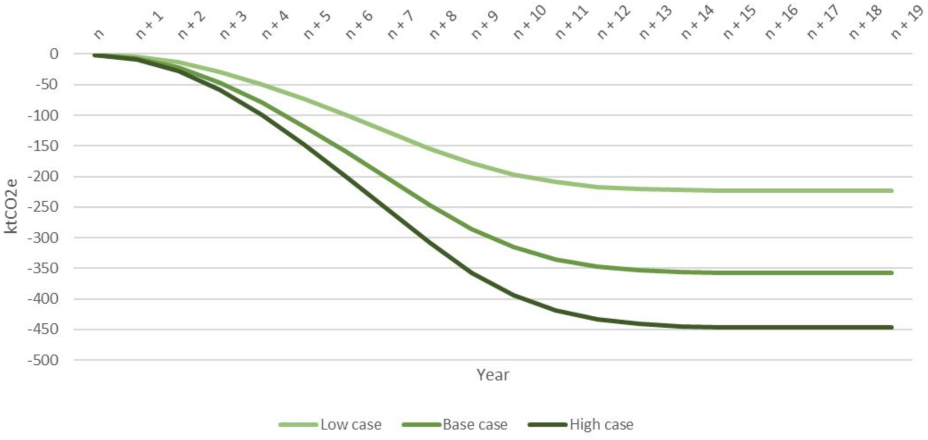
Much like with change in production levels, characteristics of the different farm systems will impact the reduction in their methane emissions. As noted in the assumptions table from page 137, Hi-CT White Clover could reduce methane emissions by 5-10% per cow per annum. After a farm system has fully integrated Hi-CT White Clover into its pasture, it could reduce its methane emissions by 25 to 140 tCO2e per farm, depending on the farm system. The potential impact could be the highest on farm system 2, due to the higher herd size on average and a relatively high proportion of the cow's diet being from home-grown feed.

Figure 31: Range in potential changes in methane emissions by farm system through the full integration of Hi-CT White Clover into the farm system.

New Zealand currently has a goal of reducing biogenic methane emissions to 10% below 2017 levels by 2030, and between 24% and 47% by 2050. In absolute terms, in 2017 there was a total of 33,500 ktCO2e of methane emissions, of which, the dairy industry was a leading contributor. Therefore to achieve the goal, there would need to be a 3,350 ktCO2e reduction in methane emissions by 2030, and at least 8,040 ktCO2e by 2050.

If national adoption of this began in the next 10 years, by 2050, methane emissions could be reduced by 220 to 440 ktCO2e, which would contribute 3 - 5% towards the 2050 goal of a 24% reduction in 2017 levels. These numbers could be further increased by increasing the peak adoption rate.

Figure 32: Change in methane emissions nationally in the low, base and high case.



Outcome Three: Urinary Nitrogen

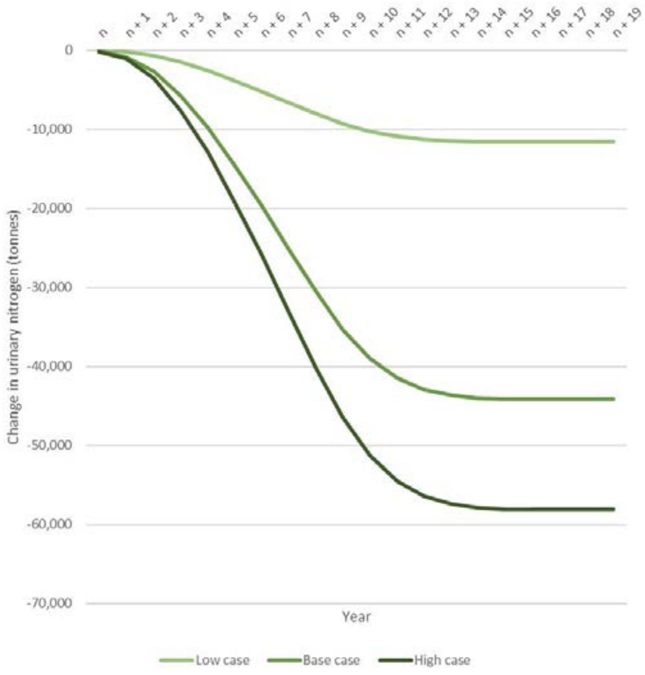
Increased condensed tannins have been shown to reduce urinary nitrogen (Lagrange, 2021, as referenced in the assumptions table from page 137). This will have implications for nitrous oxide emissions and nitrogen leaching. Whilst there is evidence to support the extent to which urinary nitrogen can be reduced with condensed tannins, the flow on implications for its byproducts is hard to determine. The model therefore only estimates the impacts on urinary nitrogen to signal the scale of the potential impact. It shows that farms could expect to reduce their total urinary nitrogen from 2 to 18 tonnes per annum.

It is unclear what the implications of this will be on the farms' pasture systems. With a reduction in the natural nitrogen application, there is a risk that farmers will look to increase their synthetic nitrogen use. However, there is a ceiling on how much they can use of 190 kg/ha/year, which implies that farmers could face an absolute decline in nitrogen in their soil - which may have negative consequences for their productivity and therefore impact their incentives to use this product.

Figure 33: Range in potential changes in urinary nitrogen by farm system through the full integration of Hi-CT White Clover into the farm system.

Drawing on the same adoption curve, national adoption of Hi-CT White Cover could see a decline in total urinary nitrogen of 10,000 to 60,000 tonnes per annum by 2039.

Figure 34:Change in urinary nitrogen nationally in the low, base and high case.



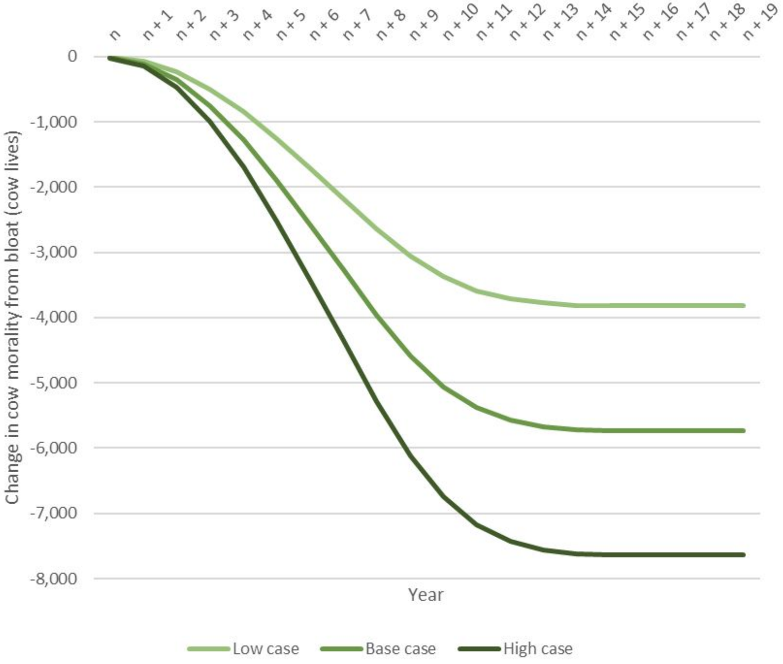
Outcome Four: Bloat Mortality

Hi-CT White Clover is suspected to reduce the incidence of bloat (as suggested in McAllister, 2019, *full reference in assumptions table*), and therefore the number of mortalities from bloat. As noted in the assumptions table from page 137, the extent of this impact is unknown. The model explores the possibility for it to reduce by bloat by 50% through to complete elimination. This has been included as the "high case". However, this could be lower, such as a 50% reduction, which has been noted as the low case. The base case is 75%, the midpoint. However, it is emphasised that this is theoretical and is not backed by strong evidence. Based on this, the model shows that farms can expect to save anywhere from 0.5 to 2.5 cow lives each year. The extent of this depends on the farm system and, ultimately, herd size.

Figure 35: Range in potential changes in bloat mortality by farm system through the full integration of Hi-CT White Clover into the farm system.

On a national level, by 2039, the model suggests that New Zealand could expect to save 4,000 to 7,500 cow lives per annum through reducing the mortality from bloat.

Figure 37: Change in bloat mortality nationally in the low, base and high case.



Model Inputs, Assumptions and Sources (1 of 5)

Input	Unit	Justification / other assumptions / notes	Source	Farm system 1	Farm system 2	Farm system 3	Farm system 4	Farm system 5
Farm specific inputs based on farm systems								
Total number of farms	farms	From connect DairyNZ, we estimate that farm system 1 & 2 account for 28% of all dairy farms. We assume that there is a 50/50 split between farm system 1 and 2, therefore account for 14% each. We also know that there are an estimated 11,000 dairy farms in New Zealand, leading us to estimate that there are 1,540 farm system 1 and 2 dairy farms in New Zealand. From connect DairyNZ, we estimate that farm system 3 accounts for 48% of all dairy farms. We also know that there are an estimated 11,000 dairy farms in New Zealand, leading us to estimate that there are 5,280 farm system 3 dairy farms in New Zealand. From connect DairyNZ, we estimate that farm system 4 & 5 account for 24% of all dairy farms. We assume that there is a 50/50 split between farm system 4 and 5, therefore both account for 12% each. We also know that there are an estimated 11,000 dairy farms in New Zealand, leading us to estimate that there are 1,320 farm system 4 and 5 dairy farms in New Zealand.	https://connect.dairynz.co.nz/content/22334e05-52ea-4763-abba-80898ee3017e/owner-operator-regional-and-systems-financial-analysis.html#production-systems-1 https://licnz.com/about/nz-dairy-industry/#:~:text=New%20Zealand%20farms%20just%20under.the%20year%20ending%20April%202023 .	1540	1540	5280	1320	1320
Total area	ha	These inputs have been derived from a case study on DairyNZ and are assumed to be representative of an average farm in this farm system.	Farm system 1 Farm system 2 Farm system 3 Farm system 4 Farm system 5	168	230	129	141	75
Herd size	cows			350	510	300	540	290
Stocking rate	cows/ha			2.1	2.2	2.3	3.8	3.9
Production total per year	KgMs/year			115,000	194,110	89,913	260,000	134,900
Profit / ha	$/ha			$4,596	$2,283	$2,341	$3,840	$5,471
% of total feed that is home-grown	%			100	95	85	75	60

Model Inputs, Assumptions and Sources (2 of 5)

Input	Unit	Justification / other assumptions / notes	Source	Value (base case)	Low case (if applied)	High case (if applied)
General farm inputs						
Average yearly methane emissions per dairy cow	tCO_2e / cow / year	DairyNZ states that the average cow produces 98kg of methane each year. In tCO_2e, this is converted by multiplying it by a factor of 29.8 to get 2.92 tonnes.	DairyNZ https://ecometrica.com/assets/GHGs-CO2-CO2e-and-Carbon-What-Do-These-Mean-v2.1.pdf	2.92		
The amount of urinary nitrogen	Tonnes / cow	This article states that the average cow excreted 210 grams of urinary nitrogen a day. This equates to 76 kg (or 0.076 tonnes) per annum.	https://www.nzherald.co.nz/nz/cow-pee-200-tonnes-of-nitrogen-leaching-each-day/S6TNZVZZL5IALY3D4N4EIRMZRM/	0.076		
Cow mortality rate per annum from bloat	% / year		https://www.msdvetmanual.com/digestive-system/diseases-of-the-ruminant-forestomach/bloat-in-ruminants	0.5		
Percent of sward that uses white clover	%	This model assumes Hi-CT White Clover comprises at least 25% of the pasture sward, as the impacts detailed in the literature are consistent with this concentration. White clover's contribution to total pasture yield has been estimated at around 20%. Further research is required to quantify the impact of Hi-CT White Clover at different pasture concentrations.	Caradus, J. R., Woodfield, D. R., & Stewart, A. V. (1995). Overview and vision for white clover. NZGA: Research and Practice Series, 6, 1-6. Roldan, Marissa B., et al. (2022). Condensed tannins in white clover (Trifolium repens) foliar tissues expressing the transcription factor TaMYB14-1 bind to forage protein and reduce ammonia and methane emissions in vitro. Frontiers in Plant Science 12: 777354. Duval, B.D., Aguerre, M., Wattiaux, M. et al. Potential for Reducing On-Farm Greenhouse Gas and Ammonia Emissions from Dairy Cows with Prolonged Dietary Tannin Additions. Water Air Soil Pollut 227, 329 (2016). https://doi.org/10.1007/s11270-016-2997-6	25		
Percent of pasture replaced each year	%	Derived from the assumption that dairy farms completely replace all pasture every 8 years.		12.5		

Model Inputs, Assumptions and Sources (3 of 5)

Input	Unit	Justification / other assumptions / notes	Source	Value (base case)	Low case (if applied)	High case (if applied)
Impact of Hi-CT White Clover ***(these are all measures based on a cow consuming 100% pasture with at least 25% white clover)***						
The increase in production per cow per year	% / year		Waghorn, G. C., 2008. Beneficial and detrimental effects of dietary condensed tannins for sustainable sheep and goat production - progress and challenges. Anim. Feed Sci. Technol., 147 (1/3): 116-139 Woodfield, D. (2020). Seed and Nutritional Technology Development PGP Programme Final Report. Retrieved from mpi.govt.nz.	9	8	10
The decrease in methane emissions per cow	% / year		Roldan, Marissa B., et al. (2022). Condensed tannins in white clover (Trifolium repens) foliar tissues expressing the transcription factor TaMYB14-1 bind to forage protein and reduce ammonia and methane emissions in vitro. Frontiers in Plant Science 12: 777354.	8	5	10
The decrease in urinary nitrogen	% / cow	It is difficult to estimate the impact of condensed tannins on nitrogen leaches and nitrous oxide emissions, due to the physiological and ecological complexities from rumen through to byproduct. To approach this, the model will focus only on the urinary nitrogen, which will act as a proxy for the potential reduction in its subsequent byproducts. The source provided highlights a few studies that illustrated that condensed tannins will reduce urinary nitrogen. The number used in the base case (38%) arises from Grosse Brinkhous et al (2016) who illustrated the difference in urinary nitrogen when cows were fed sainfoin over alfalfa pellets - a product with higher condensed tannins.	Lagrange, S., MacAdam J., Villalba, J. (2021). *The Use of Temperate Tannin Containing Forage Legumes to IMprove Sustainability in Forage-Livestock Production.* Agronomy, 11, 2264.	38	10	50
The decrease in the number of cows experiencing bloat	% / year	The evidence is weak to suggest the strength of the impact, but does support the idea that there will be one. The range provided is therefore large.	McAllister, T., Acharya, S., Wang, Y., Sottie, E. (2019). *Using condensed tannin containing forages to establish sustainable and productive forage-based cattle production systems.* Archivos Latinoamericanos De Producción Animal 23 (6). Retrieved from: http://ojs.alpa.uy/index.php/ojs_files/article/view/2671	75	50	100

Model Inputs, Assumptions and Sources (4 of 5)

Input	Unit	Justification / other assumptions / notes	Source	Value (base case)	Low case (if applied)	High case (if applied)
Adoption inputs (without intervention)						
Peak adoption rate	%	Value derived from the ADOPT model. This derived an estimate for the input based on the responses to 22 questions about the target market and the innovation. These 22 questions and the responses are attached below, along with some discussion on the results. The responses assumed that there would be a financial gain for the plantation owners through adopting the technology.	Kuehne G, Llewellyn R, Pannell D, Wilkinson R, Dolling P, Ouzman J, Ewing M (2017) Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy, Agricultural Systems 156:115-125 https://doi.org/10.1016/j.agsy.2017.06.007	45		
Time to peak adoption	Years	Value derived from the ADOPT model. This derived an estimate for the input based on the responses to 22 questions about the target market and the innovation. These 22 questions and the responses are attached below, along with some discussion on the results. The responses assumed that there would be a financial gain for the plantation owners through adopting the technology.	Kuehne G, Llewellyn R, Pannell D, Wilkinson R, Dolling P, Ouzman J, Ewing M (2017) Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy, Agricultural Systems 156:115-125 https://doi.org/10.1016/j.agsy.2017.06.007	9		

Model Inputs, Assumptions and Sources (5 of 5)

#	ADOPT question	ADOPT response
1	Profit orientation	A majority have maximising profit as a strong motivation
2	Environmental orientation	About half have protection of the environment as a strong motivation
3	Risk orientation	About half have risk minimisation as a strong motivation
4	Enterprise scale	Almost all of the target farms have a major enterprise that could benefit from this innovation
5	Management horizon	About half have a long-term management horizon
6	Short term constraints	A minority currently have a severe short-term financial constraint
7	Trialable	Easily trialable
8	Innovation complexity	Slightly difficult to evaluate effects of use due to complexity
9	Observability	Difficult to observe
10	Advisory support	A majority use a relevant advisor
11	Group involvement	A majority are involved with a group that discusses farming

#	ADOPT question	ADOPT response
12	Relevant existing skills and knowledge	Almost none will need new skills or knowledge
13	Innovation awareness	It has never been used or trialled in their district(s)
14	Relative upfront cost of the project	Minor initial investment
15	Reversibility of the innovation	Difficult to reverse
16	Profit benefit in years that it is used	Small profit advantage in years that it is used
17	Future profit benefit	Moderate profit advantage in the future
18	Time until any future profit benefits are likely to be realised	6 - 10 years
19	Environmental costs and benefits	Large environmental advantage
20	Time to environmental benefit	6 - 10 years
21	Risk exposure	Small increase in risk
22	Ease and convenience	No change in ease and convenience

Questions and responses provided using the ADOPT model for Hi-CT White Clover to get the peak adoption rate and time to peak adoption among dairy farmers.

Appendix C: Douglas-fir Model

Model Logic (1 of 2)

This model considers two applications of sterile Douglas-fir trees. The first is for transitioning plantations and the second is for new plantations. The model logic for both are outlined below:

Application One: Transitioning Plantations

New Zealand currently has Douglas-fir plantations covering approximately 95,000ha. These all have various ages and therefore different harvesting dates. This application considers the replacement of the Douglas-fir trees once they are harvested, comparing the impacts if they were to be replaced with sterile trees instead of standard ones. The model considers the implications of Douglas-fir forestry's contribution to New Zealand's wilding problem. To do this, the model considers two cases, one where all future replantings are non-sterile and the case where all future harvested Douglas-fir are replanted with sterile Douglas-fir.

In the first case, the model assumes that New Zealand's plantations contribute to the wilding area at a consistent rate per annum. These wildings, once they have reached maturity, will then also contribute wildings at the same rate, inferring exponential growth in the absence of any wilding control programme.

The second case utilises the same logic, however, the total plantation area that contributes to New Zealand's wilding problem will decrease as it is re-planted with sterile Douglas-fir. After a full harvesting lifecycle, the total area of plantations contributing to New Zealand's wilding will be zero.

The plantations contribution to the wilding problem is considered on top of the pre-existing wilding problem. The current area of New Zealand impacted by wilding Douglas-fir trees will also continue to grow at the same rate per annum.

Model Logic (2 of 2)

Application Two: New Plantations

This model considers a future where the industry plants a consistent number of hectares to Douglas-fir trees each year indefinitely. These are all considered to be sterile Douglas-fir trees. This is considered to be in place of pastoral-based farming uses of the land, where in both this case and the case with sterile Douglas-fir trees, there is no contribution to New Zealand's wilding problem. The core impacts of this will be on the additional carbon sequestered from the atmosphere and additional production volume of timber.

To model the carbon sequestered, the model draws on the government's accounting method and carbon tables for carbon sequestration. This measures carbon as the trees grow, until they reach their average age (which for Douglas-fir is 26), where the amount of carbon sequestered within that final year is then considered the average amount of carbon sequestered overtime for that hectare of land planted with Douglas-fir. This is based on the understanding that the amount of carbon will continue to grow, until the point of harvest where a proportion of the total carbon sequestered will then be released back into the atmosphere. The average age accounts for this to provide a consistent estimate over time.

The model also considers the theoretical possibility that sterile Douglas-fir trees will have a shorter harvesting lifecycle, due to faster tree growth (assuming that both have the same harvesting volume at the point of harvest). The model increases the total amount of carbon sequestered at the average age by the percentage increase in tree growth. This assumes that faster tree growth will result in a higher average amount of carbon sequestered over time.

For production volume, the model considers the total amount of timber collected at the point of harvest - determined by the average recoverable volume per hectare. This also draws on the assumption that sterile trees grow faster, and therefore have a shorter harvesting lifecycle. Once timber is harvested, the model assumes that it is re-planted again with Douglas-fir.

Model Outputs

The future of the Douglas-fir industry is uncertain. Currently there is hesitation to plant this species due the high risk of wilding. Assessment with the Wilding Tree Risk Calculator requires plantations with a high risk of potential wilding to obtain resource consent. The uncertainty of obtaining resource consent introduces a hurdle that may affect economic viability of initiating a plantation. Having access to sterile trees could cause a significant shift in attitude, resulting in a higher number of existing forestry hectares being allocated to this species, as well as the potential for new land sites to become viable for forestry. Without access to sterile trees, existing sites would likely plant other less valuable trees that are less invasive. In the latter case, where new sites become viable, it is uncertain what the alternative land use might be.

The main model output from application one is the new area of wildings from time n, where n is when we begin to consider the additional consistent number of hectares planted each year. The second application considers the secondary outputs of additional carbon sequestered and production volume. This is based on the assumption that sterile Douglas-fir trees have faster tree growth.

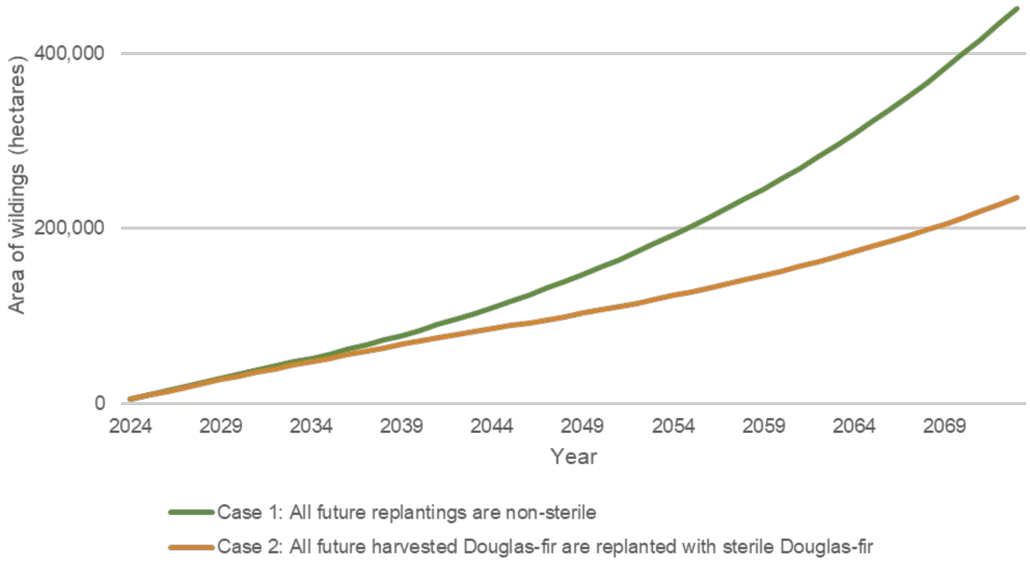
Outcome One: Hectares Impacted by Wildings (1 of 2)

The primary benefit from sterile Douglas-fir trees is the reduction in area impacted by wildings. Because new plantations would be in place of pasture-based farming, new plantations will not have a net impact on the area impacted by wilding. Transitioning plantations will be the source of the benefit for less area impacted by wildings.

Figure 38 illustrates the additional area of wildings contributed to by pre-existing Douglas-fir plantations from 2024 in two cases: the first where all future plantings (from 2024) are non-sterile standard Douglas-fir, and the second case where all future re-plantings are sterile (from 2024). Because the re-plantings occur at the point of harvest, there will be non-sterile Douglas-fir in both cases contributing to the wilding problem. In case 2, the number of non-sterile Douglas-fir will decrease as they are replaced with the sterile type, reducing the direct contribution from the plantation to zero. However, the contribution to wildings that occurred before this point will then start to wild themselves. As a result, there is exponential growth in both cases. This assumes that there are no wilding-removal programmes.

The difference in 50 years between the two cases is approximately 200,000 ha of area of wildings. In the grand scheme of things, given the current level of Douglas-fir wildings (~800,000 ha), this will only account for a 2% difference in 50 years time. Whilst this may seem negligible, it represents the idea that removing the source of wildings will play a crucial on-going role in achieving no area of wilding in a vital partnership with wilding control programmes.

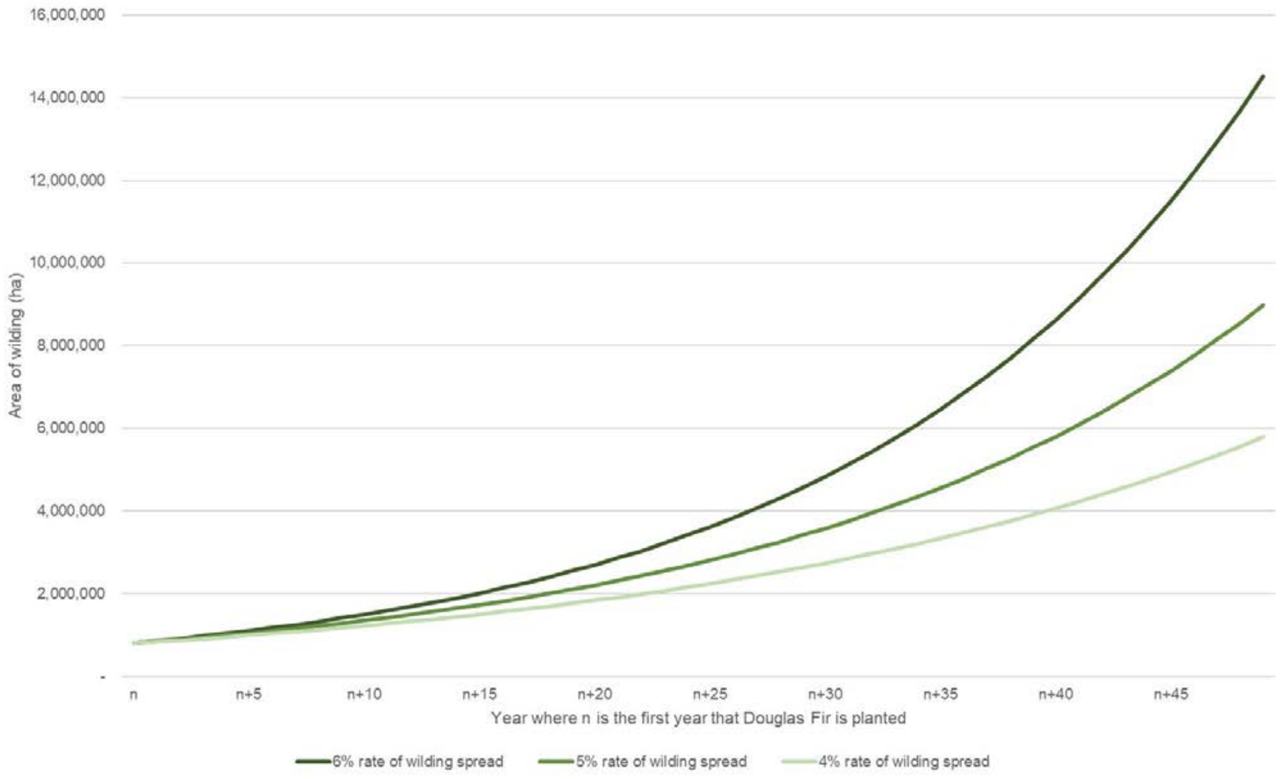
Figure 38: The number of hectares of wildings for transitioning plantations.



Note this model shows exponential growth but in reality there would be a geographical cap on the amount of wilding that would occur in a region.

Outcome One: Hectares Impacted by Wildings (2 of 2)

Figure 39: Sensitivity analysis on the rate of growth of wilding area utilising the case where none of the future Douglas-fir trees are sterile.



It is important to caveat that these model outputs are highly sensitive to the rate of increase in wilding area. To illustrate this, *figure 39* illustrates the outputs in the case where none of the future Douglas-fir trees are sterile when using three different rates of wilding spread (4, 5, and 6%).

50 years after the first planting, the area of wilding ranges from 6 to almost 15 million ha when changing the wilding rate from 4% to 6%. **This jump is very significant, highlighting this input as a key sensitivity.**

Estimating the true value of the rate of change is extremely challenging. In practice, this will be driven by a number of factors such as wind patterns, the age of the trees, and the recipient environment. Therefore, it is vital that we emphasise the role of this model is to illustrate the rough impact and not provide precise estimates.

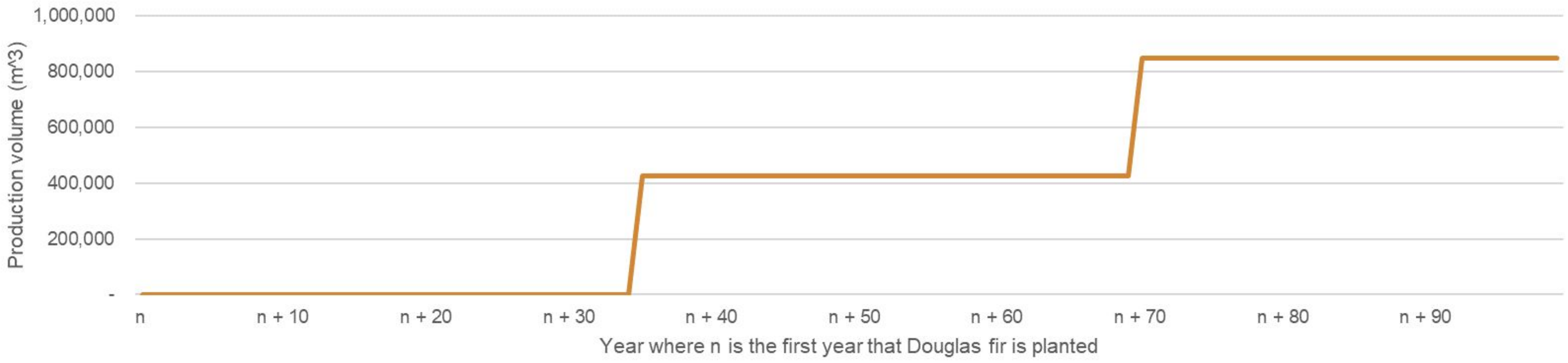
Note this model shows exponential growth but in reality there would be a geographical cap on the amount of wilding that would occur in a region.

Outcome Two: Production Volume

It is theorised that if sterile Douglas-fir trees can be achieved through the removal of their cones, that this will result in faster tree growth. This is based on the idea that the energy that would have otherwise been put into growing cones, is redirected into tree growth. As a result of this theory, the harvesting life cycle of Douglas-fir trees will shorten, unlocking the ability to harvest the trees earlier (given that they will be harvested at the same production volume). The implications of this on the aggregate production volume is summarised in *Figure 40* below for new plantations.

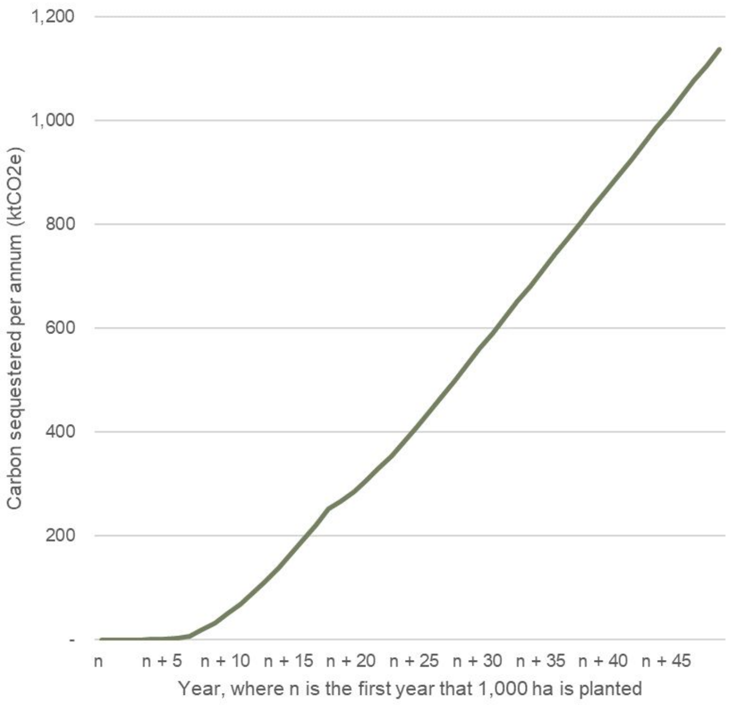
The model assumes that there is a consistent harvesting life cycle of 35 years for sterile Douglas-fir, 5 years less than for the standard type. Recalling that the first block of land is planted in year n, there is therefore nothing to harvest until year n+35. In this year, the first block of land is harvested (and hence the first jump in production volume) and replanted with more Douglas-fir, and there is an additional 1,000ha of Douglas-fir trees planted (as noted within our model logic). Therefore, another 35 years later (so year n+70), there will be 2,000 ha worth of land that is harvested, explaining the second jump up in production volume.

Figure 40: Production volume for new plantations (1,000 ha planted each year indefinitely) planting sterile Douglas-fir.



Outcome Three: Carbon Sequestration

Figure 41: The total amount of carbon sequestered from new plantations of sterile Douglas-fir.



Douglas-fir sequesters carbon as it grows. A proportion of this is then released at the point of harvest. The New Zealand government accounts for this through utilising an average amount of carbon sequestered each year to allow for a consistent stream of income for carbon credits. The model utilises this concept to represent the moving average of the amount of carbon sequestered per annum for new plantations of sterile Douglas-fir.

The model also subscribes to the idea that sterile Douglas-fir grows faster than standard Douglas-fir. Therefore, it will sequester carbon faster. It is assumed that the percentage increase in growth rates is equivalent to the percentage increase in carbon sequestered each year.

The resulting estimated of the additional amount of carbon sequestered from new plantations each year is summarised in *Figure 41*. This shows a linear increase in the amount of carbon sequestered, reaching an additional 1,000 ktCO2e sequestered roughly 40 years after the first 1,000 ha is planted.

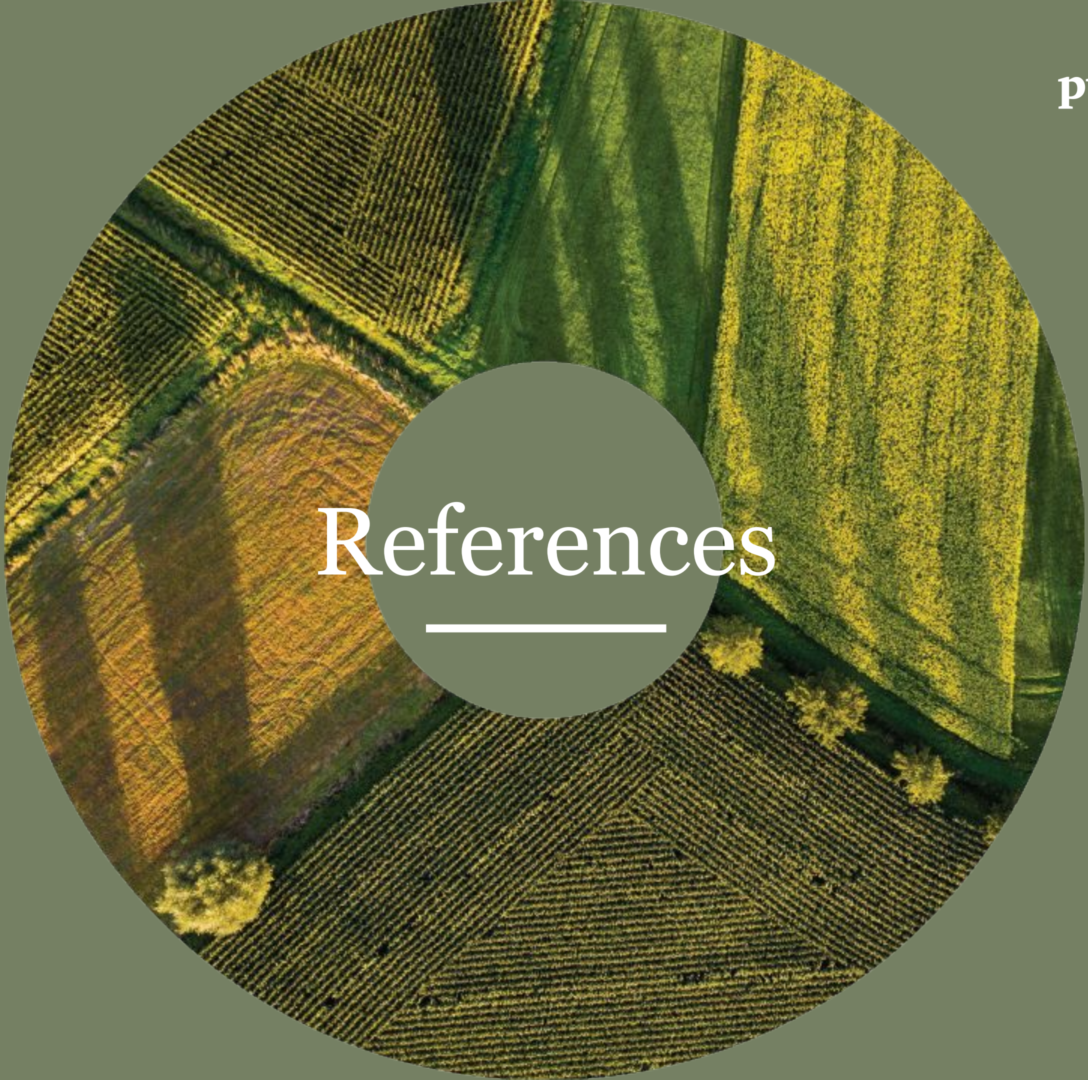
To put this in context, this is compared to New Zealand's emissions targets. Forecasts are that New Zealand will have about 55,000 ktCO2e gross emissions by 2050. With an ambition of being carbon neutral, New Zealand requires 55,000 ktCO2e of sequestration to offset this. New Douglas-fir plantations, if the first 1,000 ha was planted in 2024, would be forecasted to sequester an additional 400 ktCO2e by 2050 - offsetting 0.7% of New Zealand's predicted 2050 emissions.

Model Inputs, Assumptions and Sources (1 of 2)

Input	Unit	Justification / other assumptions / notes	Source	Value (base case)
Lifecycle of non-GE trees	years		n.d. (n.d). *NZ Farm Forestry - Douglas-fir*. New Zealand Farm Forestry Association. Retrieved February 23, 2024, from https://www.nzffa.org.nz/farm-forestry-model/species-selection-tool/species/fir/douglas-fir/#site-requirements	40
Lifecycle of GE trees	years	A change in the lifecycle is an unknown outcome. Scenario analysis will be conducted to explore the case where the lifecycle does not change, and where it is shortened as a result. In the low case, it is assumed that there is no change in growth rate, whilst in the base and high case it is assumed that there is an increase in growth rate (to varying degrees).	n.d. (2005). *NZ Farm Forestry - Growing Douglas-fir*. New Zealand Farm Forestry Association. Retrieved February 23, 2024, from https://www.nzffa.org.nz/farm-forestry-model/resource-centre/information-leaflets/farm-forestry-association-leaflet-series/growing-douglas-fir/	35
Initial stocking	stems/ha	This source states that initial stocking is 1,250 - 1,650. We have utilised the midpoint.	n.d. (n.d.). *Fir - Douglas-fir, Pseudotsuga menziesii.* Farm Forestry New Zealand. Retrieved from: https://www.nzffa.org.nz/farm-forestry-model/species-selection-tool/species/fir/douglas-fir/	1450
Production of thinning	stems/ha		n.d. (n.d). *NZ Farm Forestry - Douglas-fir*. New Zealand Farm Forestry Association. Retrieved February 23, 2024, from https://www.nzffa.org.nz/farm-forestry-model/species-selection-tool/species/fir/douglas-fir/#site-requirements	600
Stems remaining after production thinning (harvestable stems per ha)	stems/ha	This is calculated based on the difference between the initial stocking and the production of thinning.		850
Current area of Douglas-fir Wildings	hectares	It is understood that there is ~2,000,000 hectares of wilding conifers currently, of which 40% is Douglas-fir.	Discussed with stakeholders.	800,000
Current area of Douglas-fir plantations by age	hectares	The distribution of Douglas-fir forest area by age class as of 1 April 2022 is included in the source. This was used in the transitioning plantations. See the link for the full details of the total area by age class. There is ~90,000 ha in total of current Douglas-fir plantations.	n.d. (2023). *National Exotic Forest Description.* Wilding Pine Network. Retrieved from: https://wildingpinenetwork.org.nz/national-exotic-forest-description/	

Model Inputs, Assumptions and Sources (2 of 2)

Input	Unit	Justification / other assumptions / notes	Source	Value (base case)	Low case (if applied)	High case (if applied)
Average recoverable volume per ha	m^3/ha		n.d. (n.d). *Douglas-fir: information for growers*. Forest Growers Research. Retrieved February 23, 2024, from https://fgr.nz/programmes/alternative-species/douglas-fir-information-growers/	600		
Rate of increase in area impacted by wilding conifers from forestry plantations	%	This source estimates a 5% growth in area affected by wildings. Given that this is a sensitive input with uncertainty, a low and high case have been applied.	n.d. (n.d.). *Wilding conifers: Weeds*. DOC. Retrieved February 23, 2024, from https://www.doc.govt.nz/nature/pests-and-threats/weeds/common-weeds/wilding-conifers/	5	6	4
Rate of increase in area impacted by wilding conifers from existing wildings	%	Assumed to be the same as for plantations.		5	6	4
Total area planted each year	ha			1000		
Tree age before wilding contribution (when it reaches maturity)	years		Satchell, D. (2018). *Report: Trees for steep slopes.* New Zealand Farm Forestry Association. Retrieved frmo: https://www.nzffa.org.nz/farm-forestry-model/why-farm-forestry/trees-for-erosion-controlsoil-conservation/report-trees-for-steep-slopes/tree-species/douglas-fir/	12		
Average age	year		n.d.. (n.d.). *Average Accounting.* MPI. Retrieved from: https://www.mpi.govt.nz/forestry/forestry-in-the-emissions-trading-scheme/emissions-returns-and-carbon-units-nzus-for-forestry/accounting-for-carbon-in-the-ets/averaging-accounting/	26		
Carbon tables	tCO2e / ha	See link for detail on the carbon tables containing the carbon stock per hectare for Douglas-fir.	n.d. (2022). *Climate Change (Forestry) Regulations 2022.* New Zealand Legislation. *Retrieved from:* https://www.legislation.govt.nz/regulation/public/2022/0266/latest/LMS709973.html			



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