Enhancing Mauri of land and water through land use change: an exploration of potentials and effects using systems thinking and Waikato-Tainui methodologies at Nikau Farm in the Waikato region of Aotearoa New Zealand

May 2023

Authors:
Willy Cameron (EcoQuest Education Foundation)
Sudesh Sharma (ESR)
Aareka Hopkins (AM^2 & Associates)
Kristin Bohm (ESR)
Alexandra Meister (ESR)
Ria Brejaart (EcoQuest Education Foundation)
Te Ataahua Richmond (Nikau Estate Trust)
Amy Skidmore (University of Canterbury)
Tawera Nikau (Nikau Estate Trust)
Maria J Gutierrez-Gines (ESR)

Reviewed by:
Matthew Taylor (Waikato Regional Council)

Approved by:
Louise Weaver (Interim Manager Water & Environment Group, ESR)

Report Number FW23017, prepared for Our Land and Water National Science Challenge.

Acknowledgements

This is the final report of the “Think Piece” project *What land-uses or combination of them would provide long-term sustainability for the Nikau whaanau and the taiao in their rohe?* funded by the Our Land and Water National Science Challenge (grant number 2022CF001). The authors would like to acknowledge the funders for the opportunity to enhance and support the long-term collaboration between ESR, EcoQuest, and University of Canterbury (the science team), the mana whenua in the Lake Waikare Catchment, and the Waikato Regional Council. The science team is grateful for the knowledge shared by our Maaori collaborators. According to the Wai262 claim into the Waitangi Tribunal, this knowledge is taaonga and belongs to the Maaori indigenous communities (Waikato-Tainui), who generously shared it with the science team for the specific purpose of this work. The authors thank the valuable input of Olivia Adamson, Oliver McLeod and Helena Layton from Waikato Regional Council.

Table of Contents

Glossary

Glossary of Maaori terms

Aotearoa	New Zealand.
Atua	Gods/Supernatural ancestors.
Haumietiketike	Atua of uncultivated and wild food.
Hapuu	Subtribe or clan within an iwi
Hua Parakore	An indigenous food sovereignty initiative and hallmark of excellence for food and product production
Hui	Meeting or gathering.
Ika	Fish
Iwi	Extended kinship group, tribe of Maaori.
Kaakahu	Traditional cloak or garment.
Kaaeo	Freshwater mussel.
Kaitiaki	Guardian or caretaker of the environment, people, and culture.
Kaitiakitanga	The exercise of the role of Kaitiaki, by Kaitiaki.
Karakia	Ritual incantation or prayer.
Kaupapa Maaori	Customary practice or ideology.
Kawa	Primary values, rules of specific hapuu and iwi.
Kete	Traditional woven basket made from flax
Kiingitanga	The Maaori King Movement.
Kotahitanga	Unity, solidarity.
Maara	Garden, cultivated land.
Maara kai	Food garden or cultivated land for growing crops.
Maatauranga	Knowledge, wisdom, or understanding.
Maatauranga tuku iho	Traditional knowledge passed down through generations.
Mamai aroha	Sympathy or expression of condolences.
Mana	Authority, prestige, or power.
Mana Whenua	Authority and rights of the local people over their traditional lands.
Manaakitanga	Hospitality, kindness, or care towards others.
Manu	Bird.
Marae	Complex of buildings comprising the kuaha, aatea, wharenui, paepae, wharekai and outbuildings to permit and sustain life for whanau and hapuu
Maramataka	Lunar calendar or lunar phases.
Mauri	Life force, essence, or well-being of a person, community, or environment.
Moohiotanga tuku iho	Ancestral knowledge or inherited wisdom.
Motu	Island.
Muka (or whiitau)	Fibers extracted from flax (harakeke).
Ngaahere	Forest, bush.

Oneone	Soil.
Papatuu-aa-nuku	Earth mother
Pepeke	Insects both terrestrial and aquatic
Poukai	Traditional gathering, celebration to commemorate the Kiingitanga and ancestors by sharing food and korero.
Rangatahi	Youth, young.
Rangatiratanga	Chieftainship, leadership, self-determination.
Raupatu	Confiscation of Māori land or resources during colonisation.
Riwai	Potato.
Rohe	Territory, region, or district.
Rongoa	Traditional medicine or healing practices.
Rongomaitaane	Atua of cultivated foods.
Taaonga	Precious items, possessions, or cultural treasures.
Taaonga tuku iho	Treasures handed down through generations.
Taiao	Natural environment
Tamanui te Raa	The sun.
Tamariki	Children or offspring.
Taane Mahuta	Atua of forests and birds in Māori mythology.
Tangaroa	Atua of the sea, water.
Tangata whenua	Of the land
Tangi	Funeral, mourning ceremony.
Tangihanga	Funeral rites or ceremonies.
Taro	A starchy root vegetable.
Tawhirimatea	Atua of weather, associated with wind and storms.
Te ara whakahou	The pathway to renewal or a new approach.
Te Ao Maaori	The Maaori world.
Te Ao Paakehaa	The Western world.
Te Ao Tawhito	The ancient world.
Te Ihorangi	Atua associated with many kinds of rain, and tuna.
Te Whare Tapa Whaa	A model of well-being that encompasses physical, mental, spiritual, and family/social dimensions.
Tii koouka	Cabbage tree, a native New Zealand tree.
Tikanga	Customs, protocols, practices.
Tino rangatiratanga	Full authority, sovereignty, self-determination.
Toka	Rock or stone.
Tohunga	Expert or practitioner in Māori traditional knowledge or arts.
Tuupuna o mua	Ancestors or forebears.
Waananga	Traditional educational institution, a gathering for learning.
Wai	Water.
Wairuatanga	Spiritual well-being

Whaanau	Family, extended family, kinship group.
Whaariki	Woven mats made from flax
Whakapapa	Genealogy, ancestral lineage, family history.
Whanaungatanga	Relationship building, kinship, sense of collective belonging.

Glossary of English terms

Algal blooms	Excessive growth of algae in bodies of water, often due to high nutrient levels, causing ecological imbalances.
Acidification	The process of increasing acidity in water bodies or soils, often caused by human activities such as industrial pollution.
Apiculture	The practice of beekeeping and the cultivation of honeybee colonies for the production of honey and other bee products.
Anthropogenic climate change	Climate change resulting from human activities, such as the burning of fossil fuels, deforestation, and industrial processes.
Biodiversity	The variety and variability of living organisms in a given ecosystem, including genetic, species, and ecosystem diversity.
Bioaccumulation	The gradual build-up and concentration of substances, such as pollutants or toxins, in the tissues of living organisms.
Complex systems	Systems that consist of interconnected and interdependent elements or components, often exhibiting non-linear behaviour.
Causal loop diagram	A graphical representation of cause-and-effect relationships in a system, often used to analyse feedback loops and dynamics.
Critical approach	An analytical perspective that challenges existing systems, assumptions, and power structures in environmental contexts.
Conventional agricultural systems	Traditional farming practices characterised by high chemical inputs, mechanization, and monoculture cultivation.
Colonisation	The process of establishing colonies or expanding human presence in new geographical areas, often with cultural and ecological consequences.
Ethics	Moral principles and values that guide human behaviour and decision-making in relation to the environment and other beings.
Ecological traps	Situations in which environmental cues mislead organisms, leading to detrimental outcomes or population decline.
Emissions trading scheme (ETS)	A market-based approach used to limit greenhouse gas emissions, where permits to emit are traded between polluters.
Green economy	An economic system that aims to promote sustainability by integrating environmental considerations into business practices.
Indigenous knowledge	Traditional knowledge and practices of indigenous communities, often based on long-term interactions with ecosystems.
Industrialised agricultural practices	Intensive farming methods that rely on machinery, synthetic fertilisers, pesticides, and large-scale production in order to maximise productivity.
International agreements on Climate Change	Treaties and protocols established among nations to address climate change and reduce greenhouse gas emissions.
Knowledge	Information, understanding, or expertise acquired through study, observation, or experience.

Method	A systematic approach or procedure used to conduct research, collect data, or solve problems.
Methodology	The overall framework or approach used in conducting research, including the specific methods and techniques.
Model	A simplified representation of a real-world system, often used to simulate and predict complex environmental phenomena.
Monocultural systems	Agricultural systems dominated by the cultivation of a single crop species, which can lead to ecological and economic risks.
Marginalisation	The process of excluding or disadvantaging.
Natural hydrological regimes	The natural patterns and processes of water flow, distribution, and storage in an ecosystem or watershed.
Pastoral farming	Agricultural practices focused on raising livestock, such as cattle, sheep, or goats, typically in grassland or pasture areas.
Polyculture	A farming or agricultural system that involves cultivating multiple crops or plant species together in the same area.
Permaculture	A holistic approach to sustainable agriculture and design that aims to create self-sufficient, regenerative ecosystems.
Regenerative agriculture	A farming approach that emphasises soil health, biodiversity, and ecological restoration to create sustainable and resilient systems
Rich picture	A visual tool or diagram used to represent complex systems or issues, often incorporating diverse perspectives and relationships
Soft-systems methodology	An approach that recognises the inherent complexity of social and organizational systems and seeks to address issues in a flexible manner
Science	The systematic study and understanding of the natural world through observation, experimentation, and analysis.
Systems thinking	A way of understanding and analysing complex systems by considering their interconnections, feedback loops, and emergent properties.
Sustainability	The ability to meet the needs of the present generation without compromising the ability of future generations to meet their own needs.
Science funding systems	The structures, mechanisms, and processes through which scientific research is funded and supported.
Self-determination	The right and ability of individuals or communities to make decisions and control their own destiny.
Solar farming	The use of solar energy technologies, such as solar panels or solar thermal systems, to generate electricity or heat for farming.
Transdisciplinary	An approach that integrates knowledge and perspectives from multiple disciplines to address complex problems and promote collaboration.
Trust-based braiding (of knowledge)	The process of combining and interweaving diverse knowledge systems and perspectives in a way that respects and values each approach.
Value	The importance, worth, or significance attributed to something
Western science	The scientific knowledge, methodologies, and practices derived from the Western/Euro-centric scientific tradition.
Western worldview	The perspective, beliefs, and values that are influenced by Western/Euro-centric cultural and philosophical traditions.

Executive Summary

Agricultural intensification in Aotearoa New Zealand has contributed to environmental degradation and is associated with the pollution of waterways. Located in the Waikato, Lake Waikare is one of Aotearoa New Zealand's most polluted lakes. The Nikau Farm is a Maaori owned farm at the southern edge of Lake Waikare that has undergone a range of land use changes in the past five years, moving from dairying to cropping. The aspiration of the Nikau whaanau that drives these changes is to restore the mauri of Lake Waikare while operating a productive system that allows the whaanau to thrive and flourish. This report aims to (a) identify the current situation and the underlying factors that play a role on it, (b) identify and understand the aspirations of Nikau Farm for their rohe, (c) search recorded scientific and/or Waikato-Tainui maatauranga tuku iho information to provide evidence to the benefits and drawbacks of a range of selected land uses, and (d) use the previous information to discuss how changing land use could contribute to Nikau Farm's aspirations.

To achieve these objectives, we braided Waikato-Tainui tikanga and maatauranga methods with western science, and systems thinking. From this, it emerged that current industrialised agricultural practices resulted in a self-enforced "business-as-usual" trap to generate revenue. We found that marginalisation of te ao Maaori and Waikato-Tainui maatauranga and tikanga by the processes of industrialisation and land transformation, both rooted in a western worldview, has brought us to the current situation. It was identified that the Nikau whaanau desires to a) improve the mauri of the Lake Waikare catchment, rohe, and land, b) recover Waikato-Tainui tikanga and kawa by increasing capability and capacity for that change, c) be able to create a vibrant community, while d) achieving economic sustainability.

The land uses assessed in this project derived from waananga, and were either directly requested by Nikau whaanau, or were suggested by the science team as potentially suitable land uses to answer to Nikau whaanau aspirations based on their expertise. The selected land uses were solar farming, tuna rearing, greenhouses, high value crops, polyculture, and native vegetation. To assess the effects of the selected land uses on the mauri of the land and water, we used an atua method that is rooted in Moohiotanga tuku iho and aligns with systems thinking. This method is based on the existence of atua and relationships between them. In this project, using an atua framework meant that recorded scientific evidence of environmental effects of selected land uses were analysed based on the effect on the different atua and atua attributes. Apart from atua attributes, the needed work force for each land use, and the potential profit or yield per hectare were also considered in the literature review to address the rest of Nikau whaanau aspirations.

Far from getting stuck in any definition of sustainable land use and land management, our research focused on how each land use could contribute to the identified aspirations of Nikau whaanau. Based on the literature review and discussions with the team, we summarised how each land use could contribute to their aspirations and identified that a combination of the different land uses, creating a diverse mosaic in the landscape, could be most beneficial to optimise not only economic, but also environmental, social, and cultural outcomes. We envisage that such a mosaic of land uses would create for Nikau whaanau a diverse landscape that could be in "*the modern-day equivalent of the environmental state that it was in when Kiingi Taawhiao composed his mamai aroha*".

1. Introduction

In Aotearoa New Zealand, intensification of agricultural processes over the past 40 years (MacLeod & Moller, 2006) has been linked to an increase in water pollution (Julian *et al*., 2017), decrease in soil quality (Houlbrooke *et al*., 2011), and degradation of indigenous biodiversity (Lee *et al*., 2008). This has led to questioning of what land uses are appropriate and where, and how to manage them to minimise or eliminate their negative environmental impacts. The government adoption of international agreements on Climate Change is encouraging many rural producers to change the management of their land to more sustainable practices (He Waka Eke Noa, 2022), or to change their land use to other productive systems which are regarded as less polluting. There are, however, many gaps in our knowledge on the ecological and social effects of these changes in land use and rural practice. This may limit, and perhaps inhibit, achievement of the improvement of environmental outcomes sought by the changes.

Monitoring and quantification of land use change effects requires a definition of environmental improvement, or conversely which negative environmental impacts are expected to be minimised. For example, globally used terms such as sustainable agriculture or regenerative agriculture are linked to the notion that they are practices that preserve or improve the environment (Velten *et al*., 2015; Newton *et al*., 2020). However, there is neither a clear definition of those terms, nor an established way to measure or assess those claims (Velten et al., 2015; Newton et al. 2020). Although more than a hundred years of economically driven land use conversion has provided evidence of environmental impact (Julian *et al.,* 2017; Journeaux *et al.,* 2017), it is more difficult to predict the potential economic and social effects of land use change driven by environmental objectives. A key component of this discussion in the New Zealand context is Maatauranga Maaori. Application of the intergenerational knowledge held by Maaori to the question of environmental degradation can lead to very different views of the definition of what might constitute improvement, or what might be acceptable as an impact.

This *Think Piece* aims to identify possible land use changes and assess the long-term consequences of them within Aotearoa, using Nikau Farm, a 90-ha Maaori owned farm located on the edge of Lake Waikare in the lower Waikato, as a case study. The farm has gone through pronounced land use change in the last five years and the owners, Nikau Estate Trust, have plans to continue this transformation in the near future.

Lake Waikare is one of the most polluted lakes in Aotearoa, and its catchment highly modified and degraded. Decades of intensive land use practices including deforestation of the indigenous forest, pastoral farming, and more recently production forestry have accelerated erosion of soil in the wider catchment, resulting in large sediment and nutrient loads entering the lake. In addition, the flood control scheme established in the 1960s modified the natural hydrological regimes of the lake and adjacent wetlands (Figure 1). Intensive dairy farming in the lower slope areas adjacent to the lake are also a source of nitrogen, phosphorus, and pathogens to the lake, while sheep and beef farming on the hill country enhances erosion risk and sediment production. As a result of all those impacts the lake, which in 1890 was recorded as having a mean depth of 1.8-2.4 m (Haszard, 1890) now has a mean depth of only 1.5 m. The Matahuru catchment alone (within which Nikau Farm is situated) has been found to produce 165 t/km^2/y of sediment and has shown a statistically significant increase in suspended sediment yields over time (Latitude Planning, 2015). Lake Waikare is considered to be hypertrophic, experiencing a high degree of year-round turbidity and prone to regular algal blooms due to elevated nutrient levels and warm water conditions (Lawrence and Ridley, 2018). Loss of biodiversity in the Lake Waikare Catchment is also pronounced due to changes in land use and the loss of about 67% of the wetlands (Reeves *et al.,* 2012).

Nikau Farm, as a whaanau enterprise, is emulating tuupuna o mua to become agriculturalists and horticulturalists again. With a deep aspiration of restoring the mauri of Lake Waikare, and to create a productive farm that protects and sustains the whaanau and taiao of their rohe, the Nikau Farm has changed a part of their original intensive dairy farm system into a rotation of corn, watermelon, pumpkins, and wheat, and undertaken the restoration of riparian areas to native vegetation. The long-term goal of the Nikau whaanau is to design a productive system that improves the mauri of Lake Waikare and allows for the whaanau to thrive and flourish.

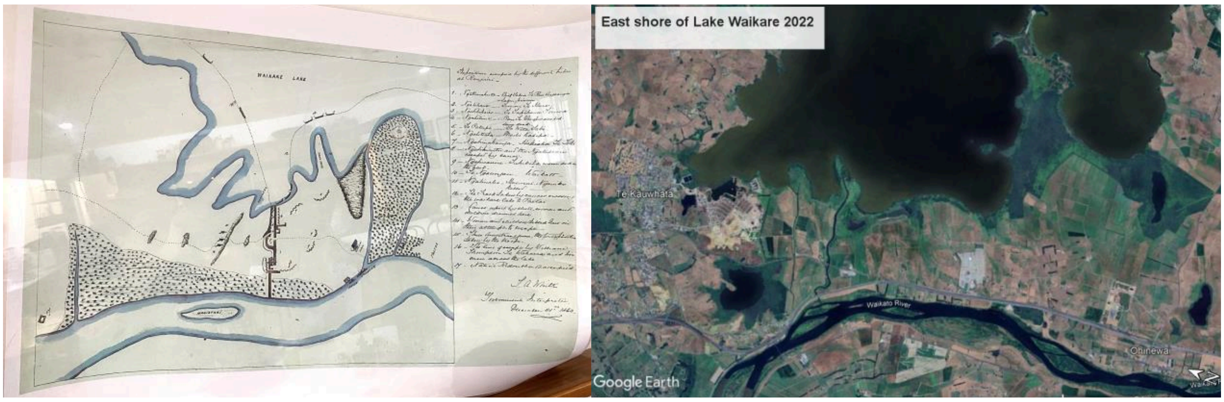


Figure 1 Left: Representation of the east shore of Lake Waikare in 1863 - Photo taken from a copy on display in Rangiriri Heritage Cafe. Right: Aerial photo of a similar area taken in 2022 from Google Earth.

2. Objectives

The first objective of the project was to investigate and understand the current situation at Nikau Farm from a broad eco-cultural perspective, utilising both systems methodologies and maatauranga Maaori, to discover the aspirations of the Nikau whaanau for the environment in their rohe generally and for the farm more specifically.

From the outset several different options for change of economic use of the land were already under consideration, but their effect on the mauri of the lake, and potential environmental impacts and benefits were unknown. There were also ideas for change that were of interest to whaanau that extended beyond economic use, but the likely effects of these kind of changes are also uncertain.

Our second objective was thus to assess the potential environmental impacts and benefits of the land uses already engaged in by, or of interest to, Nikau Farm. In carrying this out we aspired to conduct our assessment from a maatauranga Maaori viewpoint, supported by evidence and korero from the fields of expertise of the participants – the disciplinary sciences, transdisciplinary perspectives, and applied experience and oral history of Nikau whanau. This also included the discussion of potential land use changes that were not previously considered by the Nikau whaanau but which might help them achieve their aspirations.

The synthesis of all this was our third objective, specifically to discuss the merits and pitfalls - environmental, economic, and social - of the various different options for change that we had considered, and to bring this information to the Nikau whaanau to inform and support them as mana whenua and kaitiaki in their decision making.

The vision for this *Think Piece* was to contribute to land use decision making in Aotearoa that protects and enhances the environment while sustaining social, cultural, and economic benefits for the landowners in particular and New Zealanders in general. The Nikau whaanau are actively asserting their kaitiakitanga status on ancestral whenua free from the threat of colonisation thereby fulfilling their manaakitanga responsibilities for their whaanau and hapu as per their whakapapa, tikanga, and kawa. This *Think Piece* is a collaboration with ESR, EcoQuest, University of Canterbury, and Nikau Estate Trust, with support from Waikato Regional Council. It has arisen from relationships built by the whanau and researchers through research, restoration, and educational projects and initiatives that they have undertaken collaboratively in response not just to the changing external political and regulatory environment, but more importantly to support and affirm iwi assertion of kaitiakitanga within their rohe and all that derives from it.

3. Methods

This work was achieved through waananga, online discussions, and review of existing literature.

3.1. Scoping waananga

The scoping waananga was initially planned to be held at Matahuru Marae but was later moved to Ohinewai community hall, where subsequent waananga were also held. The methodology employed for this initial waananga was guided by tikanga Maaori and based on soft-systems methodology (Williams, 2005; Williams & van 't Hof, 2014) that involved a planning meeting with all the collaborators. This planning meeting built on the pre-existing collaborative and trust-based relationships between Nikau Farm mana whenua and the science team at ESR and EcoQuest Education Foundation. The Social Systems team from ESR led a process of systemic inquiry and explored the synergy it has with holistic thinking and indigenous worldviews. Soft systems methodology and systems mapping was considered appropriate for understanding the current situation of land use practices.

The two-day scoping waananga began with a karakia and participants were introduced to the creation stories and history of Waikato Tainui, which set the environment for the waananga. The rich picture method was utilised to illustrate the current situation of land uses, including context, drivers, and their social, cultural, environmental, and health impacts, focusing on Nikau Farm (Williams & van 't Hof, 2014). The rich picture approach was considered suitable as farming practices are influenced by complex sets of factors. The participants were asked to identify goals and aspirations for Nikau Farm's future land use, and connections among the wider goals were also shown. At the end of the first day, a field trip was organised to witness the current practices and have a visual reflection of the current situation, but also to see and understand some of the works that Nikau Farm has proactively taken guided by te ao Maaori.

The second day of the scoping waananga began with a review of the rich picture created on the first day to illustrate the complex situation of land use practices at Nikau Farm. To address the complexities of the issue, the participants utilised another soft systems tool called the CATWOE (Customers, Actors, Transformation process, World view, Owner, Environmental constraints) framework (Williams, 2005). This framework provides an ethical problem-solving approach by considering all perspectives and interests involved in the issue. Participants used CATWOE to identify the key transformations necessary for future land use at Nikau Farm. This involved identifying the clients or beneficiaries who would be most affected by the transformation, the actors or collaborators needed to enable the transformation, the assumptions or worldview that make the transformation sensible, the owner or decision maker who has the power to pull the plug on the transformation, and the environmental constraints that could influence achieving the desired transformation.

After the scoping waananga, a causal loop diagram (CLD) was developed by consulting with participants in regular hui. A causal loop diagram is a visual tool used to understand how different factors or variables interact with each other to produce a certain outcome or behaviour (Williams & Hummelbrunner, 2011). It consists of a set of interconnected loops, with each loop representing a cycle of cause-and-effect relationships indicating systemic traps, unintended consequences, and feedback mechanisms. The CLD synthesised the scoping waananga and presented systemic insights into the current situation and future possibilities for land use practices at Nikau Farm.

3.2. Atua as environmental indicators – Maaori frameworks for environmental reporting and planning

Models based in maatauranga Maaori have been developed to address a wide range of concerns from public health and education frameworks to environmental monitoring and reporting. These models position as normative a Maaori worldview and thus reframe the methodology for describing, assessing, and planning within, the systems under consideration.

The systems exercises at the scoping waananga were acknowledged as based in a non-Maaori worldview. However, from the exercises a clear direction emerged that the results of our work should be derived from te ao Maaori to adequately meet the needs of the whaanau and hapuu involved. The question was raised as to whether there was a kaupapa Maaori approach relating to the descriptions of systems that might be relevant and useful to this project. Te Whare Tapa Whaa was suggested as one approach that was well known, and Atua frameworks another.

Subsequent to this scoping waananga, maaori models for engaging in systems thinking and relevant to Waikato-Tainui were investigated, and more broadly the application of maaori models to land use questions explored. The Te Whare Tapa Whaa model, put forward by Durie (1984), was developed and has found use largely within the public health sector. The model has been refined and adapted through time leading to further models and applications.

One such model is the Atua Matua model developed by Dr Irirangi Heke (Waikato-Tainui). In discussing deployment of this model Heke points out that “Atua Matua, like systems thinking, has an underlying theory of change that argues for structural change. That is change will occur when the structure – pattern of relationships – in the system changes.” (Heke *et al,* 2019). What is different about the characterisation of relationships in models such as Atua Matua from traditional systems thinking is that, as Yates puts it “indigenous ontologies and ethics of care are positioned as normative” (Yates, 2021).

What emerges, in the context of this project, is that assessment of the effects of land use change depends on the choice of structural framework. Indeed, the meaning of the term “land use change” becomes ambiguous – (1) is it the change of crops and methods of production within a current system that is structurally the product of relationships built on colonisation, Raupatu, and alienation from ancestral ways, or (2) is it change that reflects a broad re-assertion of values and meaning based on a fundamentally different (Maaori) structural viewpoint? Depending on which meaning of land use change is chosen the modelling and assessment of the effects of change requires the description of very different patterns of relationships.

Fundamental to te ao Maaori is whakapapa – the interrelationship of all things through genealogical connection (Mahuika, 2019), and central to this is the existence of atua and understanding of the world in terms of the relationships between them. According to O’Regan (1984) atua are Te Ao Tawhito (of the old world) and are inherently, a framework for finding balance, rationale, order, and perceptions of te ao Maaori.

Frameworks based on atua relationships have increasingly been used for environmental monitoring, and according to Walker *et al* (2021) Atua frameworks can have the potential to be an overarching point of reference within multiple spatial planning and resource management contexts and, moreover, they can be adapted and populated according to the specific place-based traditions and narratives of iwi and hapuu, regardless of their geographies.

The work of Hopkins (2018) in "Classifying the mauri of wai in the Matahuru Awa in North Waikato", set in the catchment within which the land under consideration in the present work is located, positions as normative a whakapapa and atua-based understanding of te ao Maaori in assessing the mauri of wai. From this work we have derived a methodology to inform the appropriate use of an Atua framework within our specific context, from which Figure 2 was developed.

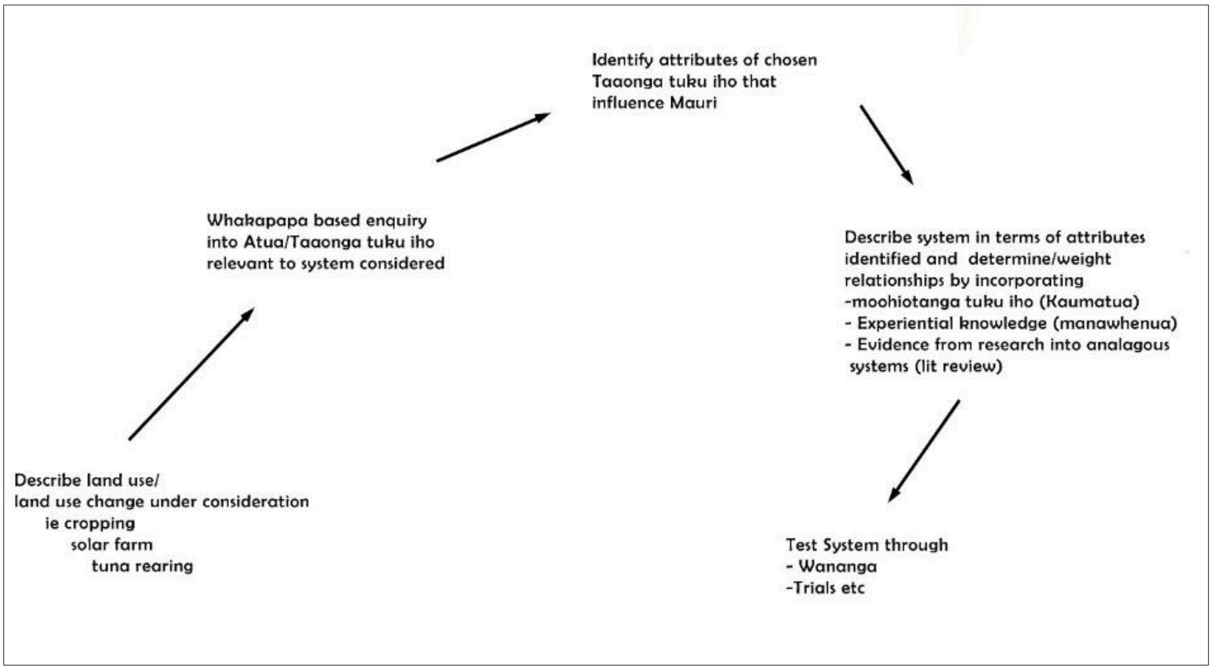


Figure 2 Methodology to inform the appropriate Atua framework to validate land use options for Nikau Farm.

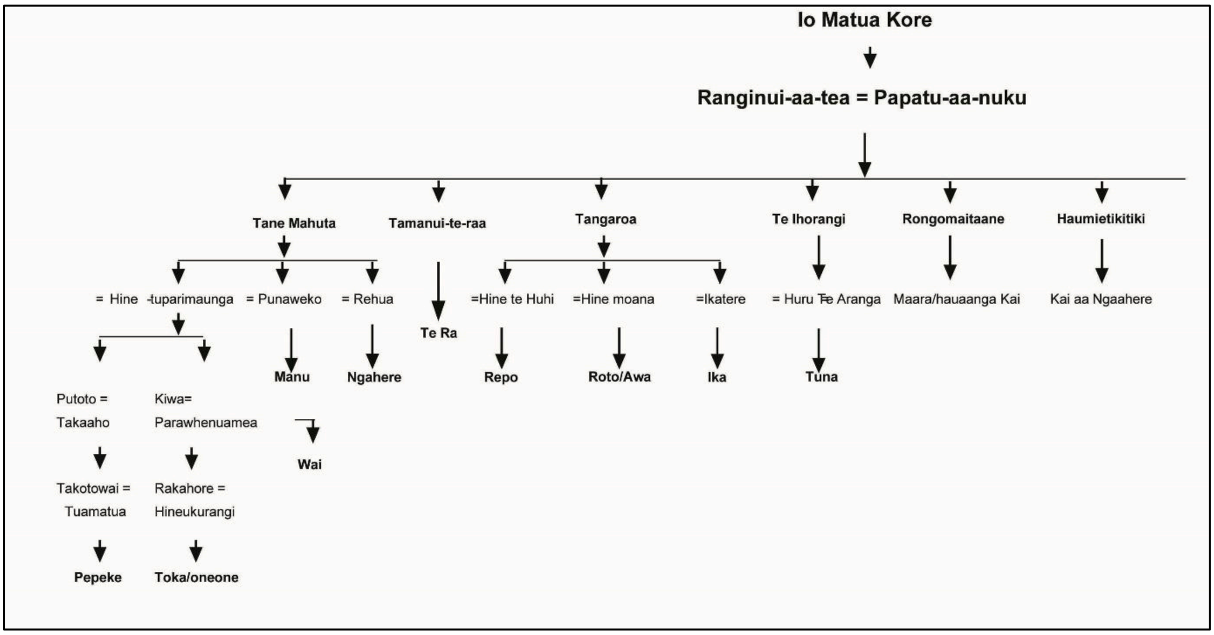


Figure 3 Whakapapa of atua, and attributes of them relating to the ecological, economic, and cultural aspects of the land uses/land use changes.

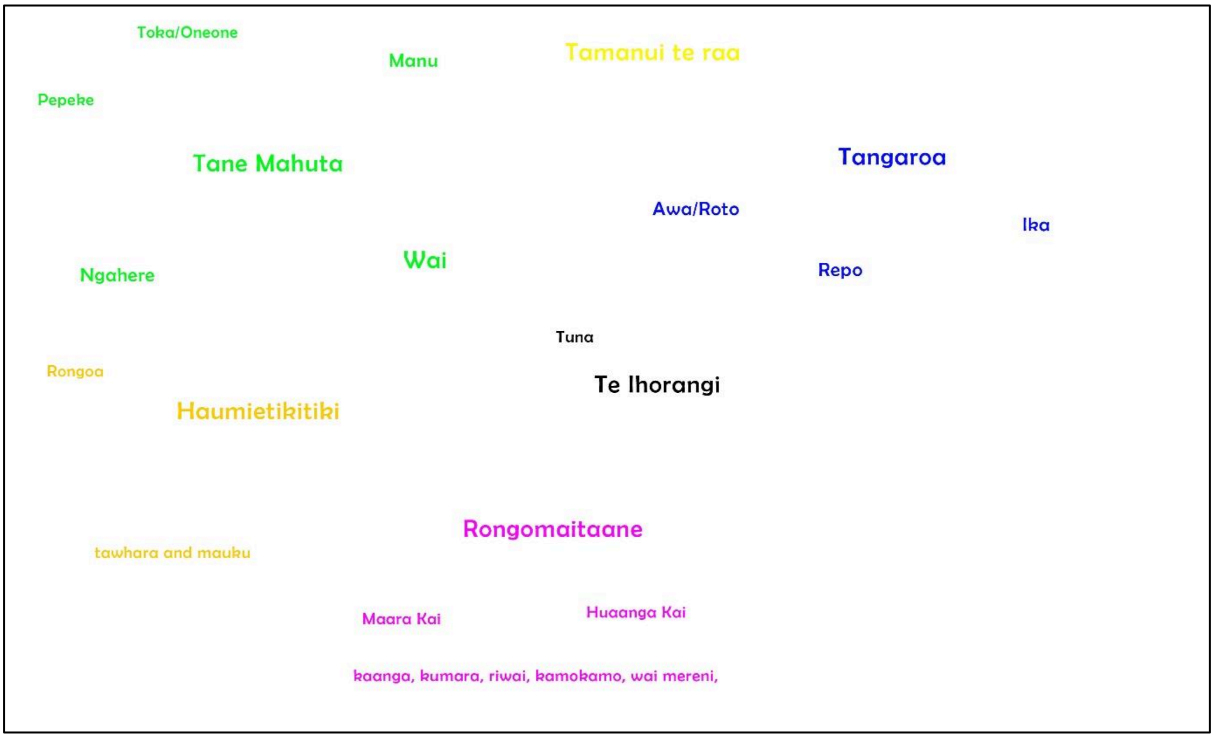


Figure 4 Cluster diagram to explore spatial and causal relationships between identified Atua from the whakapapa given in Figure 2. To aid the identification of the different Atua domains each was given a different colour, and different font size was used to denote the generational relationships within these groups. Positioning of the clusters was done intuitively and sought to position each domain relative to the others suggestive of the ecological, spatial, and social topography of the farm system.

After our second waananga, where this was presented and discussed, whakapapa of atua, and attributes of them relating to the ecological, economic, and cultural aspects of the land uses and land use changes under investigation were identified (Figure 3). Spatial and causal relationships between these atua were explored by creating a cluster diagram of the whakapapa relationships of the Atua (Figure 4).

Given that "an important hononga (connection) between these taaonga (treasures) is their combined contribution to maintaining the mauri (life force) of wai" (Hopkins 2018), the diagram is intended as a tool for visualising these connections and following the effects on mauri of actual or proposed land use at Nikau Farm. For example, given the proposal to install a solar farm the diagram may be used to explore the effect of doing so based on the relationship that the solar farm has to Tamanui te Raa, the effect of this relationship on the other atua domains (Figure 5), and thus directed our literature review towards relationships that have the potential to affect the mauri of the whole system.

From this exploration, we have taken direction for our literature review. As the work developing the Atua Matua guided methodology was undertaken in parallel with the work of the literature review, it was not evenly applied, but was more undertaken as an experimental approach which we increasingly applied to the process of information gathering.

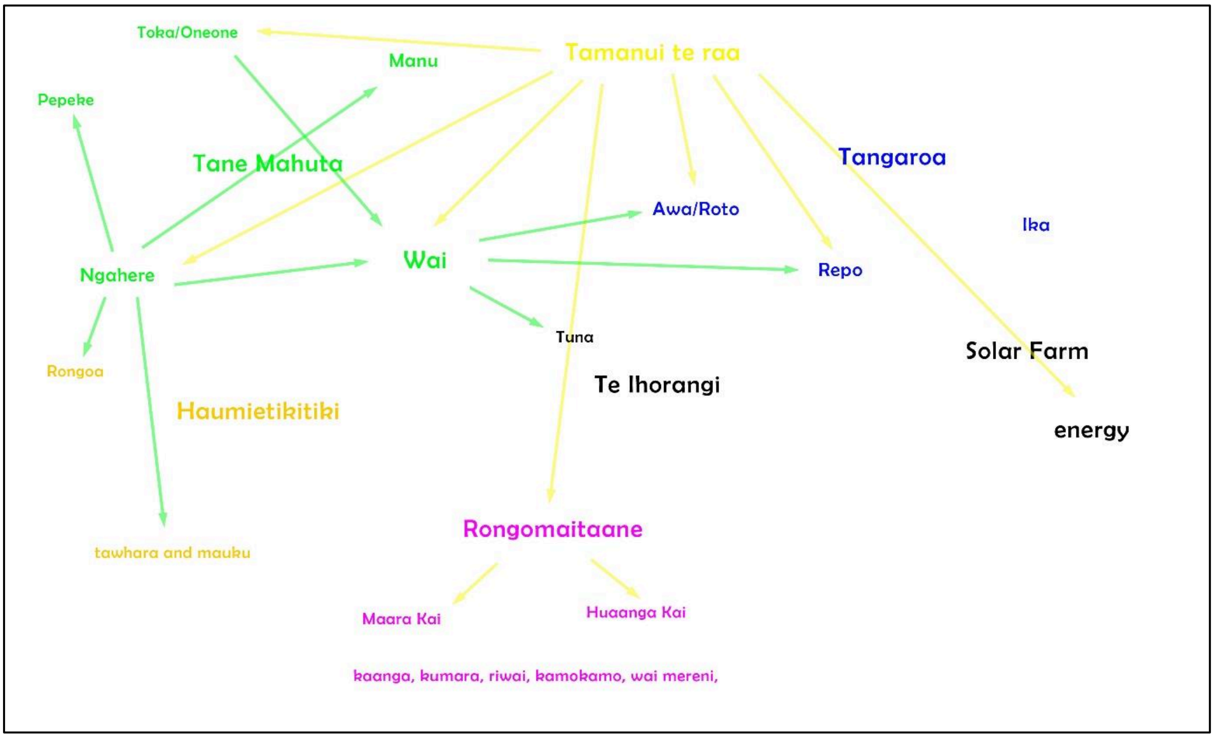


Figure 5 Exploration of the set of relationships that start from the domain of Tamanui te Raa and would thus potentially be influenced by the nature and scale of solar farming were it to be undertaken. Specifically, it has been developed in two steps, firstly through drawing in relationships where the energy of the sun is directly used or taken in (in yellow), such as Wai, Ngaahere, Maara and Toka, for example, and then secondly drawing in those secondary relationships that flow from an atua domain so linked. In this case the appropriate atua Tane Mahuta was chosen, and the relationships drawn in green. Many other drawings of the same diagram are possible.

3.3. Literature review

The literature review was a scoping review intended to find scientific evidence on the potential impacts and benefits of the land uses of interest for Nikau whaanau. It focused on potential land uses of interest for Nikau whaanau, as well as those that according to the authors' expertise could help them achieve their aspirations.

As described in Section 3.2, the methodology that we used to structure the review with regard to potential impacts or benefits from a whakapapa-based perspective was developed as we progressed. Due to time constraints, we were unable to re-evaluate work completed prior to development of the Atua methodology. For most land uses contemplated though the review used the Atua, their tamariki, and attributes of them as ecological parameters to identify the impacts and benefits of different land uses.

For the assessment of potential crops for diversifying Nikau farming system quantitative published data of nitrogen fertiliser application, nitrate leaching, or carbon dioxide equivalent emissions, and profitability was reviewed, and a robustness value, presented by Steve Thomas (Thomas et al, 2022) in the NZ Soil Science Conference 2022, was included.

The University of Canterbury Library search engine was the main platform for finding journal articles and eBooks. Other tools included the Google Search Engine, Google Scholar, interviews, documentaries, and books. When using search engines words describing the land use of interest were combined with key words such as "yield", "impacts", "profit", as well as English translations of the atua attributes identified.

The research for native restoration was carried out prior to development of the atua structure. Benefits have already been identified for this land use during a previous riparian planting project on the farm (Gutierrez-Gines *et al.,* 2022), so instead the literature review focused on additional sources of income (e.g. carbon credits). The carbon credits estimation used indigenous forest carbon stock data from the Climate Change (Forestry Sector) Regulations 2008. Two columns were adjoined that multiplied the current carbon credit value with the incremental and cumulative carbon stocks, respectively. These values were then developed into graphs which showed the potential income from carbon credits over 50 years.

4. Results

4.1. Current situation of land use practices, goals, and aspirations for Nikau Farm

4.1.1. Causal loop diagram

The rich picture and CATWOE not only enabled identification of the complex nature of the situation at Nikau Farm, but also uncovered the values, aspirations, and potential levers for future land use practices. Utilisation of the rich picture and CATWOE facilitated collaborative development of a causal loop diagram (CLD, Figure 6) that integrated the various perspectives and goals of all involved.

4.1.2. Current situation of farming practices

The CLD of the current situation of mainstream agricultural practices (Figure 6, left part of CLD with yellow and blue boxes) in Aotearoa New Zealand highlighted three thematic traps and delays. The first theme is the agri-business "business-as-usual" (BAU) trap, where current mainstream agricultural practices are financially lucrative but unsustainable and harmful to the environment. The second theme is historical and socio-economic influences, where colonisation has resulted in the alienation of the indigenous Maaori population from their land, culture, and traditional practices, perpetuating historical trauma and injustice. The third theme is the systemic marginalisation of te ao Maaori and maatauranga Maaori, where indigenous knowledge and associated wisdoms are not utilised, and industrialised agricultural practices do not align with te ao Maaori. These three themes contribute to the current unsustainability of mainstream farming practices in Aotearoa New Zealand, with a focus on economic growth at the expense of te Taiao, the marginalisation of te ao Maaori, and negative impacts on the wairuatanga of whaanau and mauri of the whenua.

The participants shared that current mainstream agricultural practices, while financially lucrative, were unsustainable from a te ao Maaori worldview due to their negative impact on the environment. Monocultural farming, for example, generated revenue but also contributed to the depletion of biodiversity and environmental pollution. The use of plastic, such as is used in bed forming for watermelon cultivation, and the application of inorganic fertilisers and pesticides are examples of this.

Contracted farming, based on western practices that do not align with te ao Maaori also contributed to the problem. As a result, the socio-economic system and industrialised farming practices were creating a trap for agri-business that was harmful to the environment (Figure 7 and 8). The agenda for sustainability and a green economy was being promoted, but the current socio-economic and science funding systems were not supporting these initiatives. For instance, common-sense action research often does not receive funding. Participants discussed that funding for scientific research on agricultural production systems favours the increase in yield, technologisation, and commercialisation over low-technology sustainability and the well-being of the environment. Funding for research perceived as non-novel, yet underpinning the state of farming systems, is very difficult to obtain, and as a result long-term fertiliser trial sites have been lost without replacement.

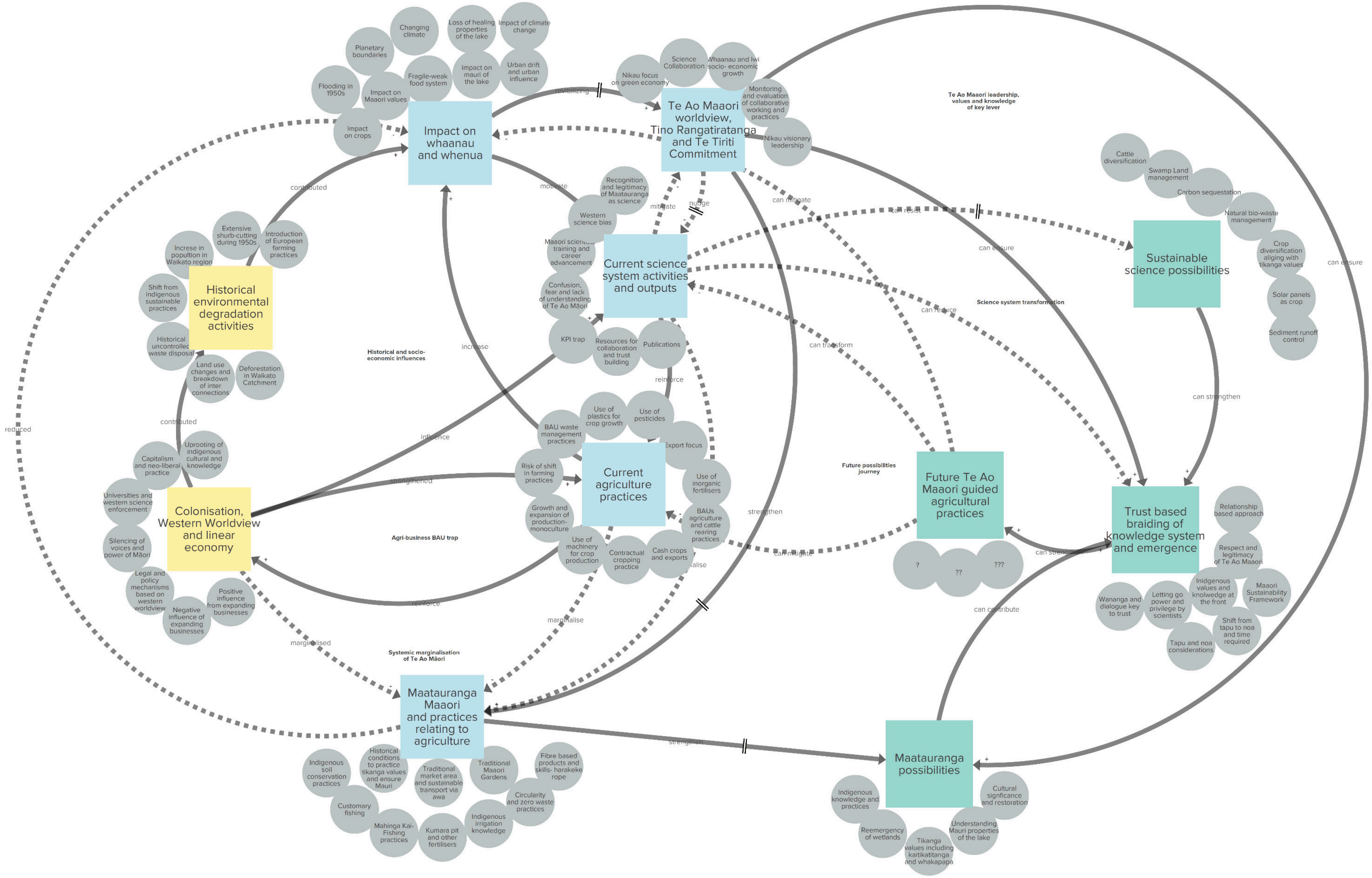


Figure 6 Causal loop diagram of systemic barriers and future possibilities for land use practice in New Zealand

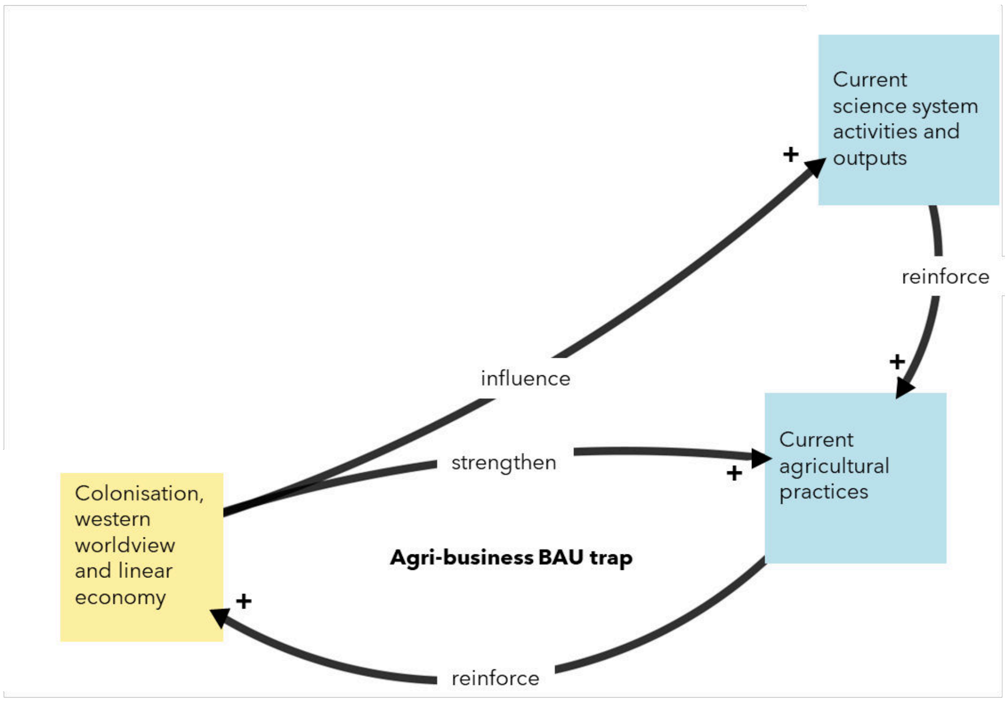


Figure 7 Agri-business "business-as-usual" (BAU) trap

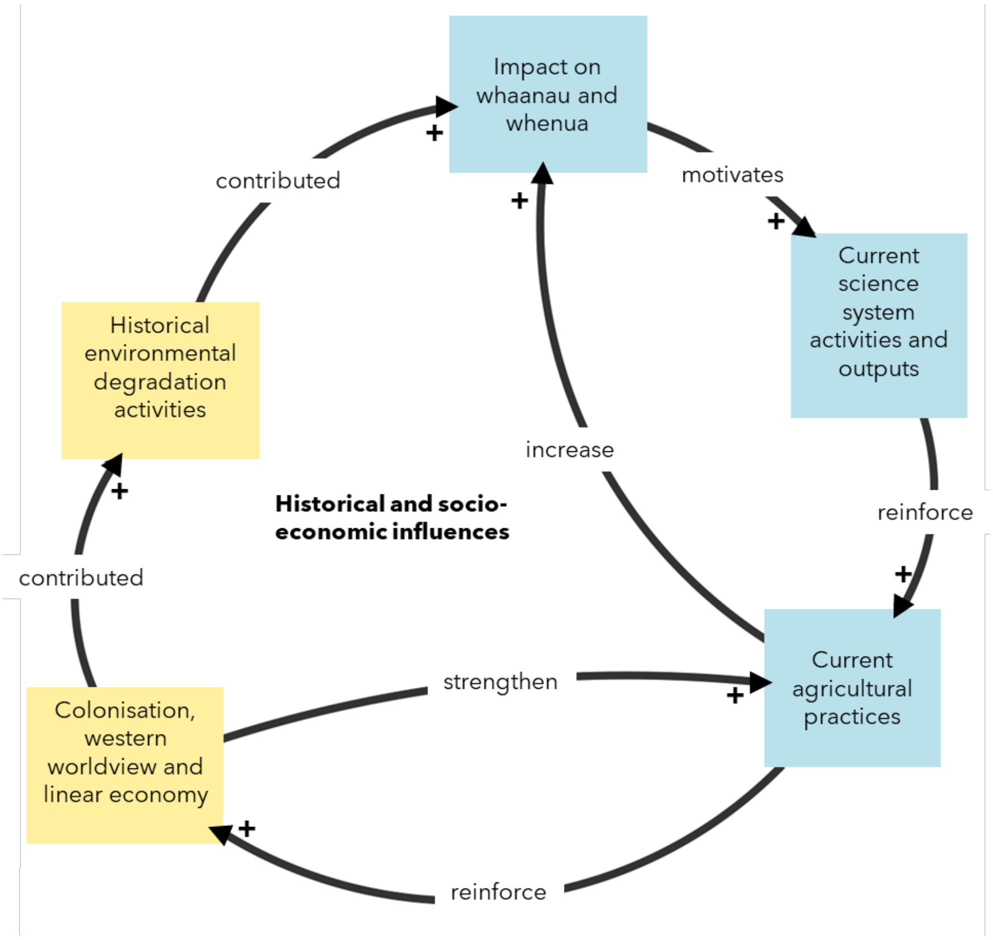


Figure 8 Historical and socio-economic influences

Participants reflected on the impact of colonisation in Aotearoa New Zealand on the socio-economic well-being of Maaori, resulting in their alienation from their land, culture, and traditional practices (Figure 9). It was observed that our dominant science system, although well-intentioned from humanist perspectives, is reductionist and primarily based on utilitarian Western values, placing it often in opposition to the holistic approach and greater-than-human values of maatauranga Maaori. This science system continues to reinforce the agri-business 'business-as-usual' (BAU) trap and perpetuate historical trauma and injustice.

Despite some positive changes, governance and science systems have not done enough to redress historic wrongs against Maaori, the results of which are often seen in terms of sustained poor socio-economic, health, and well-being outcomes. Participants shared that the interventions and services implemented by the current system have mainly been temporary or short-term and do not align with the intergenerational values and aspirations of Maaori whaanau. For example, the dairy intensification or support for monoculture farming practices has resulted in the loss of traditional maara kai practices, which were holistic and more sustainable in nature, contributing to the loss of maatauranga Maaori. Participants stressed the importance of supporting Maaori whaanau, including rangatahi and tamariki, in regaining their land, culture, and beliefs to improve their socio-economic, health, and wellbeing outcomes.

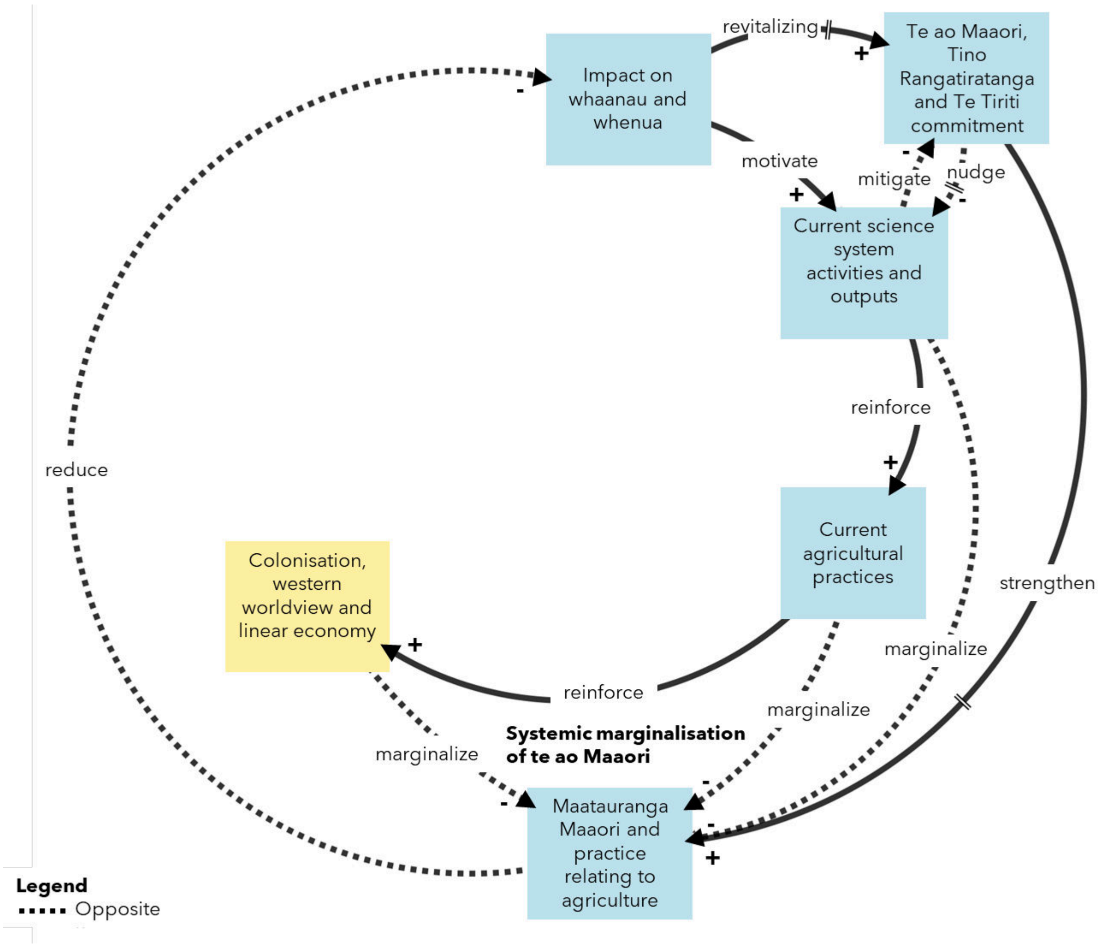


Figure 9 Systemic marginalisation of te ao Maaori and maatauranga Maaori

Participants reflected on the socio-environmental impact of current knowledge and prevalent socio-economic system, and on the failure to utilise the potential of indigenous knowledge and associated wisdoms. Waikato Tainui moohiotanga tuku iho is holistic and embeds environmental concerns, yet under the current socio-economic system, it has become increasingly marginalised and difficult to practice. Industrialised agricultural system design and practices are capitalistic in nature and focus on continuous growth at the expense of the environment. Participants highlighted that the emphasis on economic growth the expense of the environment of these systems is not supported by maatauranga Maaori. In other words, industrialised agricultural practices do not align with te ao Maaori, reinforcing the marginalisation of te ao Maaori and its impact on wairuatanga of the whanau and mauri of the whenua.

4.1.3. Future possibilities, goals, and aspirations

Utilising insights from the rich picture and CATWOE, the CLD was then expanded to include future possibilities (Figure 6, green boxes, and Figures 10 to 12) and how they could potentially alter the dynamics, ultimately helping to avoid potential obstacles and marginalisation while improving existing practices. More specifically, two aspirations for land use change at Nikau Farm were identified: 1) aspirations regarding engaging and enhancing knowledge and skills of tamariki and rangatahi relating to sustainable agriculture; and 2) aspirations regarding potential crop types and a shift to grow more diverse traditional crops. While both aspirations are linked with addressing systemic barriers through creating enabling conditions for the broader cultural, economic, and social development of the whaanau, the second aspiration is about exploring evidence of specific farming practice shifts aligning with maatauranga Maaori.

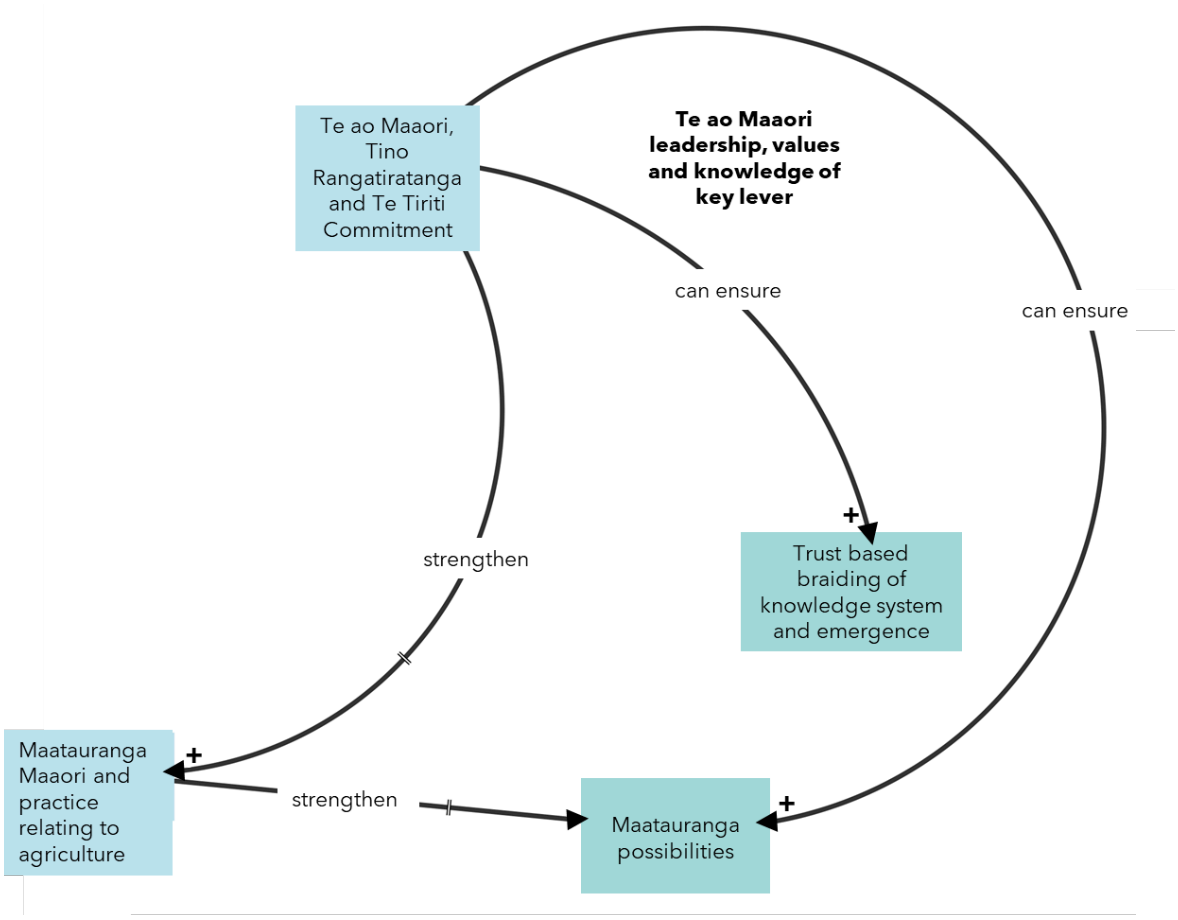


Figure 10 Leveraging te ao Maaori leadership and values for maatauranga possibilities and trust-based braiding

A key enabling conditions was te ao Maaori leadership and values which were considered as key lever to ensure maatauranga possibilities and trust-based braiding. The participants of the project shared principles such as whanaungatanga, kotahitanga, kaitiakitanga, and manaakitanga, among others, which provided an ethical framework for the project. Maaori knowledge holders and decisionmakers, or *Tohunga*, played a crucial role in guiding the application of science evidence and aligning it with maatauranga Maaori. Nikau Farm's leadership in transforming its business-as-usual agricultural practices to focus on te ao Maaori values, green economy, and intergenerational considerations for tamariki serves as a notable example of tino rangatiratanga, or self-determination. Despite the systemic challenges posed by the current socio-economic system, the participants agreed that longstanding critical collaboration between Nikau Farm and scientists demonstrated that there are possibilities for positive change.

Transformation of the current science system is essential for increasing trust and enabling sustainable science possibilities. The participants emphasised that the project was a positive example of successful collaboration between the science system, haapori Maaori, and agribusiness. However, some participants suggested that further efforts and systemic shift are needed to reduce resistance within the science system to sustainable science possibilities. To achieve this, maatauranga Maaori must be provided with trust and space to thrive within the existing science system. In particular, western science trained participants emphasise the need for a more flexible science system that can genuinely engage with whaanau and support long-term funding for sustainable science initiatives, rather than quick-fix solutions.

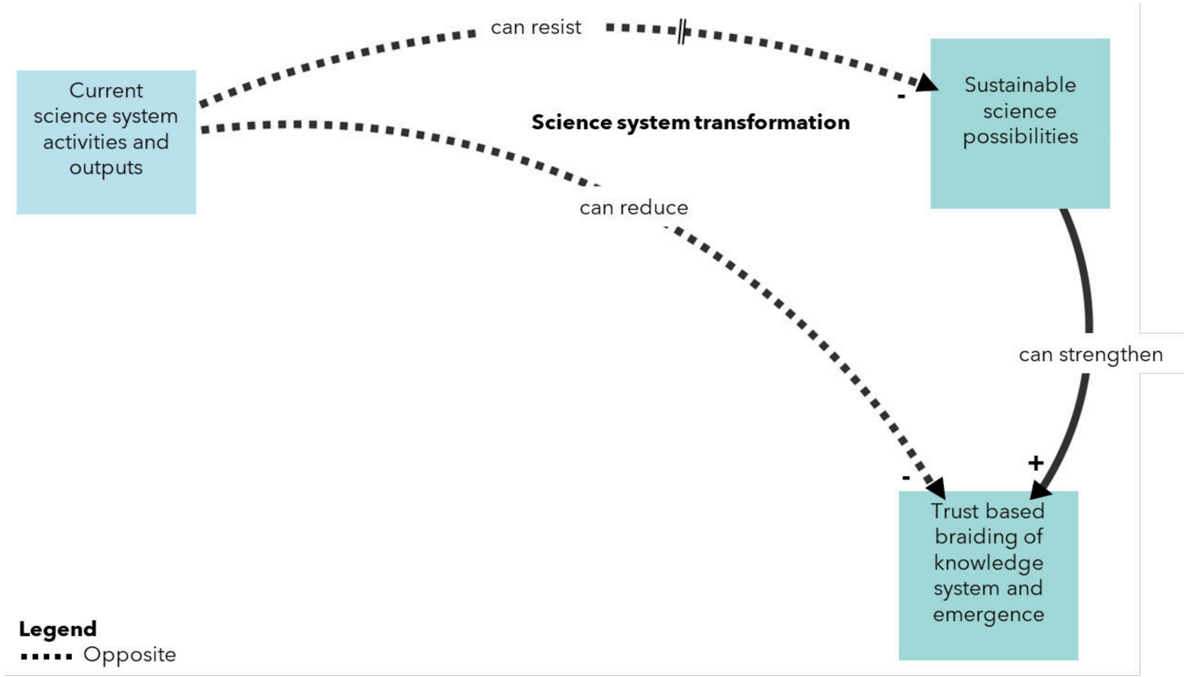


Figure 11 Leveraging science system transformation to support trust-based braiding and sustainability

This is a learning journey. The participants highlighted the importance of ongoing collaboration, learning, and improvement, and suggest that this approach will help to ensure the sustainability and success of the project over the long term. The project represents an ongoing learning journey for the trans-disciplinary team, who will continue to transform practices through continuous learning and improvement. By embedding te ao Maaori and maatauranga Maaori, the project is expected to have a positive impact on the well-being of whaanau and also contribute to broader improvements in the science system and agricultural practices.

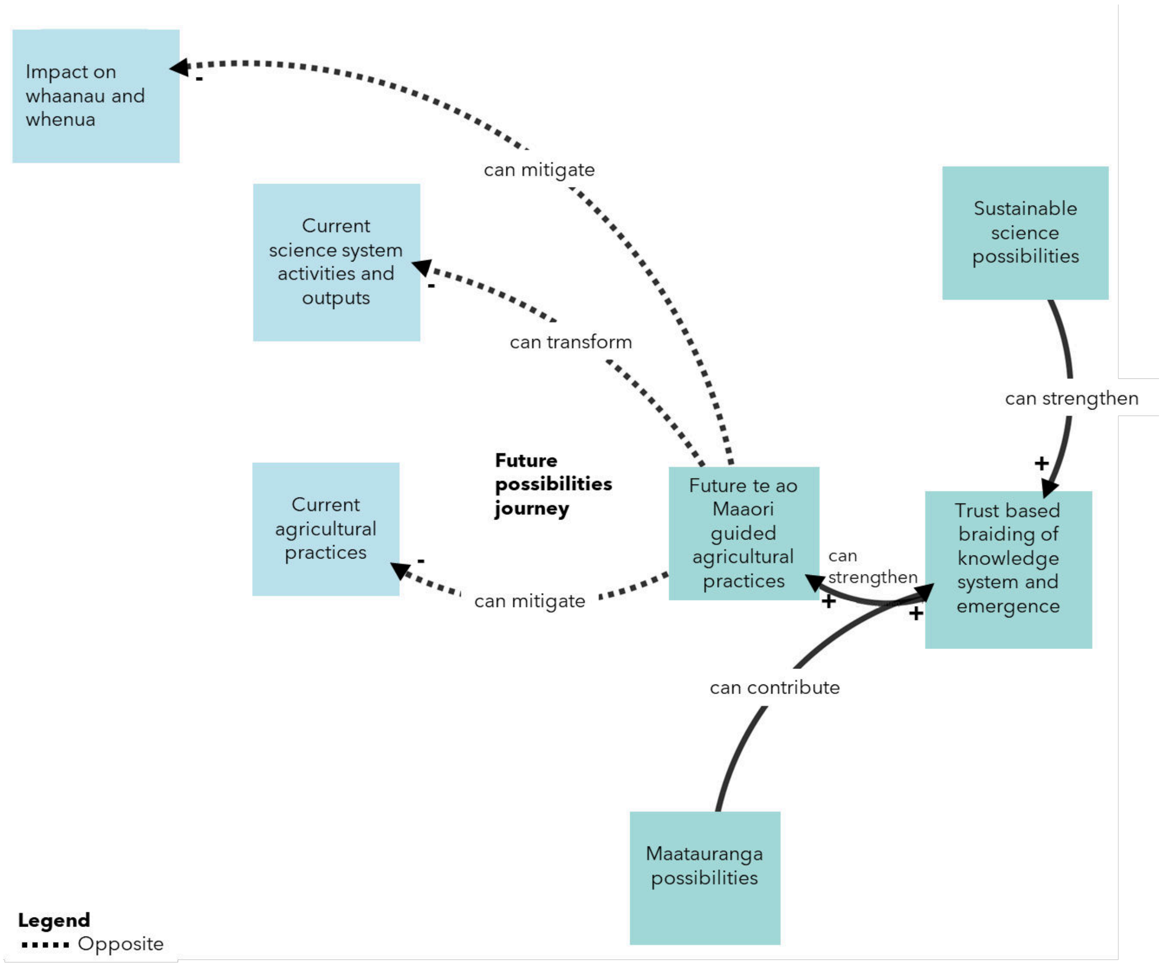


Figure 12 Leveraging power of collaboration and continuous learning to transform future agricultural practices

4.2. Potential benefits and impacts of the selected land uses

As discussed in the previous section, aspirations for land use change at Nikau Farm were found to fall into two categories, the first being aspirations regarding potential crop types and a shift to growing more diverse crops, and the second being aspirations regarding the broader cultural, economic, and social development of the whaanau.

This section summarises outcomes of the literature review in regard to potential benefits and impacts of land uses. Following the method described above in section 3.2, Atua attributes that were used by us to guide the literature review are toka/oneone (soil), wai (water), pepeke (insects), manu (birds), ngaahere (forest), ika (aquatic animals), kaaeo (freshwater mussels), and maara (cultivated land).

A wide range of potential crops were discussed. Solar farming for domestic use and export of power to the Sleepyhead factory is one productive 'crop' that the whaanau has already begun investigating but which further information regarding effects would be of use in decision making. The rearing of tuna was also discussed. This also has been investigated by whaanau already, and remains an option of interest, but again more information on the potential benefits and impacts was sought. Glasshouse production of crops such was also raised, and further information on which crops might be suitable for this approach, and what the effects might be for each of them, requested.

The production of fungi, and beekeeping, were also identified as potential diversification pathways, and a range of traditional crops discussed, particularly taro, kumara, and riwai.

Linked to the discussion of the potential for different crops was the aspiration to grow more diverse crops, that is, to conceive a system of land use that is polycultural. Non-commercial crops, wild foods, rongoa, and ngaahere were raised as elements of such a system.

4.2.1. Solar Farming

The potential to farm solar energy is appealing to the Nikau whaanau for a variety of reasons. It is seen as a way to reduce the nutrient and pesticide load of conventional farming while at the same time providing an income stream that can be used to support and develop the cultural, social, and ecological wellbeing of wai, whenua, and whaanau. The scoping review of the literature for solar farming was directed towards the effects on, and benefits to the key atua attributes identified at the waananga.

Oneone

> *"Generally, it is composed of mineral particles from weathered rock (45%), water (25%), air (25%) and organic matter and living microorganisms (1%–5%) (Hutchings, 2015). Accordingly, a handful of soil, from a Māori-values point of view, embodies a complex whakapapa of relationships with mutually sustaining obligations. This is demonstrated when one takes an Atua domains viewpoint related to soil that sees soil as Hine-ahu-one, air as Tawhirimatea and water as Tangaroa."* Hutchings *et al.,* (2018)

In a review of the environmental impacts of solar farms Dhar *et al.,* (2020) noted that the construction of solar farms requires significant modification of the site, and that compaction of the soil, grading, and other disturbance may lead to topsoil loss and an increase in the amount of sediment entering local streams, causing turbidity in nearby water bodies. While some impacts of this phase may lessen after establishment, Choi *et al.,* (2020) suggested that the significantly lower levels of total carbon and nitrogen they found in soils directly under photovoltaic (PV) panels (as compared to undisturbed soils nearby) even seven years after establishment most likely is the result of topsoil removal during the construction phase, and subsequent failure of the soil to recover.

Lambert *et al.,* (2021) investigated soil properties on solar farms built on abandoned vineyards in France. They compared the soils of three solar farms with soil sampled from semi natural shrubland and forest, and also with soil sampled from abandoned vineyards. They found that physical, chemical, and general soil quality indexes were lower in a solar park compared to semi-natural land cover types. However, they also observed that while the solar park construction resulted in a strong degradation of soil physical quality, especially of soil structure, the soil chemical quality or global quality compared to abandoned vineyards were not disturbed. The implication of these findings is that soil quality under solar farms is, to begin with at least, the product of both the pre-existing state of the soil and the methods of land preparation used in the construction of the farm.

In a study by Wu *et al.,* (2014), the effect of solar concentrators on soil temperature was assessed. They found that these structures increased the ground temperature relative to uncovered areas in the winter by 0.5-4°C, and decreased it in the summer by the same amount. They attribute this to two effects – the relatively stable air body caused by the structure (causing warming in the winter) and the shading of the panels (reducing heating in the summer). Wu *et al.,* (2014) do not comment on the implications of this, but soil temperature has a significant effect on soil respiration (and hence CO_2 cycling), with respiration found to increase exponentially up to 20°C in some temperate ecosystems (Khomik *et al,* 2009). The study of solar parks by Lambert *et al.,* (2021) reported in this regard that they found that solar panels reduced soil temperatures by up to 10% and reduced soil CO_2 effluxes by 50% but did not affect early plant successional communities.

In summary, research into the effects of solar installations on soils has found that the particular geophysical characteristics of the site, the history of the land and its past use, and the level of disturbance caused by construction are all important contributors to initial soil quality. Post-installation, the effects of shading (both reducing light and altering temperature) and altered air movement generally reduce the biological capacity of the soil relative to undisturbed soils, but these effects are not easily predicted, and again are often the product of site-specific effects.

Wai

Solar panels require cleaning to maintain maximum efficiency. According to Dhar *et al.,* (2020) the amount of water and cleaning frequency depends on site conditions (soil and dust properties, vegetation, air pollution, wind speed and direction, humidity, temperature, precipitation) and the solar system (glazing properties, panel and mirror orientation, angle of tilt). Estimates of the amount of water required for cleaning range from 20-150 L per MWh. Assuming a minimum installed annual capacity at Nikau Farm of 50,000 MWh there will be a need for between 1M and 7.5M L of water per annum available for cleaning. There is already significant heavy metal (and other) contamination in Lake Waikare and other water bodies from a number of sources (Waikato Regional Council, pers. comm.). Should water from these sources be used there is the potential for the build-up of these contaminants in the soil beneath the panels and the drainage channels between them.

There is also concern that heavy metals, particularly lead and cadmium, can leach from solar panels. Under simulated conditions of prolonged rain Ren *et al.,* (2022) found that glass panels leached significantly less lead than those with flexible PET substrates, but that in both cases the amount leached per litre exceeded the level considered acceptable. In considering the full life cycle of the solar farm, the decommissioning and recycling phase could, without the adoption of appropriate methods, also lead to significant levels of contaminants entering water (Venkatachary *et al.,* 2020).

Solar farms also affect the distribution of water to the soil. Choi *et al* (2020) found that solar panels may lead to higher soil moisture, but that they also increase the heterogeneity of soil moisture distribution. They attribute this to runoff concentrating under the lower (dripping) edge. While most visible immediately after rain they found the effect persisted in between rain events. They note that this may have implications for cropping or other productive uses between the panels.

Pepeke

Many aquatic insect species use the polarisation of light by water bodies to find egg laying sites. Solar panels polarise light more strongly than water, and thus solar farms may potentially become ecological traps for these insects, leading to rapid decline in populations. In studies of the effect of polarised light produced by solar panels on aquatic insect species Horvath *et al.,* (2010) found that, while many polarotactic (attracted by polarised light) species are indeed attracted to lay eggs around solar panels. Breaking up the area of solar-active surface with non-polarising strips could significantly reduce this effect by 10- to 26-fold. In combination with non-polarised gridding, non-reflective coatings may further reduce attractiveness to some aquatic insect species, although this effect was only evident in sunny conditions (Szaz *et al*, 2016). Szaz *et al* (2016) therefore recommended to strategically install solar panels away from waterbodies.

The effects of solar farms on terrestrial insects may be more beneficial, however. Dolezal *et al.* (2021) pointed out that solar farms do not necessarily use insecticides and thus may offer relatively benign conditions for pollinator species such as bees compared to conventional agricultural systems. However, there has been little study of the effect of solar farms on other macroinvertebrates such as ants, beetles, arthropods, and spiders (let alone stick insects). A study by Guiller *et al.* (2017) on butterflies found that both sedentary and mobile species can cope with the landscape fragmentation caused by solar farms.

Manu

As with aquatic insects, some birds sense and use the polarisation of light by waterbodies to navigate and find food and water (Szaz *et al.,* 2016) leading to conjecture that solar farms may cause death through collision. Kosciuch *et al.* (2021) found evidence of aquatic bird species being attracted to, and experiencing mortality within, solar farms distant from waterbodies in California. They did not observe maladaptive behaviours such as flocks circling and trying to land, nor did the deaths they recorded imply that this was occurring.

In a review of studies on the effects of solar installations on birds Taylor *et al.* (2019) found evidence of lower bird density within large photovoltaic arrays, and for mortality associated with collision and predation subsequent to sub-lethal collision. They caution that the studies they reviewed were for very large arrays, the results of which may not hold for smaller installations.

Taylor *et al.* (2019) also reviewed studies of bird nesting within solar farms. While some species have been observed to nest readily, one study cited found that skylarks, which are ground nesting, preferred to nest outside of solar farms, leading to the suggestion that the interruption of line of sight within the solar field may deter nesting. The effects of solar farms on birds therefore likely differ between species due to their distinct habitats and foraging behaviour (Taylor *et al*., 2019).

Ngaahere

Where forest/shrubland is associated with solar farms it is, by and large, as a screen planted as part of the consenting process to remediate scenic values (pers comm McMath, Kea energy). An effect of this can be that solar plants, if properly managed, increase the number of species in a given area, create new habitats for endangered animals and plants, and make positive use of marginal and remediated lands (German Renewable Energy Agency (2010)).

Within solar arrays, however, the presence of woody species is problematic due to the risk of fire and competition for light. Site preparation involves the removal of vegetation, and often the alteration of drainage systems that can affect plant communities downstream (Lovich *et al.,* 2011).

Recent work by Um (2022) on the potential for farm scale deployment of solar trees pointed to efforts being made to integrate solar energy production with forested landscapes. Solar trees need only occupy 1% of the land area of flat panel arrays to produce equivalent energy and allow more sunlight to reach the ground. While the technology is in its infancy, and currently more expensive due to lack of manufacturing scale, Um (2022) noted that, aside from the increased potential for carbon storage and productivity by forest underneath, solar trees as structures are more naturalistic and may be integrated into landscape without destroying natural (or desirable) character.

Maara

Production of crops under solar arrays is known as an agrophotovoltaic or agrivoltaic system, and research on them is based on emerging solar sharing theory (Um (2022)), see Figure 13 as an example. Work done in Korea (Kim *et al*., 2021) on four crop species described optimal panel configuration for maximising crop production and energy generation. This pointed to the need for well-designed arrays to maximise efficiency of these systems.

A major requirement for producing crops is the ability to cultivate using machinery, and to this end photovoltaic arrays will typically need to be about 4m above the ground (Dinesh *et al.*, 2016). Sekiyama *et al.,* (2019) recommend that the photovoltaic modules should be lightweight because they are mounted in these high locations. The modules also need to be small to reduce the shadows cast on the ground as well coping with the influence of wind.

Marou *et al.* (2013) investigated evapotranspiration rates in two crops, lettuce, and cucumbers, growing under solar arrays. Following earlier work showing that crops such as lettuce can produce high yields under the partial shade of photovoltaic arrays, Marrou *et al.,* (2013) found that evapotranspiration rates were reduced more for lettuce than cucumbers, an effect they ascribe to the greater coverage of the soil area by the leaves of lettuce lowering evaporation directly from the soil.

This has positive implications for conservation of water resources in crop production in areas prone to drying.

Figure 12 Agrivoltaics pilot plant by Fraunhofer Institute for Solar Energy Systems (ISE) located at Heggelbach farming community in the south of Germany.

We did not find any studies of the effect on soil quality in agrivoltaic systems, nor loss of sediment into waterways. The implicit assumption in the work we surveyed was that cropping under arrays is carried out using similar methods, and with similar effects on soil and water, to cropping alone (i.e., in open fields), and thus the more general body of cropping research could be assumed to apply.

Agrivoltaic systems are seen as an emerging way for farmers to increase the profitability of land, and to mitigate the inherent climatic uncertainties in crop production (Um, 2022). While both the price received for power generated and for crops grown will vary annually, the combination of the two systems can lead to significantly higher and more stable returns on average. A crop model developed by Dinesh *et al.,* (2016) showed that agrivoltaic systems may be highly productive, with increases of the overall economic productivity as high as 60–70%. The results of Dupraz *et al.,* (2011) were more conservative, showing that the value of solar generated electricity coupled to shade-tolerant crop production created an over 30% increase in economic value from farms deploying agrivoltaic systems instead of conventional agriculture.

We did not find any examples of research into agrivoltaic systems in operation in New Zealand, but the potential for grazing both young cattle and sheep is recognised within the industry (McMath, Kea Energy, pers comm.).

There are substantial knowledge gaps in relation to how different crops perform under photovoltaic panels. A key variable that has been found to be important is the light saturation point of a given crop (ie shade tolerance), although results are equivocal given that corn, which is considered relatively shade intolerant, performed better under 21.5% photovoltaic shade than in the open (Kim *et al.,* 2021).

4.2.2. Tuna

Tuna are taaonga tuku iho, and whakapapa to Te Ihorangi (Hopkins,2018), the children of whom are the many kinds of rain. Customary fishing of tuna by Waikato-Tainui continues to occur, often as harvest for events such as Tangi or Hui, and for the Poukai (Hicks *et al*., 2013), the annual sharing of food between Marae that is an important expression of Kiingitanga. (Te Ataahua Richmond. pers comm).

Discussion of rearing tuna during our waananga revealed the potential for this land use to be valued purely in terms of te ao Maori. For example, although the Poukai has traditionally been an occasion where food produced by hapu and whaanau was ceremonially shared, increasingly financial contribution has been made in lieu of food. This break with tradition is not necessarily seen as positive, and we found strong support for being able to produce for the Poukai a suitable contribution of food produced by whaanau. Tuna could be one such food.

Commercial catches of tuna in Lake Waikare in the 1980s were as much as 85 tons annually but catch numbers are now very low, and the physical condition of tuna in the lake now amongst the lowest in the Waikato/Waipaa catchments (Watene-Rawiri *et al.,* 2016). The leading causes of this decline (other than fishing pressure) are seen to be the high sediment load entering the lake and low availability of food for tuna. Watene-Rawiri *et al.,* (2016) proposed that special attention needs to be paid to Lake Waikare and Matahuru stream, recommending several approaches that may help to reverse this trend. Some of these, including managed ponds and wetlands in channels, planting of the lake edge with tall trees to shade water and encourage woody debris, and managing the fishery to encourage retention of large, piscivorous tuna, could be achieved as part of development of matauranga based tuna rearing at Nikau Farm.

We also observed that high regard for tuna is shared across iwi throughout the motu, and that in times past tuna (dried or smoked) was an item of exchange. In line with movements such as Hua Parakore (Hutchings *et al.,* 2012), we questioned whether there might be an economic potential for tuna reared and prepared by Maaori primarily for Maaori consumption. The nature and scale of tuna rearing, preparation, and distribution in such a scenario would necessarily be guided by moohiotanga tuku iho and maatauranga and could look very different to models derived from conventional aquaculture and driven by global markets. There is potential for a range of culturally desirable outcomes to be linked to such an initiative, such as restoration of oneone, repo, awa, and ngaahere, uplifting of tikanga and kawa, education of tamariki, and the creation of culturally satisfying employment.

The Waikato-Tainui Fisheries Regulations 2011 allow for a whakaaetanga holder to harvest tuna, deposit and keep them in a paa tuna, and subsequently use, so long as that at each step the use is for a customary purpose, which means:

(i) providing food at hui or tangihanga; or

(ii) sustaining the functions of a marae; or

(iii) any other customary purpose:

- (a) educational research:
- (b) environmental research:
- (c) enhancing species:
- (d) restoring species.

Under these regulations it would be possible to construct, build, and stock paa tuna for the immediate purpose of sustaining both a food source for whaanau and satisfying commitments such as the Poukai, Tangihanga, and hui of various kinds.

It is unclear whether utilising paa tuna for the commercial exchange of tuna with other iwi would be considered an ‘other customary purpose’, but the regulations make this a matter for the Waikato-Tainui Trust Board to decide. Even were the sale of tuna from such a system approved under the

Waikato-Tainui customary system it would trigger a requirement (at least) to be registered as a fish farm under the Freshwater Fish Farming Regulations 1983.

There is currently no aquaculture of tuna in Aotearoa (Hirt-Chabbert*,* 2011), although in recent years Raglan Eels has developed and tested a system they call Nitro EELS. This system was "conceived to create new, highly productive ecosystems constructed using NZ native plants and animals supercharged by farm nitrate runoff." (Nitro EELS website). The system has been considered for use in wastewater treatment by Waikatio Regional Council, but to our knowledge has not been implemented. We were unable to access further information on this system during this study, and the proof-of-concept site is no longer operating.

Internationally eels are an aquaculture species of high value. Various systems are used, ranging from low density ponds to high density reticulation systems. Commercial cultivation of eels has ancient roots, and modern methods have been developed for Japanese and European species from 1879, beginning with Japanese pond systems (Hirt-Chabbert*,* 2011).

Owing to the complex life cycles of all eel species, where eggs are laid and juvenile stages occur in oceanic habitats, the aquaculture of eels relies on the harvest of glass eels (juveniles recruiting to fresh water from the sea), or elver and juvenile (yellow eels) stages, although this is less common. Large scale commercial harvesting of these life stages of Japanese and European eels for aquaculture is thought to have contributed to the large decline in numbers of migrating glass eels observed in recent years (Hoyle & Jellyman (2002).

In Aotearoa the taking of glass eels for any purpose, other than very limited catches for research purposes, is currently forbidden (Hirt-Chabbert, 2011). This limits the scope for development of eel aquaculture based raising glass eels through to harvestable size. In addition to this the two common tuna species (*Anguilla australis* – Shortfin eel, and *Anguilla dieffenbachia* – Longfin eel) are increasingly seen to need different management strategies to maintain the health of stocks. The longer breeding cycle of the Longfin, and need for better quality habitat render its management even as a wild stock more difficult (Hoyle & Jellyman (2002).

The effects of intensive rearing of eels through monocultural aquaculture were researched within relevant atua domains.

Wai

Aquaculture systems produce large volumes of wastewater rich in nitrogen, phosphorus, and suspended solids (Turcios & Papenbrock, 2014). Wastewater also has the potential to contain disinfectants and other treatments used in the control of disease, which is one of the main threats to intensive aquaculture (Chen *et al.*, 2018). Growth hormones are also used in many eel aquaculture systems and can remain in wastewater (Sweeny *et al.,* 2021).

Recirculating aquaculture systems often use filtration and settling technologies to remediate wastewater, with the resultant sludge used to produce compost, or even after treatment directly applied as fertiliser to land. Increasingly, "constructed wetlands technology is becoming more and more important in these systems because wetlands have proven to be well-established and a cost-effective method for treating wastewater", although they may require significant land area (Turcios & Papenbrock, 2014).

Pond systems employ a wide range of different methods. "Solids removal is accomplished by sedimentation, sand, or mechanical filtration. Biological processes such as submerged biofilters, trickling filters, rotating biological contactors, and fluidised bed reactors are employed for the oxidation of organic matter, nitrification, or denitrification" (Turcios & Papenbrock, 2014). Other approaches, such as integrated multi-trophic aquaculture attempt to balance biological and chemical processes through "the appropriate selection and ratios of different species providing different ecosystem functions". Turcios & Papenbrock (2014) point out that 'co-cultured species are typically more than just biofilters; they are harvestable crops of commercial value'.

In the context of the present work the description by Turcios & Papenbrock (2014) of the historical roots of aquaculture pointed to numerous pre-modern systems that were highly productive and achieved high levels of ecological integration. Of particular note are the rice paddy systems of Asia, and the chinampas of Mexico City (Figure 14). Both kinds of system are still in use today and remain highly productive.

Pepeke

No sources were found that showed any benefits to insects as a result of introducing eels, especially since eels eat insects. However, habitat restoration that comes with tuna is likely to also improve invertebrate habitat, and zooplankton being a source of food.

Figure 13 Chinampas, Mexico City (Image ©Andrea Reynosa (www.andreareynosa.com), used with permission)

Ika

Koi carp are abundant in Lake Waikare and considered a pest species of special importance due to the effect of their overwhelming numbers on turbidity, plant and macrophyte abundance, and predation upon and competition with native fish (including juvenile tuna) and other aquatic species (Nikau whaanau pers. comm.). Koi are already caught and processed for animal food by the Nikau whaanau in an effort to help reduce numbers in the lake. They have also conducted trials using a slurry of koi to directly fertilise the land. Tuna have been observed by the whaanau to eat koi caught in nets and could potentially provide a food source for any effort to raise tuna intensively (Tawera Nikau, pers comm).

The koi in Lake Waikare are exposed to high levels of many contaminants. If these are bioaccumulating in the fish then potentially using them for fertiliser could spread contamination to the soils presently uncontaminated (Matthew Taylor, WRC, pers comm). Likewise using koi from the lake to rear tuna could lead to further bioaccumulation of contaminants in tuna, reducing their value as a food source. We did not find any literature investigating this effect in this particular setting. However, such concerns are increasingly being researched by and for iwi, such as the study of the Te Arawa lakes (Phillips *et al.,* 2011), and recent work undertaken by the Cawthron Institute on the effects of algal blooms on the safety of tuna for eating from Lake Whakakī near Wairoa (Cawthron Institute, 2022).

Watene-Rawiri *et al.,* (2016) noted that 'generally, bioaccumulative contaminants of most concern include organochlorine pesticides (especially DDTs and dieldrin), polychlorinated biphenyls (PCBs) and dioxins (particularly in the vicinity of timber treatment plants), pentachlorophenol, and selected heavy metals such as mercury, arsenic, cadmium, and lead", and further that 'there is the possibility that the fishery could be limited in the future by mercury levels in eel flesh, especially in the upper hydro- reservoirs [above Lake Waikare], and through tainting and toxicity from blue-green algal blooms [in the Lake Waikare area]'.

Kaaeo

Native freshwater mussel species (kaaeo) play an important role in maintaining water quality in natural waterbodies but are currently in decline in many places due similar threats to those facing tuna. Restoration of tuna habitat, such as making drainage ditches wider, shallower, and better shaded (Watene-Rawiri *et al.,* 2016) may benefit kaaeo populations.

Energy and Carbon

Tsakiridis *et al.* (2020), in comparing aquaculture to other food production systems concluded that aquaculture is found to have the greatest output multiplier and a low to medium carbon footprint compared to pastoral livestock products (beef and veal, sheep meat, dairy)' but go on to comment that 'aquaculture is energy intensive, and therefore production requires the efficient use of energy and resources, and the employment of low carbon technologies that strengthen aquaculture's sustainability.

Recent innovation in aquaponic culture systems, where fish production is linked to systems growing hydroponic crops, have begun to incorporate solar power into the mix in what is termed solar aquaculture (Vo *et al.,* 2021).

4.2.3. High Value Crops

In recent years land use at Nikau Farm has changed from dairying to cropping. Some land adjacent to the lake has been planted in native shrubs and trees, much of it is swamp maanuka. Nearly all the remaining area is now used for growing crops of watermelon, pumpkin, maize, and wheat. Some land near the lake, which has been successfully cropped in the past, has been too wet in the last two seasons, and has remained fallow. An area has also been set aside as maara for whaanau to develop, and growing in this are kumara, tomatoes, cucumbers, and other vegetables.

Nikau farms as a whaanau enterprise is emulating tuupuna o mua to become agriculturalists and horticulturalists again. Nikau farms are actively asserting their kaitiakitanga status on ancestral whenua free from the threat of colonisation thereby fulfilling their manaakitanga responsibilities for their whaanau and hapuu as per their tikanga and kawa. (A. Hopkins, pers. comm.)

At the scoping waananga two motivations for crop growing were identified – the production of commercial crops for market, and economic return to support whaanau, marae, and other hapu and iwi functions, and the growing of traditional crops in maara kai for directly feeding whaanau and supporting the marae, tangihanga, hui, poukai etc with culturally valued food of high nutritional quality.

The growing of food in maara kai was seen as important for connecting tamariki and reconnecting whaanau with the whenua, and as an activity that would uplift tikanga and kawa, and enhance connection to maramataka.

The review of literature relating to commercial crops looked at high value crops identified during the scoping waananga and compared their effects, with relation to nitrogen application and nitrate leaching, CO_2 emissions (kg CO_2 equivalent/ha), profitability ($/ha), and robustness with both dairying and with crops currently being grown (Tables 1 and 2).

Table 1 Nitrogen application, leaching, carbon emissions and profitability of selected field crops.

Crop	Nitrogen application	Nitrate leaching	Emissions (kg CO_2-e/ha) [1]	Profitability ($)/ ha [1]	Robustness [1]
Dairy	241 kg/ha [2]	43 kg/ha/yr leaching with 3.0 cows/ha (fertiliser N at 170 kg N/ha/year) [3] 59 kg/ha/yr [2]	198	$1,800	****
Watermelon	30 -120 kg/ha [4] 120 kg/ha [5] 270 kg/ha [6]		-		-
Corn	250 kg/ha cropmaster, 250 kg/ha Urea [7] 100 kg/ha [8] 320 kg/ha [9]	6.6 kg/ha/yr [8]	-	$788 [10]	-
Pumpkin	212 kg/ha [2]	13 kg/ha/yr [2]	-		-
Peas	5 - 10 kg/ha [11] 0 kg/ha [7]	90 kg/ha/yr [8] 25 - 50 kg/ha/yr [11]	302	$1,537	**
Onions	2 Passes 1,800 kg/ha Pre plant (Base) 15% Pot super 800 kg/ha Post Emergence (Side) CAN 3,000 kg/ha Lime [7]	105 kg/ha/yr [2]	1,229	$5,385	**
Potatoes	600 kg/ha Triple Super 250 kg/ha SOP 250 kg/ha Kieserite 200 kg/ha DAP (x3) 100 kg/ha MOP [7] 268 kg/ha (Main crop potatoes), 543 kg/ha (Early potatoes) [2] 0 - 491 kg/ha [8]	31 kg/ha/yr (Main crop potatoes) 217 kg/ha/yr (Early potatoes) [2] 25 - 219 kg/ha/yr [8]	1,909	$3,373 (processed), $6,331	**
References : [1] Thomas *et al.,* 2022, [2] Crush *et al.*, 1997, [3] Ledgard *et al.*, 2011, [4] Buwalda & Freeman, 1986, [5] Sanders *et al.*, 1999, [6] Gülüt, 2021, [7] AgInfo, 2020, [8] Welten *et al.*, 2021, [9] Reid & Morton, 2019, [10]Te Puni Kokiri Factsheets, [11] GRDC, 2018,					

The data we found were all related to crops grown in monoculture using conventional cultivation techniques, synthetic fertilisers, and pesticide regimes. However, most of these crops can be integrated into a polycultural farming system (e.g. in Aotearoa NZ, permaculture with avocados, pumpkins and other species (Ecothrifty Life, 2023), and maize-based polyculture systems (Bamboriya et al., 2022)).

Table 2 Nitrogen application, leaching, carbon emissions and profitability of selected fruit and speciality crops.

Crop	Nitrogen application	Nitrate leaching	Emissions (kg CO_2-e/ha) [1]	Profitability ($) per ha [1]	Robustness [1]
Apples	56 - 84 kg/ha, mean 69 kg/ha [2] 110 kg/ha [3]	5.2-141 kg/ha/yr [4]	809	$17,147 Hawke's Bay, $14,770 Nelson	****
Avocados	200 kg/ha [5] 140 kg/ha [6] 98 - 1,950 kg/ha [7]	5 - 22 kg/ha/yr [7]	526	$27,000	**
Blueberries	80 - 155 kg/ha [8] 50 - 150 kg/ha [9] 144 kg/ha [10] 100 - 150 kg/ha [11]	11 - 16.5 kg/ha/yr [11]	300	$66,000	*
Cherries	90 - 283 kg/ha [12] 75 kg/ha [13]	Up to 80 kg/ha [13]	734	$40,000	*
Chestnuts	28 - 80 kg/ha [14] 30 kg/ha [15]		<8	$8,155	*
Kiwifruit	337 kg/ha [16]	22 kg/ha/yr [16]	1,250	$17,697 green, $61,500 (Sungold)	****, ***
Wine grapes	4.9 kg/ha (Marlborough), 29.3 kg/ha (Gisborne) [17] 25 kg/ha di-ammonium phosphate = 5 kg-N/ha Range: 1.2 - 14.0 kg NO3-N/ha [18] < 200 kg-N/ha (Marlborough) [17]	8 kg/ha/yr [18]	311	$15,285	****
Truffles	0 kg/ha [19]	-	220	$40,000	*
Maanuka + honey	-	-	<8	$1,300	**
References : [1] Thomas *et al.,* 2022, [2] Palmer *et al.*, 2006, [3] Scudellari *et al.*, 1993, [4] Hardie *et al.,* 2015, [5] McCarthy, 2010, [6] Salvo, 2005, [7] Kiggundu *et al.*, 2012, [8] Ehret *et al.*, 2014, [9] Bryla & Marchardo, 2011, [10] Messiga *et al.*, 2020, [11] Bandaranayake *et al.*, 2020, [12] Haifa Group, 2018, [13] James, 2011, [14] Arrobas *et al.*, 2023, [15] Arrobas *et al.*, 2017, [16] Crush *et al.*, 1997, [17] Herath *et al.*, 2013, [18] Clothier & Green, 2017, [19] Bradshaw, 2005.					

We found that for many crops the measured or calculated values of nitrogen use and of nitrate leaching varied significantly between studies. This variability is likely to be the consequence of differences between studies in underlying soil fertility, growing regimes, and in rainfall and other site-specific variables. In addition, the source that we found for the data on emissions, profitability, and robustness did not provide data for the crops currently being grown (i.e. watermelons, corn, pumpkins, wheat). In general, the field crops (Table 2) for which we do have data show a wide range of nitrogen use, with the currently grown crops of watermelon, corn, and pumpkins similar to, or lower than, dairying. While some field crops appeared to have lower leaching properties compared to diary (e.g. watermelon or potatoes depending on the fertilisation rate) other have similar or even higher leaching abilities (e.g. onions). Peas, being fixers of nitrogen, are an exception to these observations, often needing little or no added nitrogen, but leaching moderate levels.

Among the available data, the most profitable field crops were found to be onions and potatoes, but these were also the crops that had the highest nitrogen requirements and subsequent leaching. In addition, all the field crops had higher CO_2 equivalent emissions than dairy and were seen to be less robust.

Rates of nitrogen application generally appear lower for the fruit and speciality crops that we assessed (Table 3) compared to the field crops (Table 2), although again there was considerable variability in the reported figures. Kiwifruit had the highest carbon emission (Table 3), almost as high as for onions. Blueberries had the highest profitability per hector ($66,000) and also seemed to have the lowest environmental impact in terms of carbon emissions and nitrate leaching amongst all fruit and speciality crops as well as assessed field crops.

4.2.4. Greenhouses

Interest was shown at the scoping waananga in the potential for crops to be grown in greenhouses. We questioned whether there might be synergies between greenhouse cultivation and the energy available from solar farming, and also whether greenhouses offered a way to generate high return from a relatively small portion of the land, freeing other parts for different uses and for achieving different goals.

Production in glasshouses and other covered cropping systems in Aotearoa ranges from small (0.05ha) operations to some as large as 34ha. The average size of covered cropping operations is around 1.8ha (Te Puni Kokiri), but for different crops different economies of scale apply, for example tomatoes are often grown in large multi hectare glasshouses, whereas herbs and other high value/specialist crops tend to be produced at a smaller scale.

The structures required for covered cropping are best suited to flat areas that are not subject to waterlogging or swampiness (Te Puni Kokiri), potentially limiting the area that may be considered suitable at Nikau Farm.

The capital costs involved in setting up covered cropping are high, and vary significantly between modes of cover, for example low tech blueberry tunnels may cost $400-500K/ha, whereas a tomato glasshouse is in the range of $2-3M/ha (Te Puni Kokiri - factsheets).

A wide range of crops are grown under cover of some description. We reviewed information, primarily from industry sources, of some crops and highlighted features (Table 3) which might support integration of these in a greenhouse context on Nikau Farm in future.

Generally, greenhouses offer a stable alternative to traditional open-air farming practices, as they allow for consistent, year-round crop growth supported due to controlled microclimate generated underneath the protective cover (O'Connor & Mehta, 2016). However, besides these benefits of greenhouses as land use options other disadvantages may occur as described hereafter.

Oneone

Greenhouse cultivation can lead to soil degradation due to excessive fertilization, acidification, and secondary salinization (Liang *et al.*, 2013; Wu *et al.*, 2020), especially for plastic greenhouse vegetable cultivation. These changes in soil properties can lead to changes in the soil microbiome and affecting its stability (Song *et al.*, 2018) and may cause higher frequency of pests. Fertilization with compost or manure instead of inorganic fertilisers can be an option to promote plant growth and to reduce soil acidification (Goldammer, 2019). However, it has the drawback of potentially increasing heavy metal concentrations and residue accumulation of tetracycline antibiotics and pesticides (Tong *et al.*, 2022). Implementation of cropping rotation models were suggested to prevent soil degradation in the greenhouse (Liang *et al.*, 2013).

Wai

Due to the prevention of excessive evaporation by the protective cover, less water would be needed to support crop growth in greenhouses compared to open-field farming (O'Connor & Mehta, 2016).

However, humidity can develop quickly in greenhouses from respiring plants and can increase the spread of fungal pests). To minimise this, growers open vents leading to the loss of heat, which is often mitigated by using fossil fuels to re-heat the greenhouses and resulting in a higher energy demand compared to open-field farming. Installation of dehumidifying units can counteract heat-loss and decrease the demand of fossil fuel use (EECA, 2023).

Table 3 Features of selected greenhouse crops.

Crop type	Size and Location	Economics	Future trends and opportunities
Tomato	Largest crop grown under cover in Aotearoa and the industry is dominated by large growers. Commercial covered tomatoes need at least 4,000 m^2 of flat land for the greenhouse itself.	Entry into this industry has high capital costs compared to other forms of covered growing, and high production costs. However, the yield of 150 and 200 t/ha in greenhouses is more than twice as much as in open-field (around 85 t/ha). (Martinez-Blanco *et al*.., 2011)	There is increasing demand for niche varietal, vine ripened, and cherry tomatoes, which may be able to be produced in competition with the bulk growers and in smaller operations.
Capsicum	Capsicum growing has the highest energy use of any covered crop (Nederhoff, 2022). Minimum covered area for commercial production is considered to be 0.4 ha, but as with tomatoes the industry is dominated by a few large growers.	Mid-range facilities for capsicums (plastic tunnels) may cost around $1.7M/ha, but once operational can produce $300-350K/ha return per annum over running costs of $850-900K.	
Cucumber	Cucumbers also require high temperatures and thus have high energy demands, but this is offset by their relatively high yield as a crop.	Crops yield (and thus labour) can be spread over the entire year, with premium prices in winter offsetting the loss of productivity over summer occasioned by the planting of winter bearing plants.	
Lettuce	Using modern high-spec glasshouses as little as 2000 m^2 is necessary for commercial scale lettuce production. Older systems may require a minimum of 1 ha. Hydroponic systems are common.	Lettuce can be expected to offer lower returns per hectare than tomatoes, peppers, or cucumbers, at around $110K/ha, but also have a significantly lower demand for heat, and lower nitrogen requirements.	
Berries	Covered cropping of berries is concentrated around the Waikato and in Hawke's Bay, with many growers using low tech plastic tunnel houses.	The marketable yield under the plastic tunnels can be as high as three times what you might achieve in the field (Christie & Nichols, 2016.)	Local expertise in growing these crops is likely to be available should Nikau Farm enter this industry. The blueberry industry is in a state of rapid growth, with many new growers entering and significant research and marketing efforts being driven by government and industry (NZ Grower, 2021).

Pepeke

Studies have shown that survival and pollination efficiency of insects can significantly decrease under greenhouse conditions (Kendall *et al*., 2021). Kendall *et al* suggested that increased access to floral diversity, through the inter-planting of crops, inclusion of additional floral resources, or allowing pollinators to forage outside the covered system can mitigate loss of pollinators.

Manu

When birds' habitat and sky are visible through glass (as with a greenhouse, atrium, sunroom, or deck panels), birds may attempt to fly through what they see as a continuation of outdoor space. Occasionally, a bird will attack a window when it sees its own reflection. This most often occurs during mating season when the bird may believe its territory is threatened (Pelczar, 2022).

Ngaahere

The physical restriction of greenhouses and other forms of cover prevents the movement of birds, pollinators, and native seeds, which inhibits the growth of ngaahere. Additionally, any land cleared for greenhouse construction also reduces the health of the forest.

Energy and Carbon

All covered vegetable crops require significant inputs of energy, especially during the winter months (NZIER, 2020). Blueberries grown in unheated, low-tech tunnel houses will yield more than a crop grown in the open, but will produce even better when some heating is used (Te Puni Kokiri, Factsheet). Over eighty percent of the energy for heating covered crops in Aotearoa is currently provided by non-renewable resources (MBIE, 2019). Renewable energy sources including wood pellets (NZIER, 2020) or geothermal energy (Eng *et al.*, 2008) could be used as alternative where suitable.

Innovations such as utilising heat pumps, and heat pump driven dehumidifiers (which can be powered with solar arrays) rather than opening panels for ventilation, and installing thermal screens that reduce heat loss, are proving to significantly reduce energy use (Energy Efficiency & Conservation Authority, 2023). This is an area in which the government, through the Energy Efficiency & Conservation Authority (EECA), is supporting research and development, and opportunities may exist for engagement with this should covered cropping be attempted at Nikau Farm.

On account of the high use of non-renewable fuels to heat covered crops, the industry in New Zealand was estimated in 2018 to generate 221,000 tonnes of carbon dioxide emissions (MBIE, 2019). The government's Emissions Trading Scheme has so far granted credits to producers of tomatoes, cucumbers, and peppers, but many smaller growers are liable for the full cost of their emissions. Coupled with increasing labour costs this is seen as creating significant uncertainty in the calculation of profitability for many existing operations (NZIER, 2020).

4.2.5 Native vegetation

Over the past seven years, riparian areas at the Nikau Farm have been planted in native vegetation. This was initially done with the intention to reduce sediment and contaminant inputs from farmland into Lake Waikare, but its further development has been by whaanau in their role as kaitiaki, and for the enhancement of mauri and mana. Further plantings of native trees were considered for potential future land use with a view to providing income from essential oils, honey, culturally valuable timber and fibres, or carbon credits, and included experimental restoration plantings established in collaboration with several authors of this report. Given the extensive knowledge on the benefits of restoration plantings for restoring the mauri of the lake, including our own research results (Gutierrez-Gines *et al.,*. 2021), in this section we focused solely on the potential economic benefits that such restoration areas could provide to Nikau Farm. The return of currently farmed land into native forest was mainly discussed for areas that are not suitable for other productive purposes, such as those that were too wet for crops.

One option to generate income from native forest is through the emissions trading scheme (ETS). However, to be eligible to earn carbon credits from the ETS, plantings must be at least 1 ha and 30 m wide on average. Furthermore, tree crowns must cover at least 30% and trees must reach a minimum height of 5 m at maturity (MPI, 2023). Some species that could potentially be included in such plantings at Nikau Farm are: Nikau palms, maanuka, tii koouka, pukatea, maire taweke, puriri, houhere, matai, kowhai, totara, and pokaka. Assuming that one carbon credit is worth $105.60 (mynativeforest.com, 2022), the cumulative income per ha is shown in Figure 15.

Harvest is restricted in forests earning carbon credits, and an alternative productive use of forest is the harvest of high-value timbers (Tuahine, 2018). Some native species, Totara and kauri for example, are prime timber species that are in high demand in Aotearoa New Zealand, as are a range of exotic species that produce speciality timbers. Puriri, Rewarewa, kokekohe, and mangaeao are other native hardwood species that are cultivated in the North Island and could produce timber.

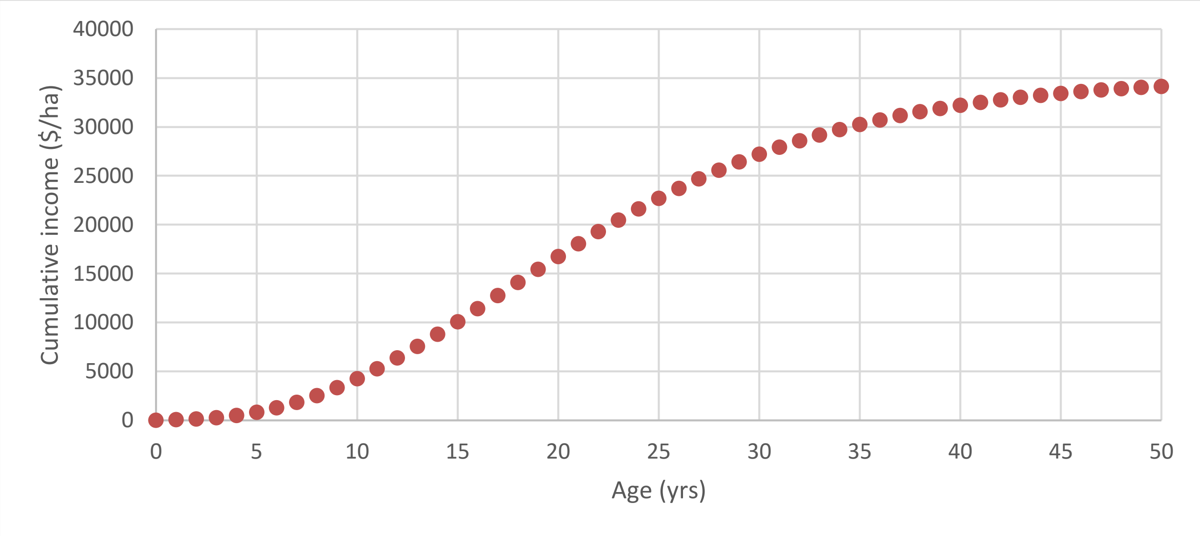


Figure 14 Cumulative income per hectare for native forest from carbon credits through the Emissions Trading Scheme, assuming one carbon credit is worth $105.60 (mynativeforest.com, 2022). Carbon stock values taken from Climate Change (Forestry Sector) Regulations 2008

Significantly increasing the area nationally managed as mixed species closed canopy forestry, from which such high value timbers could be produced, is a central aim of the *Te ara whakahou - ahumahi ngaahere : Forestry and wood processing industry transformation plan* (MPI, 2022). We see support from government for initiatives by Nikau Farm that engage with this process of transformation, and the potential for closed canopy forestry to produce high quality native and exotic timbers of high cultural and monetary value for whaanau.

A third potential for generating revenue from native tree crops is through the production of manuka honey. While maanuka honey is the most valuable of all types of honey (Table 4), maanuka is not a preferred food source for honeybees, and where other species are available bees prefer to feed on those. Large contiguous areas of manuka are thus recommended, or else the dilution of maanuka honey by other nectar sources reduces its value. To generate high-value monofloral maanuka honey, it is advised that plantings cover at least 50 ha, with apiaries situated in the middle (Kauri Park, 2015). There are concerns that the influx of honeybee populations in the last few decades may place pressure on New Zealand's solitary native bees through competition for nectar and pollen (Hancock, 2018).

Alternatively, maanuka could be planted in hedgerows to be simultaneously used for the production of essential oils, which can generate a revenue of $1,700-$4,250 per hectare (Kauri Park, 2015). Maanuka essential oil is known for its antimicrobial properties and used in a wide range of medical and personal care products (Kauri Park, 2015). Native vegetation also has the potential to be productive of resources such as fibres, medicinal plants (Rongoa), and fungi.

Table 4 Production, price and potential total gross income for different honey and other products made by bees, derived from data in Apiculture Monitoring report 2020 (MPI, 2020).

Product	Hives/ha	kgs/hive	Price per kg (range)	Total gross income/ha/yr
Manuka	2	25-31	$8 - $120	$1,550 - $7,440
Light (clover type)	6	25-31	$3.60 - $6	$540 - $1,116
Light amber	6	25-31	$3.50 - $6	$525 - $1,116
Dark, including honeydew	6	25-31	$3 - $7	$450 - $1,302
Beeswax (light)	6	0.45-0.56	$7 - $11.50	$18.90 - $38.64
Beeswax (dark)	6	0.45-0.57	$5 - $7.50	$13.50 - $25.80
Pollen (not dried or cleaned)	6	30	$20 - $35	$3,600 - $6,300
Pollen (dried and cleaned)	6	30	$40 - $50	$7,200 - $9,000

There are several native species that could be cultivated for fibre and are already growing at Nikau Farm. The most prominent example is harakeke, used for plaiting of kete (containers) and whaariki (mats). The extracted fibres (muka or whiitau) are used for traditional kaakahu (cloaks) and for cordage (Landcare Research, 2010). The leaves of Tii koouka are also used in cordage and make a strong and durable rope (Ngarangi Marsh, pers comm.). These plants are an important component of the cultural landscape, and further inclusion of them beneficial to the enhancement of whaanau knowledge of tikanga and kawa relating to them, and use of them in everyday life.

Native vegetation could also provide an environment that may be suitable for the establishment of mushrooms. Gathering of mushrooms from native bush could therefore be an additional food source for the whaanau. Alternatively, for a more productive system, growing of oak species, or logs of willows and poplars that have been cut to be replaced with native vegetation could be inoculated with mushrooms. Suitable culinary mushrooms for inoculation on logs are oyster, shiitakke, enoki, tawaka, woodear (Mycologic, n.d.). However, a mushroom grow log will require several months to completely colonise with mycelium and will take at least six months, and more commonly one to two years, to produce its first flush of mushrooms (Mycologic, n.d.).

4.2.6. Complex systems of land use – Polyculture and agroforestry systems

The majority of the land at Nikau Farm is currently used for agricultural production based on monocultural systems. The change from running a dairy herd to the current crop rotations represents a diversification of production, but as a land use remains structurally (ecologically, economically, and culturally) similar. One of the important goals for land use change expressed by whaanau at the scoping waananga was expressed as 'the diversification of crops.' We discovered this goal, when expressed from the te ao Maaori perspective, went beyond an aspiration to increase the diversity of commercial crops, and included a vision of the restoration of culturally significant (and diverse) landscape and cultural use.

The term we first started using to discuss and investigate diversified and more complex land use was 'polyculture'. This term covers a wide range of practice, from conventional cropping systems that produce more than one type of crop (for example, at most simple, crop rotations, and various kinds of inter- and mixed-cropping) (Adamczewska-Sowińska & Sowiński, 2019), to the 'multi-layered, shaded coffee agroforests of Mexico and Central America (Perfecto *et al.,* 1996) and the complex systems of approaches such as permaculture (Geno & Geno, 2001).

Both polyculture within a conventional cropping framework, and polycultures within more complex indigenous, peasant and modern systems, were of interest to whaanau. Indeed, as we discussed, they are not exclusive – many traditional farming systems existing for Waikato-Tainui prior to confiscation were complex polycultures producing not only food but also fibre, building materials, medicines, and fuel (Te Ataahua Richmond, personal communication).

Polyculture farming systems can have many environmental benefits which we will summarise hereafter.

Oneone

Different studies have demonstrated that polycultures have a positive effect on soil fertility, physical soil characteristics and microbial activity in soils (Adamczewska-Sowińska and Józef Sowiński, 2019; Bamboriya *et al.,* 2022). For example, a polyculture combining trees with annual crops of millet and sorghum (i.e. an agroforest system) studied in Africa demonstrated increase of organic matter by 25-40% when compared to annual crops grown alone (Geno & Geno, 2001). Another study by Guzman *et al.,* (2021) showed that polycultures of eggplant and squash increased the diversity and richness of available arbuscular mycorrhizal fungi communities in soils as well as increased the soil cation exchange capacity and C/N ratio when compared to monocultural situations.

Wai

Polyculture systems can decrease leaching of contaminants such as phosphorus or nitrogen into waterways by enhanced uptake of these nutrients (Adamczewska-Sowińska and Józef Sowiński, 2019). However, for organically managed systems the composition of leachate and risks of nitrogen and phosphorus loss might not be significantly different between monoculture or polyculture cropping systems (Noor *et al.*, 2020). Due to improvements in soil structure the water retention capacity, resistance to drought can be increased for polyculture systems (Bamboriya *et al.*, 2022; Altieri *et al.*, 2015).

Pepeke

A meta-study analysing over 25 single studies with 300 observations showed that polyculture can improve pest control (Iverson *et al.*, 2014), who suggest that "biocontrol benefits may result from associational resistance, such as a decrease in food concentration for specialised pests (i.e. resource concentration hypothesis) or an increase in their natural enemies (i.e. enemies hypothesis)". Similarly, in a review of 617 studies it was noted that population densities of 66% of monophagous (specialised feeding on one species) herbivore insects decreased in the polyculture systems when compared with the corresponding monocultures (Geno & Geno, 2001). However, wrong crop combinations can also increase pest infestation as shown for example for chili and melon (Wang *et al.*, 2020). It is not advised to grow watermelons in combination with pumpkins, cucumbers, or squash because of potential attraction of the cucumber beetles (Hassani, 2022). Besides combining different crops, implementing a wildflower strip can significantly reduce pest density and pest-induced crop damage. For example, a study reported a reduction of pest-induced damage of winter wheat by cereal leaf beetles of up to 40% when a wildflower strip was planted aside the crop (Tschumi *et al.*, 2016).

Manu

Introducing living fences into the cropping system can strengthen biodiversity by providing a habitat for birds, who can contribute to natural pest management and eat insects that may be in the fields (Thompson, 2019). A study by Eyster *et al.*, (2022) demonstrated that woody perennial polyculture (i.e. growing food-producing woody perennials together with vegetative groundcover), had a higher bird diversity associated with it than a traditional high-intensity farm optimised for maximum yield of corn, soybeans, or hay-like crops. Thus, the authors concluded that woody perennial polyculture can help to conserve the local bird diversity, including threatened species (Eyster *et al.*, 2022).

Ngaahere

High intensity monocultural farming systems are dependent on the extensive application of pesticides and herbicides (Sharma *et al.,* 2019). This can lead to the evolution of herbicide resistant weeds. Herbicide resistance in a range of arable grass weeds is becoming a serious problem throughout Aotearoa (Buddenhagen *et al.,* 2021). A study performed in 2019 detected weed resistance to different herbicides, including glyphosate, in over 25% of tested fields in Canterbury and over 50% of tested arable farms in Southland, Waikato, and Bay of Plenty as well as vineyards in Marlborough and Canterbury (AgResearch News, 2021). Polyculture approaches can facilitate internal, self-regulating, and adaptive processes that control weed and pest infestation naturally (Geno & Geno, 2001). For example, an intercropping study showed that combining barley with radish significantly reduced weed growth and increased crop yield (Bainard *et al*., 2020).

Besides the positive outcomes related to atua attributes, polyculture farming practice may require more labour, potentially leading to higher costs. However, a meta-study of Sanchez *et al*., (2022) identified that the gross income leading to farm profit do also increase for diversified and polycultural farming systems. Moreover, simultaneous cultivation of two or more plant species in the same plot may be a cost-effective insurance against crop failure (Bamboriya *et al*., 2022) which may occur more often in the current context of climate change and accompanied extreme weather events.

The increased labour requirement of agroecological system is often seen as problematic, however we see synergy between the reconnection of whaanau with the farm and change to relationship with land that requires more (and differently capable) labour. The community led labour structures of agroecological systems differ from the market driven and individualist systems of conventional agriculture and we found in our discussions that maatauranga Maaori supported building capacity to work in this way.

5. Discussion and Conclusion

5.1. Land uses and practices that could help achieve Nikau whaanau aspirations.

Broadly speaking, the discussion of land use change and the scoping review of literature that we carried out had two distinct aspects. The first was discussion and research into the effects of changing from the current commercial cropping regime to other commercial crops or commercially productive systems. Considering ‘land use change’ as a change between any of these crops would not necessarily address the underlying systemic issues we had identified, and had strong potential to fall into a ‘business as usual’ trap.

The second strand of our discussion thus conceived of ‘land use change’ in a broader sense. The clear aspiration expressed by whaanau to actively assert their kaitiakitanga status with regard to the land, and the discussion that evolved from there, led us to envisaging ‘land use change’ not just as encompassing the shift from one crop to another, but also meaning transformative change that allowed full expression of the vision of Waikato-Tainui as expressed in their Environmental Plan (Waikato-Tainui, 2013): “to return the Waikato-Tainui rohe to the the modern-day equivalent of the environmental state that it was in when Kiingi Taawhiao composed his mamai aroha tongikura”.

What is the nature of this change? At most basic we found that it is that the whaanau continue to move from a position of decision-making regarding land that focuses primarily on economic use (that is the result of colonial and capitalist understandings of the world) to a position of decision-making that focuses on supporting the whakapapa relationships that lie at the core of Waikato-Tainui Maaturanga Tuku iho.

Our use of the atua and their attributes to direct the literature review was an exploration of how decision-making that focuses on supporting the whakapapa relationships might be done, and where such an approach might lead. We chose to explore this framework, based on the guidance of whaanau, and the work of Hopkins (2018) in particular, as we came to understand that the strong aspiration that whaanau have to improve the mauri of the land and water can only be achieved through a system that contains and supports the atua and their relationships.

An important initial outcome of this exploration was the observation that the present cropping regime (which may be seen as the maara kai of Rongomaitane) occupies the land in such a way as to encroach on the domains of other atua necessary for the maintenance of mauri. For example, there currently is little room for forest, the domain of Tane Mahuta, and cultivation continues across ephemeral wetland areas (*repo*) that are in the domain of Tangaroa.

First steps in land use change for whaanau of Nikau Farm to achieve their aspirations could be to address imbalances they see in atua relationships. Only a portion of the land now cultivated might be considered suitable for the kinds of crops currently grown (or envisaged), giving space for the restoration and development of the productive and supporting capacities of other atua domains.

Action of this kind would also be a starting point for the aspiration that whaanau have expressed to produce a diversity of crops (where crops is taken to mean both field crops and other sources of food, fibre, building materials, and energy), and to do so within a cultural landscape that reflects Maaori values.

Such action would also represent for Nikau Farm a fundamental shift away from conventional, monocultural agriculture towards, in modern parlance, polycultural production within an agroecological system. Agroecological systems of polyculture are a feature not only of traditional indigenous and peasant agricultures globally (of which the pre-confiscation, whakapapa based, and tikanga led world of Waikato-Tainui is an example) but also of modern rural movements such as permaculture, organics, regenerative agriculture, and, indigenous to Aotearoa, Hua Parakore (Hutchings *et al.,* 2012).

What could such a system look like that integrates the land uses we investigated?

There is considerable interest in solar farming within the Nikau whaanau. The system that has been investigated by whaanau is a large flat panel array, supplying power to the new Sleepyhead factory nearby. This option would be a significant source of income, especially if, as is proposed, the array is to cover most of the currently cropped land area, or even adjacent farms. Such an array would however leave very little of the land available for other uses, maintaining the potential for imbalance observed in the current cropping regime and thus potentially inhibiting the restoration of a system of strong atua relationships.

A further consideration is that, other than during construction, a solar array may not lead to a significant increase in employment opportunities on the land. This may be seen as positive if labour is scarce as currently it is, with most whaanau living far away from the land, but the aspiration we found was to encourage more whaanau to live in direct connection with the farm, and to derive livelihoods from it. One clear potential for whanau from any adoption of solar farming is to acquire training in the skills relevant to the installation and maintenance of solar arrays that can be capitalised on through employment within the emerging solar farming industry across Aotearoa New Zealand.

Assuming the adoption of a polycultural approach, the potential we see for solar power generation at Nikau Farm that could help to achieve the broader aspirations of whaanau lies in emerging technologies that combine power generation with cropping, so called agrivoltaic systems (Mamun *et al.,* 2022). Systems such as these require more specialised structures than flat arrays but have benefits both for the crop and for the generation of power. There are trade-offs in productivity both for the power generation and the crop, but numerous systems both in Asia and Europe, are in use or being trialled and are seen as a viable solution to combining energy and food production (Mamun *et al.,* 2022).

A wide range of crops are being grown in agrivoltaic systems, many of which are grown already in covered cropping situations (Sarr *et al.*, 2023). Agrivoltaics could thus combine the interest that whaanau has shown in high value covered cropping with their interest in solar power production. Such a system would have the potential for a high value return from a small area, combined with the requirement of a larger labour force and could form the financially productive core of a polycultural, atua- based agroecology at Nikau Farms. There is a working example of an agrivoltaic system in the Netherlands that is producing raspberries (BayWa, 2023). We propose that for Nikau Farm this may be a model that could be emulated with one of the berry crops (strawberries, blueberries) for which there is already knowledge and technical support available in the Waikato.

The installation and operation of an agrivoltaic system embedded within an agroecological matrix that reflects the cultural values of whaanau would place Nikau Farms as an innovator and leader in the transition to ecologically sustainable and culturally appropriate primary production. Through government bodies such as the EECA, MPI and MBIE we see opportunities for funding to further research the technologies and methods necessary.

The area that we would envisage covered by an agrivoltaic system containing blueberries could be as little as 2 ha (based on profitability estimates for blueberries), but may need to be more in order for the solar array to generate sufficient power for sale. Much of the land currently cropped on the farm in such a system would then become available for alternative uses.

An early observation that we made when visiting the farm was the presence of damp spots and old watercourses in the cropping space. These areas are problematic in the cropping regime, as crops planted in them are liable to fail through drowning during years with higher rainfall. We also noted that the growth of crops seemed to reflect the movement of nutrients between drier land and these areas leading to at times patchy growth as the evenness of fertilisation was disrupted. These wet areas we saw as being *repo* that whakapapa to Tangaroa, and as the crops of Rongomaitane struggle to grow there now, so too they are potentially not suitable for solar farming, especially within an agrivoltaic cropping system.

We see the opportunity to re-configure the areas of *repo*, through planting of long-lived grass, shrub, and tree species, as spaces where the relationship between Tangaroa (repo), Tane Mahuta (ngaahere), and Haumietiketike (uncultivated foods), is expressed. From an agroecological perspective these spaces would form part of a high-quality matrix that supports taaonga and agriculturally beneficial species, supporting the aspiration that whaanau have for the return of abundance in this regard. Rongoa (medicinal plants), and minor food crops could be grown in or around these areas in perennial polycultures. These crops would not necessarily be for commercial production but would enrich whaanau through direct provision of high quality and culturally valued food and other resources.

We see the greatest benefit of this approach in the mitigation and even beneficial use of nutrient flows that are currently not fully used by the cropped land. While in the system we are discussing the current open field cropping system would lose area to both the agrivoltaic regime (which might occupy the best situated contiguous area of flat dry land), and to these wet areas (where it is becoming increasingly untenable anyway), we would not envisage the discontinuation of it in the short or even the long term. It is a system that is well understood by whaanau currently farming the land and can evolve through integration with the broader agroecological matrix as it develops.

For example - the threat of flooding disrupting open field cropping at Nikau Farm will remain even if the wettest areas are returned to *repo* matrix, and the potential for this is seen to be increasing due to climate change. Examples from the agroecological literature demonstrate the benefits of raised beds in mitigating the adverse effects of flooding on crops grown in areas subject to flooding (Altieri, 2015). A possible strategy at Nikau Farm could be to increase the ditching system to create raised beds on which cropping could occur. A synergy with this approach was found in our research on tuna aquaculture. There we identified examples, such as the chinampas system in Mexico, of indigenous polycultures that used raised bed cultivation in tandem with aquaculture in the channel systems between (Turcios & Papenbrock, 2014). These systems are found to be highly productive, and we see potential at Nikau Farms for the development of a similar approach.

From our review of the literature, we found that rearing of tuna commercially faced many hurdles, both bureaucratic and environmental. For Waikato-Tainui tuna are an important taaonga and kai species for which special effort is being made to restore habitat and increase numbers. We see an opportunity within an agroecological system such as we have described for Nikau whaanau to develop an approach to rearing tuna that is based on ancestral knowledge and practices, supports manaakitanga, and helps to reconnect whaanau and enhance the cultural practices that maintain mauri.

A system of raised cultivation and ditches would also provide habitat for the freshwater mussel, *kaaeo,* the restoration of which is a strong aspiration for whaanau, and for Waikato-Tainui. Although once a food source kaaeo are no longer favoured as such (T. Nikau, pers. comm.), but remain an important taaonga tuku iho, recognised for their ability to filter water and thus their important role in maintaining the mauri of wai.

In our waananga we distinguished commercial field cropping from traditional maara kai, which would support the production of kai to sustain directly whaanau living both on and off the whenua - home gardens as they are often described in the literature (Galhena *et al*., 2013). Gardening of this kind directly sustains the people living with the land and is an important factor in the resilience of rural communities globally. These gardens are often complex polycultures and their composition built around traditional crops that are of dietary and cultural importance. As with tuna, we see the inclusion of maara kai in the Nikau Farm system as connecting and sustaining whaanau and supporting manaakitanga.

Traditionally Waikato-Tainui grew crops in a pattern of shifting cultivation that saw ngaahere cleared and cultivated for a period of years before reverting once again to ngaahere. This intersection of the domains of Tane Mahuta and Rongomaitane in the cycle of kai production still occurs in many parts of the world but in Aotearoa ngaahere that could sustain such a system no longer exist. We raise it here to highlight the crucial ecological, cultural, and economic place that forest has in many polyculture systems (Ickowitz *et al.,* 2022), and that for Waikato-Tainui this is expressed in the understanding that ngaahere is the cloak of Papatuu-aa-nuku (Hopkins, 2018).

Forests provide carbon and nutrients for agriculture, and the habitat they create for birds, insects, and other species supports the emergence and maintenance of complex trophic webs that can increase pollination and the control of pest species, leading to increased crop health and production. Forest also has a wider role to play in the sequestration of carbon that is believed necessary to slow rate of anthropogenic climate change. Most significantly, however, forests are a source of materials, especially timber and other wood products, which can be used both within the farm for the construction of dwellings and other facilities, can provide a source of industry and employment, and native timbers of especially high value if produced for market. Where currently the areas of forest restoration at the farm exist within a predominantly agricultural matrix our work suggests the potential for the farm system to be areas of agriculture within a predominantly forest matrix.

Woven through this discussion is the aspiration for whaanau to be able to live in relationship with the whenua, supporting and supported by the atua. The establishment of papakaainga for whaanau will be an integral part of any land use change going forward and decisions around where on the land inhabitation is situated, and how development is approached, will affect from the outset the success and direction of all other initiatives.

5.2. Towards an approach/tool for supporting sustainable land use decision making

The research project was a mana whenua led, tikanga Maaori guided, collaborative research initiative among transdisciplinary collaborators (Nikau Farm, Waikato Tainui, EcoQuest, Waikato Regional Council, ESR), and focused on weaving western science and Waikato-Tainui Maatauranga tuku iho to inform future land use decision. Systems thinking contributed to this weaving process by providing a big picture view of the complex and interconnected systems involved in environmental, cultural, and economic sustainability. Our first waananga began the development of a shared understanding of the current situation of land use in Aotearoa, and identification of values and aspirations for future land use practices on whenua Maaori. Based on the findings of this first waananga, we developed a causal loop diagram that illustrated the complexity of current land use practices and how key elements of the land use systems map interact and create systemic barriers for sustainable land use practices. The causal loop diagram highlighted three thematic traps and delays: the agri-business "business as usual" trap, historical and socio-economic influences, and systemic marginalisation of te ao Maaori and Maatauranga Maaori. By questioning the interrelationships between different components of the system, the team identified potential leverage points for positive change for preventing traps and marginalisation:

- te ao Maaori leadership and values as a key lever to ensure Maatauranga possibilities and trust-based braiding,
- current science system transformation essential for increasing trust and enabling sustainable science possibilities, and
- collaborative research as a continuous learning journey.

The decision-making tool was an output of a collaborative process (several online meetings and second waananga) among the project team. The aim of the tool was to enable the Nikau Farm to engage in reflective discussions with whaanau and make informed decisions based on the complex interactions among key elements of the land use system and guided by Atua framework. The causal loop diagram provided a practical foundation for developing a collaborative decision approach and tool (Figure 16) that would enable users to reflect on the complex interactions among key elements of the land use system and make informed and te ao Maaori guided decisions based on the Atua framework. Initially, while drawing draft causal loop diagrams for each of the land use decisions (for e.g. solar farming, tuna farming), there was repetition of emerging themes, so allowing identification of key concepts. As a result, the development of a collaborative decision tool with a causal loop diagram was considered an effective way to support sustainable land use decision making.

Guided by critical systems perspective, the team developed some reflective questions for the decision-making tool.

- What elements, relationships, and dynamics are important to us (Nikau Farm and Waikato Tainui)? Why?
- What is missing from the map that might be important? Why?
- What are the benefits of certain farming decisions?
- What are the negative effects of certain farming decisions?
- How will you evaluate the trade-offs based on the evidence?
- How does the decision align with te ao Maaori?
- Who has the most power to influence the decision? Why?
- What are some of the people affected by our decisions? Who benefits most?
- How can whaanau exercise more control over the decision?
- Where would you take action if you had the power to redesign ideal te ao Maaori guided farming practices?
- After studying the systems map, what new insights do you have? How will these insights affect your collective action?

Figure 15 First draft of tool presented during second waananga.

These reflection questions were designed to promote a more critical and reflexive approach to land use decision-making, which takes into account the systemic and feedback dynamics that contribute to the social, economic, environmental, and cultural impacts of current land use practices. These questions can help whaanau make decisions that are aligned with sustainability and te ao Maaori, and that respect the whenua and whakapapa.

During the second waananga in March 2023, participants had the opportunity to critique the decision support tool and reflective questions developed based on the causal loop diagram. Some participants found the map difficult to understand and suggested simplifying it to make it more accessible. Others proposed engaging the community in finalising some of the reflective questions to ensure they were relevant and resonated with them. The feedback highlighted the importance of making the decision support tool and reflective questions user-friendly and inclusive to ensure that everyone could engage meaningfully in the sustainable land use decision-making process. The critique session was a valuable opportunity to refine the tool and questions, ensuring that they were effective in supporting collaborative decision-making processes. The final model after the feedback is represented in Figure 17.

Some tensions were also observed during the second waananga due to differences in perspective arising from the Western and Maaori worldviews in interpreting the complexity of the land use system and the application of te ao Maaori. However, it was recognised that this tension presents an opportunity for cross-cultural dialogue and learning, enabling participants to understand each other's perspectives and work collaboratively towards sustainable land use decision making.

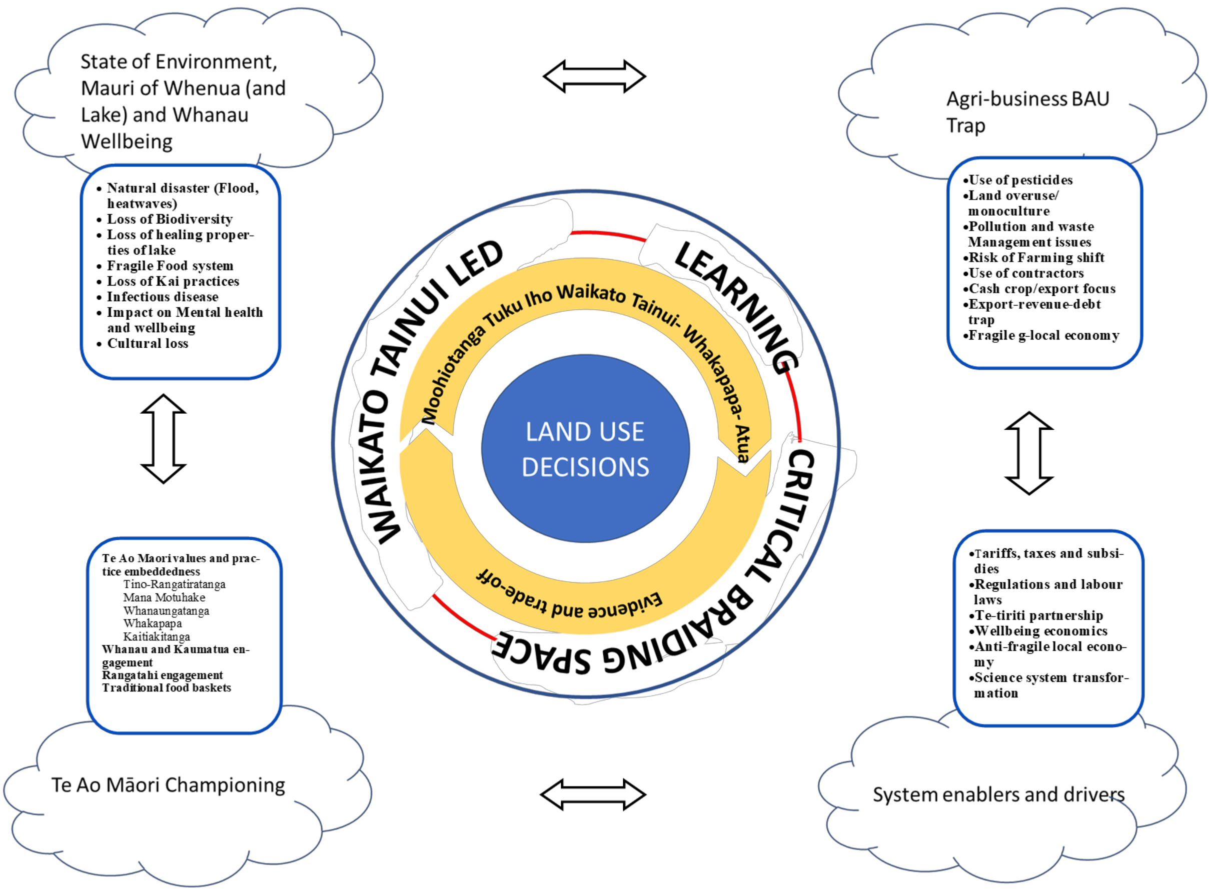


Figure 17 Tool for supporting land use decision making (second draft)

The critique session highlighted the importance of creating a safe and inclusive space for all partners to share their perspectives and engage in constructive dialogue to ensure that the decision support tool and reflective questions were effective for all collaborators. We did not sense any implicit tensions regarding Maaori partners' trust in the process and willingness to share their indigenous knowledge with Western-trained scientists. However, we cannot say for certain our process of engagement was free of unconscious tension and bias. This tension can often be attributed to historical and colonisation reasons, where Maatauranga Maaori and perspectives have been marginalised and disregarded in the Western scientific paradigm. The impact of this historical context can make it challenging for Maaori partners to trust the process and feel confident in sharing their knowledge and perspectives with Western scientists. The tension also highlights the fundamental difference in the two knowledge systems: western science and maatauranga Maaori. The fundamental difference is hardly discussed when the science system in Aotearoa expects for the two knowledge systems to work together, but hardly provide guidance on how this might be implemented. It is essential to acknowledge and address these implicit tensions to create a safe and inclusive space where both Maaori and scientists can feel comfortable sharing their knowledge and perspectives. This requires building trust and establishing meaningful relationships based on mutual respect and understanding, which has been a crucial feature of this collaborative endeavour since 2016, and an example that such implementation of maatauranga-science projects can occur.

References

Adamczewska-Sowińska, K., & Sowiński, J. (2020). Soil Health Restoration and Management. In *Soil Health Restoration and Management*. Springer Singapore. https://doi.org/10.1007/978-981-13-8570-4

AgInfo - Lincoln University (2020) *Financial Budget Margins – Gross Margin 2020*. https://issuu.com/aginfo-lincoln/docs/lin3414_financial_budget_manual_print

AgResearch News, (2021). *Herbicide resistance greater than expected; growing concern:* https://www.agresearch.co.nz/news/herbicide-resistance-greater-than-expected-growing-concern/

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development*, *35*(3), 869–890. https://doi.org/10.1007/S13593-015-0285-2/TABLES/2

Arrobas, M., Silva, J., Busato, M. R., Ferreira, A. C., Raimundo, S., Pereira, A., Finatto, T., de Mello, N. A., Correia, C. M., & Rodrigues, M. Â. (2023). Large Chestnut Trees Did Not Respond to Annual Fertiliser Applications, Requiring a Long-Term Approach to Establishing Effective Fertilisation Plans. *Soil Systems*, *7*(1), 4–4. https://doi.org/10.3390/soilsystems7010002

Arrobas, M., Afonso, S., Ferreira, I. Q., Moutinho-Pereira, J., Correia, C. M., & Rodrigues, M. Â. (2017). Liming and application of nitrogen, phosphorus, potassium, and boron on a young plantation of chestnut. *Turkish Journal of Agriculture and Forestry*, *41*(6), 443–443. https://doi.org/10.3906/tar-1705-79

Bainard, J. D., Serajchi, M., Bainard, L. D., Schellenberg, M. P., & Lamb, E. G. (2020). Impact of Diverse Annual Forage Mixtures on Weed Control in a Semiarid Environment. *Frontiers in Sustainable Food Systems*, *4*, 92. https://doi.org/10.3389/FSUFS.2020.00092/BIBTEX

Bamboriya, S. D., Bana, R. S., Kuri, B. R., Kumar, V., Bamboriya, S. D., & Meena, R. P. (2022). Achieving higher production from low inputs using synergistic crop interactions under maize-based polyculture systems. *Environmental Sustainability 2022*, *5*(2), 145–159. https://doi.org/10.1007/S42398-022-00228-7

Bandaranayake, W. M., Syvertsen, J. P., Schumann, A., & Kadyampakeni, D. M. (2020). Leaching losses from blueberries grown in sandy soils amended with pine bark. *Journal of Environmental Quality*, *49*(6), 1542–1550. https://doi.org/10.1002/jeq2.20169

BayWa, (2023). Solar installations bear fruit for Netherlands Agri-PV. https://www.baywa-re.com/en/cases/emea/solar-installations-bear-fruit-for-netherlands-agri-pv. Accessed 21/04/23.

Bradshaw, B. P. (2005). *Physiological aspects of Corylus avellana associated with the French black truffle fungus Tuber melanosporum and the consequence for commercial production of black truffles in Western Australia.* https://researchrepository.murdoch.edu.au/id/eprint/449/2/02Whole.pdf

Bryla, D. R., & Machado, R. M. A. (2011). Comparative effects of nitrogen fertigation and granular fertilizer application on growth and availability of soil nitrogen during establishment of highbush blueberry. *Frontiers in Plant Science*, *2*, 1–1. https://doi.org/10.3389/fpls.2011.00046

Buddenhagen, C. E., James, T. K., Ngow, Z., Hackell, D. L., Rolston, M. P., Chynoweth, R. J., Gunnarsson, M., Li, F., Harrington, K. C., & Ghanizadeh, H. (2021). Resistance to post-emergent herbicides is becoming common for grass weeds on New Zealand wheat and barley farms. *PLoS ONE*, *16*(10 October). https://doi.org/10.1371/journal.pone.0258685

Buwalda, J. G., & Freeman, R. E. (1986). Melons: Effects of vine pruning and nitrogen on yields and quality. *New Zealand Journal of Experimental Agriculture*, *14*(3), 355–355. https://doi.org/10.1080/03015521.1986.10423051

Cawthron Institute (2022). *Cawthron scientists welcome Vision Mātauranga funding for tuna (eel) food safety monitoring project*. https://www.cawthron.org.nz/our-news/cawthron-scientists-welcome-vision-matauranga-funding-for-tuna-eel-food-safety-monitoring-project/. Accessed 19/04/23

Chen, X., Lai, C., Wang, Y., Wei, L., & Zhong, Q. (2018). Disinfection effect of povidone-iodine in aquaculture water of swamp eel (Monopterus albus). *PeerJ*, *2018*(11), 1–2. https://doi.org/10.7717/peerj.5523

Christie, B., & Nichols, M. (2016). Wee Red Barn. *Practical Hydroponics and Greenhouses*, (164), 26–32. https://search.informit.org/doi/10.3316/informit.818215163840148

Choi, C. S., Cagle, A. E., Macknick, J., Bloom, D. E., Caplan, J. S., & Ravi, S. (2020). Effects of Revegetation on Soil Physical and Chemical Properties in Solar Photovoltaic Infrastructure. *Frontiers in Environmental Science*, *8*, 4–5. https://doi.org/10.3389/fenvs.2020.00140

Clothier, B., & Green, S. (2017). *The leaching and runoff of nutrients from vineyards*. http://flrc.massey.ac.nz/publications.html.

Crush, J. R., Cathcart, S. N., Singleton, P., & Longhurst, R. D. (1997). Potential for nitrate leaching from different land uses in the Pukekohe area. *Proceedings of the New Zealand Grassland Association 59*. https://www.nzgajournal.org.nz/index.php/ProNZGA/article/view/2266/1894

Dhar, A., Naeth, M. A., Jennings, P. D., & Gamal El-Din, M. (2020). Perspectives on environmental impacts and a land reclamation strategy for solar and wind energy systems. In *Science of the Total Environment* (Vol. 718). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2019.134602

Dinesh, H., & Pearce, J. M. (2016). The potential of agrivoltaic systems. *Renewable and Sustainable Energy Reviews 54*, 299–308. https://doi.org/10.1016/j.rser.2015.10.024

Dolezal AG, Torres J, O'Neal ME. (2021) Can Solar Energy Fuel Pollinator Conservation?. *Environmental Entomology, 50*(4), 757-761. doi: 10.1093/ee/nvab041.

Durie, M. (1984). Te taha hinengaro: An integrated approach to mental health. *Community Mental Health in New Zealand, 1*(1), 4-11.

Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, A., & Ferard, Y. (2011). Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. *Renewable Energy*, *36*(10). https://doi.org/10.1016/j.renene.2011.03.005

Ecothrifty Life, (2023). *Permaculture Productivity*. https://ecothriftylife.com/2023/01/

Energy Efficiency & Conservation Authority (2023) https://www.eeca.govt.nz/insights/case-studies-and-articles/3-innovations-in-the-indoor-cropping-field/. Accessed 19/04/23

Ehret, D. L., Frey, B., Forge, T., Helmer, T., Bryla, D. R., & Zebarth, B. J. (2014). Effects of nitrogen rate and application method on early production and fruit quality in highbush blueberry. *Canadian Journal of Plant Science*, *94*(7), 1166–1166. https://doi.org/10.4141/CJPS2013-401

Eng, Gary., Bywater, Ian., & Hendtlass, C. A. (Charles A.). (2008). *New Zealand energy information handbook*.

Eyster, H. N., Srivastava, D. S., Kreitzman, M., & Chan, K. M. A. (2022). Functional traits and metacommunity theory reveal that habitat filtering and competition maintain bird diversity in a human shared landscape. *Ecography*, *2022*(11), e06240. https://doi.org/10.1111/ECOG.06240

Galhena, D.H., Freed, R. & Maredia, K.M. (2013) Home gardens: a promising approach to enhance household food security and wellbeing. *Agric & Food Security 2*(8). https://doi.org/10.1186/2048-7010-2-8

Geno, L. M., & Geno, B. J. (2001). *Polyculture production: principles, benefits and risks of multiple cropping land management systems for Australia*. Rural Industries Research and Development Corporation. https://agrifutures.com.au/wp-content/uploads/publications/01-034.pdf

German Renewable Energy Agency. (2010). **Solar Parks –** Opportunities forBiodiversity. *Renews Spezial 45*.

Goldammer, T. (2019). *Greenhouse Management, A Guide to Operations and Technology.* Apex Publishers. ISBN (13): 978-0-9675212-4-4. https://www.greenhouse-management.com/greenhouse_management/greenhouse_production_systems/soil_culture.htm

Guiller, C., Affre, L., Deschamps-Cottin, M., Geslin, B., Kaldonski, N., & Tatoni, T. (2017). Impacts of solar energy on butterfly communities in mediterranean agro-ecosystems. *Environmental Progress and Sustainable Energy, 36*(6), 1817-1823. https://doi.org/10.1002/ep.12626

Gülüt, K. Y. (2021). Nitrogen and boron nutrition in grafted watermelon I: Impact on pomological attributes, yield, and fruit quality. *PLOS ONE*, *16*(5 May), 1–1. https://doi.org/10.1371/journal.pone.0252396

Gutierrez-Gines, M.J., Bishit, A., Meister, A., Robinson, B.H., Clarke, D., Tupuhi, G., Alderton, I., Horswell, J., Wang, K.I.K., Bohm, K., Taylor, M., Adamson, O.M., Simcock, R., O'Neill, T.A., Nikau, T., Ambrose, V. (2022). *Maanuka dominated ecosystems to improve water and soil quality in Lake Waikare catchment*. Client Report No CSC22012, prepared for Waikato River Authority. June 2022.

Guzman, A., Montes, M., Hutchins, L., DeLaCerda, G., Yang, P., Kakouridis, A., Dahlquist-Willard, R. M., Firestone, M. K., Bowles, T., & Kremen, C. (2021). Crop diversity enriches arbuscular mycorrhizal fungal communities in an intensive agricultural landscape. *New Phytologist*, *231*(1), 447–459. https://doi.org/10.1111/NPH.17306

Haifa Group, (2018). *Fertilization of cherry trees: when and how?* https://www.haifa-group.com/fertilization-cherry-trees-when-and-how

Hancock, F., (2018). The dark side of NZ's honey bee. https://www.newsroom.co.nz/the-dark-side-of-nzs-honey-bee. Accessed 21/04/2023

Hardie, M. A., Oliver, G., Clothier, B. E., Bound, S. A., Green, S. A., & Close, D. C. (2015). Effect of Biochar on Nutrient Leaching in a Young Apple Orchard. *Journal of Environmental Quality*, *44*(4), 1280–1280. https://doi.org/10.2134/jeq2015.02.0068

Hassani, N. (2022). *Companion Plants for Watermelons*. https://www.thespruce.com/companion-plants-for-watermelons-5069542. Accessed 19/05/2023

Haszard, H. D. M. (1890). Art. LX.—Thermal Springs in Lake Waikare, Waikato. *Transactions and Proceedings of the Royal Society of New Zealand*, *23*, 527.

Heke, I., Rees, D., Swinburn, B., Waititi, R. T., & Stewart, A. (2019). Systems Thinking and indigenous systems: native contributions to obesity prevention. *AlterNative*, *15*(1), 22–30. https://doi.org/10.1177/1177180118806383/FORMAT/EPUB

Herath, I., Green, S., Horne, D., Singh, R., McLaren, S., & Clothier, B. (2013). Water footprinting of agricultural products: Evaluation of different protocols using a case study of New Zealand wine. *Journal of Cleaner Production*, *44*, 159–167. https://doi.org/10.1016/j.jclepro.2013.01.008

He Waka eke Noa. 2022. *He Waka Eke Noa – Primary Sector Climate Action Partnership.* https://hewakaekenoa.nz/about/

Hicks, B. J., Allen, D. G., Kilgour, J. T., Watene-Rawiri, E. M., Stichbury, G. A., & Walsh, C. (2013). *Fishing activity in the Waikato and Waipa rivers*. https://www.waikato.ac.nz/__data/assets/pdf_file/0007/154951/ERI-rept-7-MPI-SEC2010_06-Waikato-fishing-activity-secured.pdf

Hirt-Chabbert, J. A. (2011). *Adding value to New Zealand eels by aquaculture*. https://openrepository.aut.ac.nz/bitstream/handle/10292/1387/Hirt-ChabbertJ.pdf?sequence=3&isAllowed=y . Accessed 17/04/2023.

Hopkins A. (2018). Classifying the mauri of wai in the Matahuru Awa in North Waikato. *New Zealand Journal of Marine and Freshwater Research*, *52*(4), 657–6 65. https://doi.org/10.1080/00288330.2018.1556195

Horvath, G., Blaho, M., Egri, A., Kriska, G., Seres, I., & Robertson, B. (2010). Reducing the Maladaptive Attractiveness of Solar Panels to Polarotactic Insects. *Conservation Biology, 24*(6)*,* 1644-1653.

Houlbrooke, D. J., Paton, R. J., Littlejohn, R. P., & Morton, J. D. (2011). Land-use intensification in New Zealand: Effects on soil properties and pasture production. *Journal of Agricultural Science*, *149*(3), 337–349. https://doi.org/10.1017/S0021859610000821

Hoyle, S. D., & Jellyman, D. J. (2002). Longfin eels need reserves: Modelling the effects of commercial harvest on stocks of New Zealand eels. *Marine and Freshwater Research 53(*5). https://doi.org/10.1071/MF00020

Hutchings, J. (2015). *Te mahi māra hua parakore: A Māori food sovereignty handbook.* Ōtaki, New Zealand: Te Tākupu, Te Wānanga o Raukawa.

Hutchings, J.*,* Tipene, P., Carney, G., Greensill, A., Skelton, P., & Baker, M. (2012). Hua parakore: an indigenous food sovereignty initiative and hallmark of excellence for food and product production. *MAI Journal: A New Zealand Journal of Indigenous Scholarship, 1*(2), 131-145.

Hutchings, J., Smith, J., & Harmsworth, G. (2018). Elevating the mana of soil through the Hua Parakore Framework. *MAI Journal: A New Zealand Journal of Indigenous Scholarship*. https://doi.org/10.20507/maijournal.2018.7.1.8

Ickowitz, A., McMullin, S., Rosenstock, T., Dawson, I., Rowland, D., Powell, B., Mausch, K., Djoudi, H., Sunderland, T., Nurhasan, M., Novak, A., Gitz, V., Meybeck, A., Jamnadass, R., Guariguata, M. R., Termote, C., & Nasi, R. (2022). Transforming food systems with trees and forests. *The Lancet Planetary Health 6*(7), e632–e639. https://doi.org/10.1016/S2542-5196(22)00091-2

Iverson, A. L., Marín, L. E., Ennis, K. K., Gonthier, D. J., Connor-Barrie, B. T., Remfert, J. L., Cardinale, B. J., & Perfecto, I. (2014). Do polycultures promote win-wins or trade-offs in agricultural ecosystem services? A meta-analysis. *Journal of Applied Ecology*, *51*(6), 1593–1602. https://doi.org/10.1111/1365-2664.12334

James, P. (2011). *Australian Cherry Production Guide*. https://www.cherrygrowers.org.au/assets/australian_cherry_production_guide.pdf

Journeaux P, van Reenen E, Manjala T, Pike S, Hanmore I, Millar S. (2017). *Analysis of drivers and barriers to land-use change*. A Report prepared for the Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/23056-ANALYSIS-OF-DRIVERS-AND-BARRIERS-TO-LAND-USE-CHANGE

Julian JP, de Beurs KM, Owsley B, Davies-Colley RJ, Ausseil, AGE. (2017). River water quality changes in New Zealand over 26 years: response to land-use intensity. *Hydrol. Earth Syst. Sci., 21*, 1149–1171. https://doi.org/10.5194/hess-21-1149-2017.

Kauri Park, (2015). http://www.rotorualakes.co.nz/vdb/document/1175. Accessed 21/04/23

Kendall, L. K., Evans, L. J., Gee, M., Smith, T. J., Gagic, V., Lobaton, J. D., Hall, M. A., Jones, J., Kirkland, L., Saunders, M. E., Sonter, C., Cutting, B. T., Parks, S., Hogendoorn, K., Spurr, C., Gracie, A., Simpson, M., & Rader, R. (2021). The effect of protective covers on pollinator health and pollination service delivery. *Agriculture, Ecosystems & Environment*, *319*, 107556. https://doi.org/10.1016/J.AGEE.2021.107556

Khomik, M., Arain, M. A., Liaw, K.-L., and McCaughey, J. H. (2009), Debut of a flexible model for simulating soil respiration–soil temperature relationship: Gamma model, *J. Geophys. Res.*, 114, G03004, https://doi.org/10.1029/2008JG000851.

Kiggundu, N., Migliaccio, K. W., Schaffer, B., Li, Y., & Crane, J. H. (2012). Water savings, nutrient leaching, and fruit yield in a young avocado orchard as affected by irrigation and nutrient management. *Irrigation Science*, *30*(4), 278–281. https://doi.org/10.1007/s00271-011-0280-6

Kim, S., Kim, S., & Yoon, C. Y. (2021). An efficient structure of an agrophotovoltaic system in a temperate climate region. *Agronomy*, *11*(8). https://doi.org/10.3390/agronomy11081584

Kosciuch, K., Riser-Espinoza, D., Moqtaderi, C., & Erickson, W. (2021). Aquatic habitat bird occurrences at photovoltaic solar energy development in southern California, USA. *Diversity*, *13*(11), 14–14. https://doi.org/10.3390/d13110524

Lambert, Q., Bischoff, A., Cueff, S., Cluchier, A., & Gros, R. (2021). Effects of solar park construction and solar panels on soil quality, microclimate, CO2 effluxes, and vegetation under a Mediterranean climate. *Land Degradation and Development*, *32*(18), 5190–5198. https://doi.org/10.1002/ldr.4101

Landcare Research, (2010). Weaving plants – biology, distribution, and propagation**.** https://www.landcareresearch.co.nz/tools-and-resources/collections/new-zealand-flax-collections/weaving-plants/. Accessed 21/04/2023

Lawrence L, Ridley G. (2018). *Lake Waikare and Whangamarino Wetland Catchment Management Plan*. https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/hazard-catchment-management/CMP-catchment-management-plans/lake-waikare-whangamarino-wetland/Pt1-catchment-overview.pdf

Latitude planning. 2015. LAKE WAIKARE AND WHANGAMARINO CATCHMENT PLAN

Ledgard, S., Sprosen, M., Judge, A., Lindsey, S., Jensen, R., Clark, D., & Luo, J. (2011). *Nitrogen leaching as affected by dairy intensification and mitigation practices in the resource efficient dairying (red) trial.* https://assets.ctfassets.net/bo1h2c9cbxaf/44hYXIlacAXH18zJRK7Szv/91ec599c634f5753f1289e8321ef52c8/Nitrogen_leaching_as_affected_by_dairy.pdf

Lee, W. G., Meurk, C. D., & Clarkson, B. D. (2008). Agricultural intensification: Whither indigenous biodiversity? *New Zealand Journal of Agricultural Research*, *51*(4), 457–460. https://doi.org/10.1080/00288230809510475

Liang, Y., Lin, X., Yamada, S., Inoue, M., & Inosako, K. (2013). *Soil degradation and prevention in greenhouse production*. 11–15. http://www.springerplus.com/content/2/S1/S10

Lovich, J. E., & Ennen, J. R. (2011). Wildlife conservation and solar energy development in the desert Southwest, United States. *BioScience*, *61*(12). https://doi.org/10.1525/bio.2011.61.12.8

McCarthy, A. (2010). Improving technology uptake in the WA avocado industry. *Horticulture Australia*. https://www.avocado.org.au/wp-content/uploads/2016/12/AV06002-Improving-Technology-Uptake-in-the-WA-Avocado-Industry.pdf#page=94

MacLeod, C. J., & Moller, H. (2006). Intensification and diversification of New Zealand agriculture since 1960: An evaluation of current indicators of land use change. *Agriculture, Ecosystems & Environment*, *115*(1–4), 201–218. https://doi.org/10.1016/J.AGEE.2006.01.003

MBIE. (2019). Indoor Cropping – Process Heat and Greenhouse Gas Emissions – Fact Sheet. https://www.mbie.govt.nz/dmsdocument/5334-indoor-cropping-factsheet-process-heat-and-greehouse-gas-emissions

Mahuika, N. (2019). A Brief History of Whakapapa: Māori Approaches to Genealogy. *Genealogy*, *3*(2), 32. https://doi.org/10.3390/genealogy3020032

Mamun, M. A. al, Dargusch, P., Wadley, D., Zulkarnain, N. A., & Aziz, A. A. (2022). A review of research on agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, *161*, 112351. https://doi.org/10.1016/J.RSER.2022.112351

Marrou, H., Dufour, L., & Wery, J. (2013) How does a shelter of solar panels influence water flows in a soil–crop system? *European Journal of Agronomy, 50*, 38-51. https://doi.org/10.1016/j.eja.2013.05.004.

Martínez-Blanco, J., Muñoz, P., Antón, A., & Rieradevall, J. (2011). Assessment of tomato Mediterranean production in open-field and standard multi-tunnel greenhouse, with compost or mineral fertilizers, from an agricultural and environmental standpoint. *Journal of Cleaner Production*, *19*(9–10), 985–997. https://doi.org/10.1016/J.JCLEPRO.2010.11.018

Messiga, A. J., Dyck, K., Ronda, K., van Baar, K., Haak, D., Yu, S., & Dorais, M. (2020). Nutrients leaching in response to long-term fertigation and broadcast nitrogen in blueberry production. *Plants*, *9*(11), 3–3. https://doi.org/10.3390/plants9111530

MPI, (2020). Apiculture Monitoring Report 2020. https://www.mpi.govt.nz/dmsdocument/44068-Apiculture-Moniotoring-Report-2020

MPI, (2022). *Te ara whakahou - ahumahi ngahere : Forestry and wood processing industry transformation plan.* https://www.mpi.govt.nz/dmsdocument/54472-Te-Ara-Whakahou-Ahumahi-Ngahere-Forestry-and-Wood-Processing-Industry-Transformation-Plan

MPI, (2023). https://www.mpi.govt.nz/forestry/forestry-in-the-emissions-trading-scheme/about-forestry-in-the-emissions-trading-scheme/different-kinds-of-forest-land-in-the-ets/#size-and-cover. Accessed 20/04/2023

Mycologic, (n.d.). GROWING MUSHROOMS ON LOGS. Webpage https://www.mycologic.nz/growing-on-logs. Accessed 21/04/2023.

mynativeforest.com (2022) https://www.mynativeforest.com/carbon-price-nz?gclid=Cj0KCQiA4OybBhCzARIsAIcfn9InPVaiz9HXt-29p1fCVfRxz4SiKUtNLir6DCQFbJFi4BmokF1pRQ0aAiR2EALw_wcB. Accessed 20/11/2022.

Nederhoff, E. (2022). Energy benchmarking in the covered crops industry Produced for Tomatoes NZ, Vegetables NZ and EECA. https://www.eeca.govt.nz/assets/EECA-Resources/Energy-Benchmarking-in-Covered-Cropping.pdf

Newton P, Civita N, Frankel-Goldwater L, Bartel K, Johns C. (2020). What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. *Front. Sustain. Food Syst., 4*: https://doi.org/10.3389/fsufs.2020.577723.

NZ Grower. (2021). *Covered Crop Efficiency*. https://www.hortnz.co.nz/assets/News-Events/Magazines/NZGrower-June-2021.pdf

NZIER. (2020). The potential impact of the Emissions Trading Scheme on covered crops. NZIER report to the Covered Crops industry. www.nzier.org.nz

Nitro Eels Website - http://raglaneels.com/. Accessed 17/04/2023.

Noor, N. M., Leong, N., & Nadri, H. M. (2020). *Plant Growth Performance of Maize (Zea MaysL.) Cultivars Influence by Different Fertilizer Application Rate and Method Under Biotic Farming Condition*. https://www.researchgate.net/publication/347913662

O'Connor, N., & Mehta, K. (2016). Modes of greenhouse water savings. *Procedia Engineering*, *159*, 259–266. https://doi.org/10.1016/J.PROENG.2016.08.172

O'Regan S. (1984). Maaori perceptions of water in the environment: An overview. Waiora, waimaori,waikino, waimate, waitai: Māori perceptions of water and the environment. Occasional paper. University of Waikato, Hamilton.

Pelczar, R. (2022, August 27). How to Prevent Birds from Flying into Your Windows. *Better Homes & Gardens*. https://www.bhg.com/gardening/design/nature-lovers/prevent-birds-from-flying-into-windows/

Perfecto, I., Rice, R. A., Greenberg, R., & van der Voort, M. E. (1996). Shade coffee: A disappearing refuge for biodiversity: Shade coffee plantations can contain as much biodiversity as forest habitats. *BioScience*, *46*(8), 598–608. https://doi.org/10.2307/1312989/2/46-8-598.PDF.GIF

Phillips, N., Stewart, M., Olsen, G., & Hickey, C. (2011). Contaminants in kai-Te Arawa rohe*. Te Arawa Lakes Trust Health Research Council of New Zealand*.

Reeves P, Hancock N, Mazzieri F. (2012). *Ecological Impacts of the Flood Control Scheme on Lake Waikare and the Whangamarino Wetland, and Potential Mitigation Options*. Contract Report No. 2766, prepared for Department of Conservation and Waikato Regional Council. https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/HR/S32/D/3154305.pdf

Reid, J. B., & Morton, J. D. (2019). *Nutrient management for vegetable crops in New Zealand*.

Ren, M., Qian, X., Chen, Y., Wang, T., & Zhao, Y. (2022). Potential lead toxicity and leakage issues on lead halide perovskite photovoltaics. *Journal of Hazardous Materials*, *426*. https://doi.org/10.1016/j.jhazmat.2021.127848

Salvo, J. E. (2005). The Effect of Nitrogen and Plant Growth Regulators on Sylleptic and Proleptic Shoot Development of 'Hass' Avocado (Persea americana Mill.) - Relationship to Yield. https://www.proquest.com/docview/305001828?fromopenview=true&pq-origsite=gscholar

Sánchez, A. C., Kamau, H. N., Grazioli, F., & Jones, S. K. (2022). Financial profitability of diversified farming systems: A global meta-analysis. *Ecological Economics*, *201*, 107595. https://doi.org/10.1016/J.ECOLECON.2022.107595

Sanders, D. C., Cure, J. D., & Schultheis, J. R. (1999). Yield Response of Watermelon to Planting Density, Planting Pattern, and Polyethylene Mulch. *HORTSCIENCE 34*(7), 1221-1223.

Sarr, A., Soro, Y. M., Tossa, A. K., & Diop, L. (2023). Agrivoltaic, a Synergistic Co-Location of Agricultural and Energy Production in Perpetual Mutation: A Comprehensive Review. *Processes 2023, Vol. 11, Page 948*, *11*(3), 948. https://doi.org/10.3390/PR11030948

Scudellari, D., Marangoni, B., Cobianchi, D., Faedi, W., & Maltoni, M. L. (1993). Effects of fertilization on apple tree development, yield, and fruit quality. https://link.springer.com/chapter/10.1007/978-94-017-2496-8_72

Sekiyama, T., & Nagashima, A. (2019). Solar sharing for both food and clean energy production: Performance of agrivoltaic systems for corn, a typical shade-intolerant crop. *Environments - MDPI*, *6*(6). https://doi.org/10.3390/environments6060065

Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., Kohli, S. K., Yadav, P., Bali, A. S., Parihar, R. D., Dar, O. I., Singh, K., Jasrotia, S., Bakshi, P., Ramakrishnan, M., Kumar, S., Bhardwaj, R., & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences*, *1*(11), 1–16. https://doi.org/10.1007/S42452-019-1485-1/TABLES/4

Song, Y., Xu, M., Li, X., Bian, Y., Wang, F., Yang, X., Gu, C., & Jiang, X. (2018). Long-Term Plastic Greenhouse Cultivation Changes Soil Microbial Community Structures: A Case Study. *Journal of Agricultural and Food Chemistry*, *66*(34), 8941–8948. https://doi.org/10.1021/acs.jafc.8b01829

Sweeney, C., Brown, C., Bennett, J., Ross, N., & Gagnon, G. (2021). An extensive clean-up method for extraction of 17β-estradiol from eel aquaculture waste solids for quantitation via high-performance liquid chromatography tandem-mass spectrometry. *Aquaculture, 542,*736873. https://doi.org/10.1016/j.aquaculture.2021.736873.

Száz, D., Mihályi, D., Farkas, A. *et al.,* (2016). Polarized light pollution of matte solar panels: anti-reflective photovoltaics reduce polarized light pollution but benefit only some aquatic insects. *J Insect Conserv 20*, 663–675. https://doi.org/10.1007/s10841-016-9897-3

Te Puni Kokiri. *Greenhouses and covered crops in NZ: industry guidance.* https://www.tupu.nz/en/fact-sheets. Accessed 19/04/23

Taylor, R., Conway, J., Gabb. O., & Gillespie, J. (2019) *Potential impacts of ground mounted solar panels.* Online https://www.bsg-ecology.com/wp-content/uploads/2019/04/Solar-Panels-and-Wildlife-Review-2019.pdf. Accessed 17/04/2023.

Thomas, S., Ausseil, A.G., Guo, J., Herzig, A., Khaembah, E., Renwhich, A., Teixeira, E., van der Weerden, T., Wakelin, S.J., & Vetharaniam, I. (2022). Changing land use to high value crops is an alternative methane emission mitigation. New Zealand Soil Science Society Conference. Blenheim Nov 18 - Dec 1st 2022.

Thompson, K. A. (2019). *Exploring Indigenous Permaculture for Land Management Strategies: Combining People, Food and Sustainable Land Use in the Southwest*. https://nau.edu/wp-content/uploads/sites/140/Thompson-MF-Professional-Paper.pdf

Tsakiridis, A., O'Donoghue, C., Hynes, S., & Kilcline, K. (2020). A comparison of environmental and economic sustainability across seafood and livestock product value chains. *Marine Policy*, *117*. https://doi.org/10.1016/j.marpol.2020.103968

Tschumi, M., Albrecht, M., Bärtschi, C., Collatz, J., Entling, M. H., & Jacot, K. (2016). Perennial, species-rich wildflower strips enhance pest control and crop yield. *Agriculture, Ecosystems and Environment*, *220*, 97–97. https://doi.org/10.1016/j.agee.2016.01.001

Tuahine, H. (2018) *Supporting native plantation forestry in the NZ ETS: Combining revenue from carbon, native timber, and co-benefits.* Report for Tāne's Tree Trust, Motu Economic and Public Policy Research. https://www.motu.nz/assets/Documents/our-work/environment-and-agriculture/climate-change-mitigation/emissions-trading/Supporting-native-plantation-forestry-in-the-NZ-ETS-final-report.pdf

Turcios AE, Papenbrock J. (2014). Sustainable Treatment of Aquaculture Effluents—What Can We Learn from the Past for the Future? *Sustainability* *6*(2), 836-856. https://doi.org/10.3390/su6020836

Tong, L., Li, J., Zhu, L., Zhang, S., Zhou, H., Lv, Y., & Zhu, K. (2022). Effects of organic cultivation on soil fertility and soil environment quality in greenhouses. *Frontiers in Soil Science*, *2*, 78. https://doi.org/10.3389/FSOIL.2022.1096735

Um, D. B. (2022). Exploring the operational potential of the forest-photovoltaic utilizing the simulated solar tree. *Scientific Reports*, *12*(1). https://doi.org/10.1038/s41598-022-17102-5

Velten S, Leventon J, Jager N, Newig J. (2015). What is sustainable agriculture? A systematic review. *Sustainability, 7*(6), 7833-7865. http://dx.doi.org/10.3390/su7067833.

Venkatachary, S. K., Samikannu, R., Murugesan, S., Dasari, N. R., & Subramaniyam, R. U. (2020). Economics and impact of recycling solar waste materials on the environment and health care. *Environmental Technology and Innovation*, *20*, (10). https://doi.org/10.1016/j.eti.2020.101130

Vo, T. T. E., Ko, H., Huh, J. H., & Park, N. (2021). Overview of Solar Energy for Aquaculture: The Potential and Future Trends. *Energies 2021*, *14*(21), 6923. https://doi.org/10.3390/EN14216923

Waikato-Tainui, (2013) *Tai Tumu, Tai Pari, Tai Ao*. https://waikatotainui.com/wp-content/uploads/2022/08/Waikato-Tainui-Environmental-Plan-2013.pdf. Accessed 21/04/2023

Walker, D. P., Ataria, J. M., Hughey, K. F. D., Park, P. T., & Katene, J. P. (2021). Environmental and spatial planning with ngā Atua kaitiaki: A mātauranga Māori framework. *New Zealand Geographer*, *77*(2), 90–100. https://doi.org/10.1111/nzg.12300

Wang, Z., Wang, Y., Zhang, H., Jamaluddin, F., Nurariaty, A., & Amin, N. (2020). The fluctuation of fruit fly attack (Bactrocera spp.) in a polycultural system of chili and watermelon crops. *IOP Conference Series: Earth and Environmental Science*, *486*(1), 012146. https://doi.org/10.1088/1755-1315/486/1/012146

Watene-Rawiri, E. *et al.,* (2016). *Restoring Tuna - a guide for the Waikato and Waipaa River Catchment*.

Welten, B., Mercer, G., Smith, C., Sprosen, M., & Ledgard, S. (2021). *Refining estimates of nitrogen leaching for the New Zealand agricultural greenhouse gas inventory*. http://www.mpi.govt.nz/news-and-resources/publications/

Williams, B. (2005). *Soft Systems Methodology*. http://users.actrix.co.nz/bobwill

Williams, B. & Hummelbrunner, R. (2011). *Systems Concepts in Action: A Practitioner's Toolkit*. Redwood City: Stanford University Press. https://doi.org/10.1515/9780804776554

Williams, B., & van't Hof, S. (2014). *Wicked Solutions, A Systems Approach to complex problems.* https://www.researchgate.net/profile/Sjon-Van-t-Hof/publication/297168031_Getting_Started/links/56dd5d1208ae07e3f617e0f9/Getting-Started.pdf

Wu, R., Sun, H., Xue, J. *et al.,* (2020). Acceleration of soil salinity accumulation and soil degradation due to greenhouse cultivation: a survey of farmers' practices in China. *Environ Monit Assess* *192*, 399. https://doi.org/10.1007/s10661-020-08363-6

Wu, Z., Hou, A., Chang, C., Huang, X., Shi, D., & Wang, Z. (2014). Environmental impacts of large-scale CSP plants in northwestern China. *Environmental Science: Processes and Impacts*, *16*(10), 2437–2439. https://doi.org/10.1039/c4em00235k

Yates, A. M. (2021). Transforming geographies: Performing Indigenous-Maori ontologies and ethics of more-than-human care in an era of ecological emergency. *New Zealand Geographer*, *77*(2), 101–113. https://doi.org/10.1111/nzg.12302

Appendix - Presentations prepared for waananga of this project

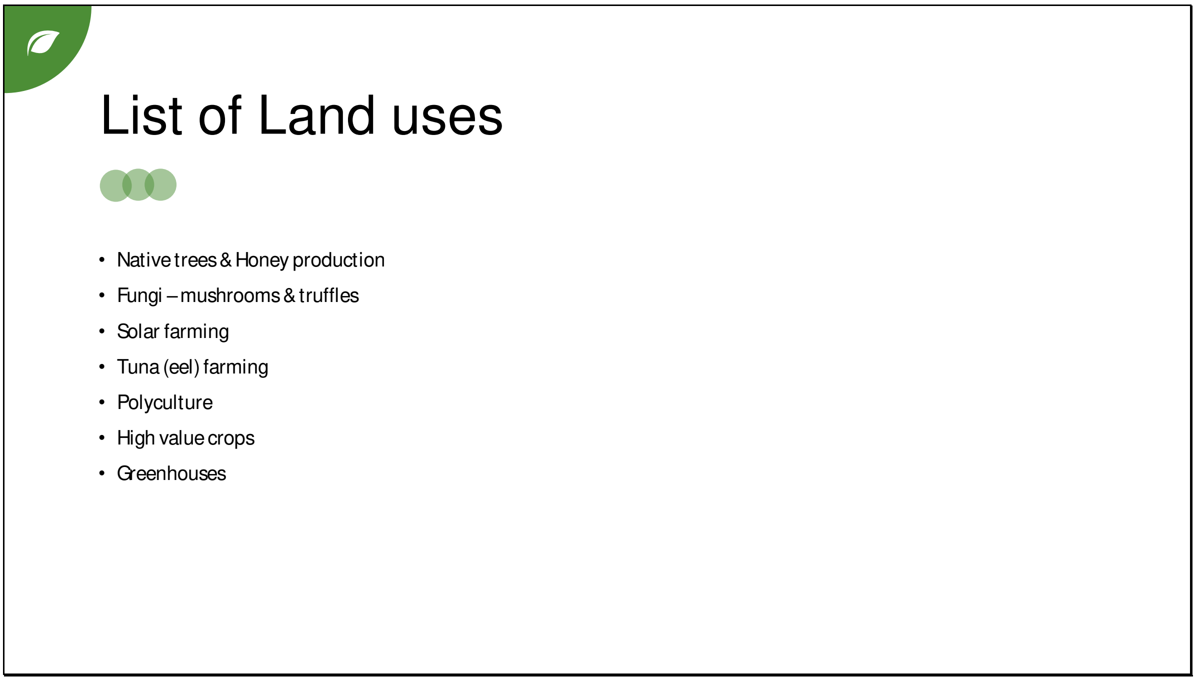


Table template

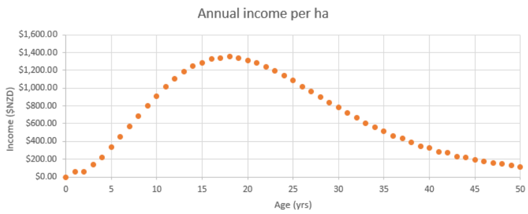
Land use	Climate conditions	Habitat	Soil type	Labour	Yield	Economics	Energy	Emissions
Species/Crop 1	Fact about Species/Crop 1 climate conditions. [1]							
Species/Crop 2								
Species/Crop 3								
Species/Crop 4								
Species/Crop 5								

Atua	Impacts 1	Impacts 2	Impacts 3	Benefits 1	Benefits 2	Benefits 3	Knowledge Gaps
Toka/oneone (soil)							
Wai (Water)							
Pepeke (insects)							
Manu (birds)							
Ngahere (forest)							
Hau (Wind)							

References		
[1]	Author, Year	url link
[2]		
[3]		

Native trees

- Identified natives and crops that can grow in seasonal swampy and dry areas (e.g., taro, harakeke, maanuka).
- Identified native trees suitable for carbon credits: nikau palms, maanuka, tī kōuka, pukatea, maire tawake, puriri, houhere, matai, kowhai, totara and pokaka.
- Carbon credits for native forestry reach a peak of $1,400 per ha after 17-18 years. (See graph below)



Honey production

- Honey production can earn a gross income up to $1,116/ha/yr for light, $1,302/ha/yr for dark and $7,440/ha/yr for manuka honey.
- Other bee products can have high value: pollen can earn a gross income up to $9,000/ha/yr and raw propolis can earn up to $1,182/ha/yr.
- We have identified a concern that the influx of honeybee populations in the last few decades may place pressure on New Zealand's solitary native bees through competition for nectar and pollen but haven't found evidence to support this.

Fungi – truffles

- Net income for truffle growing can range from $0-$360,000/ha/yr; it is high risk, high reward.
- No fertilizers are needed, in fact fertilization can inhibit mycorrhiza growth, reducing the yield.
- 99% of the carbon allocated to the truffles comes from the host tree, so they don't directly degrade the soil. However, truffles may have a localized effect on the soil microbiome, one example is the visible brûlé (burns).
- Truffles have a low carbon footprint (0.09 CO_2-eq/kg).
- Truffles need to outcompete other native ectomycorrhizae in order to grow, changing the surrounding fungal structure. No evidence was found that investigated how truffles may impact native fungi.
- Truffles are inoculated in non-native trees such as Hazel nut, English Oak, and Pinus radiata. But the Southern Woods nursery identifies several potentially suitable native species: Akeake, Broadleaf, Ribbonwood, Flax, Kowhai, Totara and several Coprosma and Pittosporum species.

Fungi –mushrooms

- Many different species of edible mushrooms can be grown in NZ, including Birch bolete, porcini, button, hakeke, tawaka, and brown oyster.
- Some are mycorrhizal meaning they have a mutualistic symbiosis with the roots of a plant, and some a saprophytes and grow freely in soil.
- There are similar concerns surrounding the need to outcompete other fungi, but little research has been done.
- There is contrasting information as to whether fertilizers are worthwhile, but a good compost is crucial.
- Mushrooms can be grown from inoculated sawdust or dowels. Barton Acres, from MycoLogic, recommended oyster, enoki, wood ear, tawaka and turkey tail for growing in willow trunks. This creates an opportunity for a circular system by giving the willows cleared from the wetlands another purpose.

Solar farming

- Impacts on the soil: compaction during construction, reduced ability to sequester carbon and temperature changes below panels shift respiration rates. However, solar reduces nitrogen loss compared to other bioenergy sources.
- Impacts on water: hail and fires can remove toxic cadmium and lead particles and wash them into nearby waterbodies, but the extent is not well known. Cleaning and degradation may also contribute to this issue.
- Insects such as horseflies and mayflies are attracted to the panels, forming an ecological trap which causes reproductive failure of laid eggs and death from exhaustion. White-gridded panels can mitigate this attraction. Birds may also experience this attraction, but there is little evidence supporting this.
- Solar generally requires vegetation removal and councils may require perimeter planting to reduce the visual impact.
- Agrivoltaic systems should be considered, there is potential for mushrooms, potatoes, lettuces, cucumbers, etc.
- Potential for grazing sheep and young cattle underneath using a ground coverage ratio of 1/3.
- Solar has lower carbon and mercury emissions than traditional sources of energy.

Tuna farming

- There are three species of eel in NZ: longfin, shortfin, and spotted eels. Longfins are rarer and less pollution tolerant.
- In 1980, Lake Waikare was reported to produce 10 tons annually, but it is now a fraction of this record due to poor water quality and population decline.
- SS, TN and TP are commonly low in aquaculture effluents, but waste can be collected and used as compost. Nitrogen runoff from farms can be used to promote algae growth, thereby increasing the eel food source zooplankton.
- Tuna are migratory fish, so structures that deny pest fish many also deny eels.
- Koi fish compete with eels, but larger eels are piscivorous so may have a role in controlling the koi population.
- Eel farming has shown to increase disease overseas, but no quantifiable evidence was found to support this in NZ eels.
- Aquaculture has a low to medium carbon footprint compared to pastoral livestock products.
- There are potential health risks from mercury and toxic blue-green algal blooms, but little research to support.

Polyculture

- Generally, yields increase and despite a higher labour demand, the net income is higher.
- Polycultures improve the following soil characteristics: microbial communities, earthworm biomass, soil structure, phosphorus availability, nitrogen mineralization, organic matter, leaching, and erosion.
- Crop diversity generally improves drought tolerance, reduces evaporation and reduces the water demand. However, legumes require high volumes of water.
- Legumes supply between 0-80% of the nitrogen demand of non-legumes, reducing the need for nitrogen fertilization.
- Polycultures have a net reduction on the number of pests, reducing the need for insecticides. But some monophagous (specialized feeding on one species) insect populations may increase.
- Organic systems show increased weed biomass compared to conventional farms, but polycultures may suppress weeds through shading. One Indian farm created an allelopathic spray from mature sorghum extract to control weeds.

High value crops

- Compared the nitrogen application, nitrate leaching, carbon dioxide equivalent emissions, profitability and robustness.
- High value crops included: apples, avocados, blueberries, cherries, chestnuts, manuka (honey), kiwifruit, onions, peas, potatoes, truffles and wine grapes. These were compared against watermelon, corn, pumpkin and dairy.
- Nitrogen application ranged from 0 kg/ha/yr (truffles, peas & maanuka) to over 300 kg/ha in some crops. However, there was a lot of variation in the values based on the source.
- Nitrate leaching ranged from 5 – 217 kg/ha/yr, again with high variation.
- Carbon emissions for the high value crops ranged from <8 – 1,909 kg CO2-e/ha/yr and was 8,198 kg CO2-e/ha/yr for dairy.
- The profitability was highest for blueberries ($66,000/ha/yr), Sungold kiwifruit ($61,500/ha/yr) and truffles ($44,000/ha/yr). It was lowest for manuka honey ($1,300/ha/yr) and peas ($1,537/ha/yr).
- Truffles, chestnuts, cherries and blueberries had the lowest robustness whereas dairy, apples, green kiwifruit and wine grapes had the highest.

Greenhouses

- Crops: tomatoes, capsicums, cucumbers, lettuce, berries, cherries, beans, courgettes, melons, flowers and eggplants.
- High capital costs where investments are made over 20 to 30 years.
- Coal boilers for heating are less affordable as the ETS charges are increasing, so should consider a renewable system.
- Greenhouses generally improve yield compared to open-field growing. One study showed open field yield for strawberries was 5.4 t/ha compared to 72.5 t/ha in the greenhouse.
- Tunnels, netting and greenhouses can reduce hive numbers due to the physical barrier and increased temperatures.
- Flower strips for more open systems outside improves the number of beneficial predators, pollinators and reduces the number of pests.
- The persistence of pesticides is increased by covers due to decreased photodegradation and hydrolysis. But biological controls such as predator mites and pheromone traps are more effective in a covered crop than outdoor cultivation.
- Compacted or concreted floors damage the soil. Hydroponic systems and using the growing medium coir also doesn't improve the soil health.

Shared understanding of current land use practices at Nikau Farm for future decision making

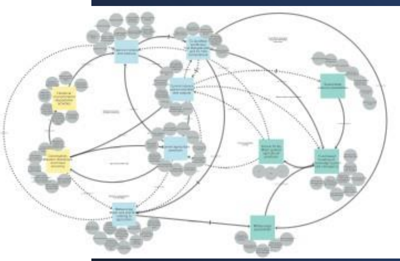
Sudesh Sharma

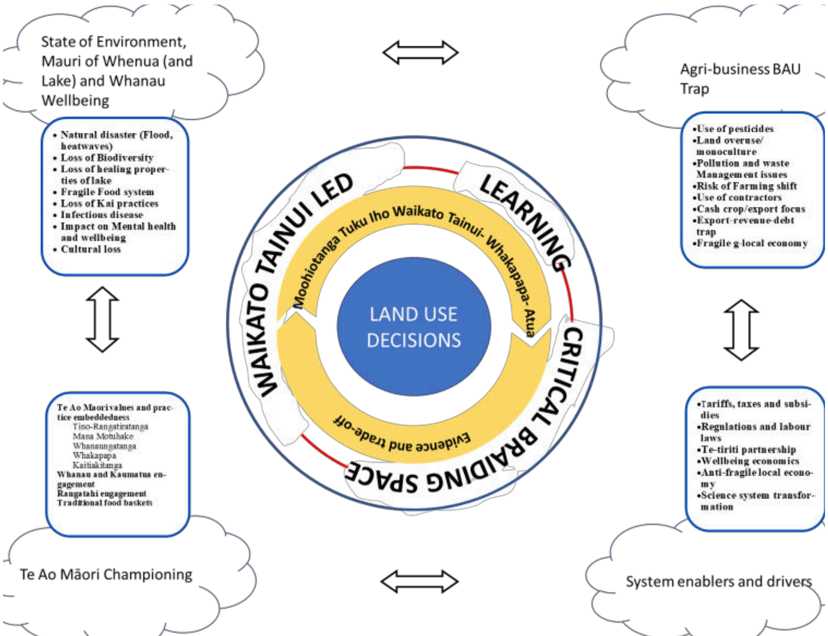
Summary

- Pre-existing trust and relationship
- Transdisciplinary collaborators (Nikau Farm, Waikato Tainui, EcoQuest, Waikato Regional Council, ESR)
- Focused on weaving western science and Waikato -Tainui Maatauranga tuku iho to inform future land use decision
- Systems thinking contributed to this weaving process by providing a big picture view and system insights
- Revisited creation story, history of Waikato Tainui
- Illustrated contexts, drivers and impacts on Nikau farm, whanau and whenua as a result of current agricultural practices
- Identified key transformation for future land use by considering multiple -viewpoints and guided by Te ao Māori values
- Deveoped an interconnected cause-effect map to show systemic traps, unintended consequences and feedback mechanisms
- Proposed an approach/tool for supporting decision making

Systems map analysis

- **Three systemic issues**
  - Agri-business "business as usual" trap
  - Historical and socio-economic influences
  - Systemic marginalisation of TeAo Māori and Mātauranga Māori
- **Three key systemic opportunities or levers**
  - Te Ao Māori leadership and values
  - Current science system transformation
  - A collaborative learning journey





Proposed decision making tool/approach

Purpose of tool: to enable the Nikau Farm to engage in reflective discussions with whaanau and make informed decisions based on the complex interactions among key elements of the land use system and guided by Atua framework.

Understanding the benefits and effects of land use change in the context of Maatauranga at Nikau Farm

Scoping Wananga

- “messy situation” picture captured complexity of the situation from multiple perspectives
- Key drivers and decision making processes based on Moohiotanga tuku iho/Maatauranga identified
  - Support and enhancement of Mauri
  - Protection of Waahi Tapu
  - Kaitiakitanga, Manaakitanga
  - Education and learning for Tamariki
  - Tikanga and Kawa
  - Maramataka
  - Moohiotanga tuku iho
- Question – What maatauranga exists that can be used to describe and model systems such as Nikau Farm, and if so how can it be applied?

Moohiotanga tuku iho and Maatauranga

- Moohiotanga Tuku iho is a knowledge system that has its Moohiotanga roots in the era before the colonisation of Aotearoa by tauiwi.
- Moohiotanga Tuku iho comprises a pool of inherited knowledge based on whakapapa. Moohiotanga Tuku iho concepts include tikanga, kawa, manaakitanga, wairuatanga, whanaungatanga, mana, mauri, ritenga, kaitiakitanga, waahi tuturu, raahui and others captured in whakairo, whakatauki, waiata and tauparapara. The pool of inherited knowledge includes ngaa whetu, te taiao, te moana, ngaa awa, ngaa roto me ngaa taaonga o roto, hauaanga kai, maara kai and kaimoana.
- Maatauranga Maaori according to Te Aka online dictionary is "Maaori knowledge, the body of knowledge originating from Maaori ancestors including the Maaori world view and perspectives, creativity and cultural practices"
- Maatauranga therefore is a modern term, also referred to as Taha Maaori and Kaupapa Maaori.

- From the perspective of this work Matauranga can be seen flow from, but not replace or alter moohiotanga tuku iho. Modern Maaori models and frameworks based in moohiotanga tuku iho may be considered Matauranga.

Matauranga Models and Frameworks

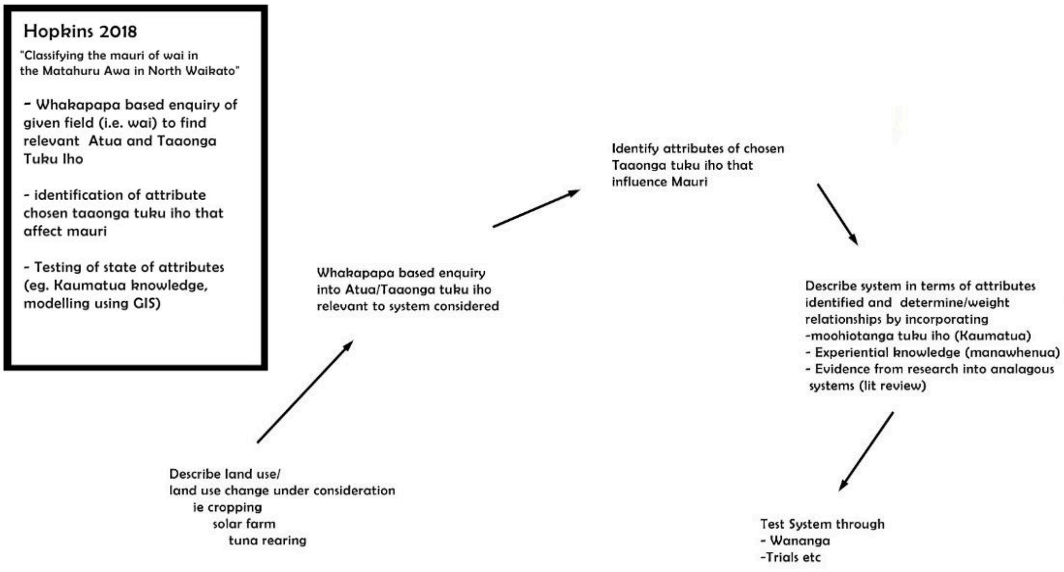
- *Te Whare Tapa Wha* - public health focused
- Mauri models
- Braided Rivers Approach
- Atua frameworks – for example *Atua Matua* (Heke *et al,* 2019)

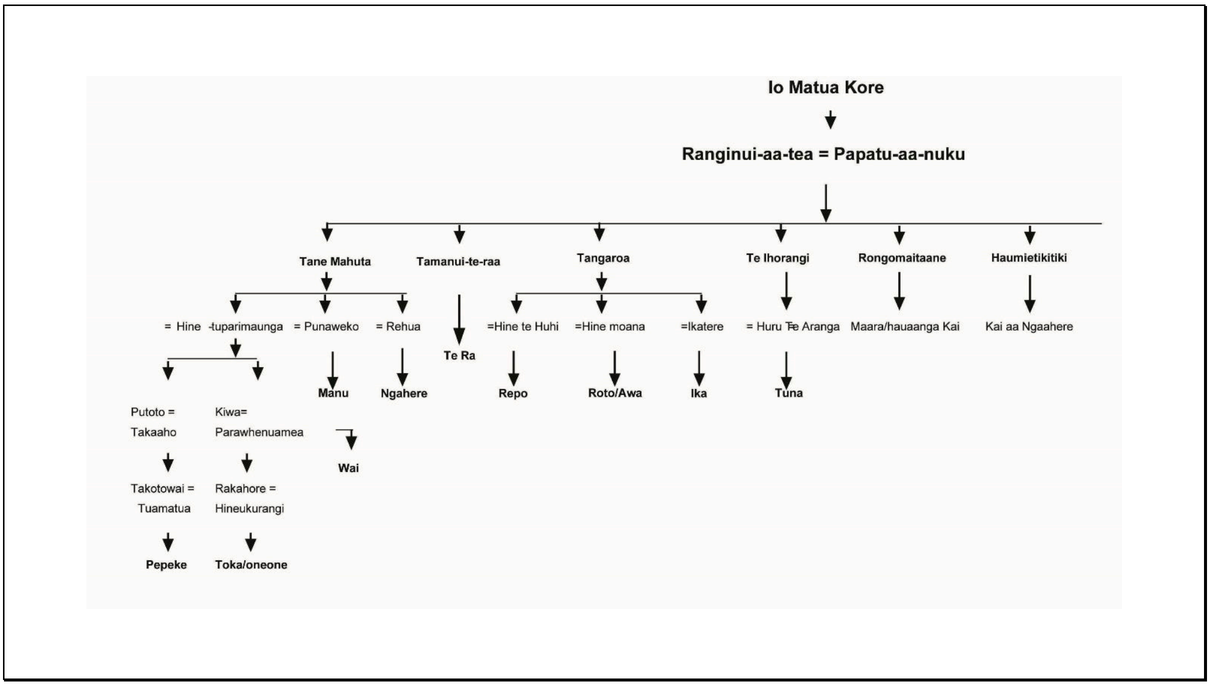
- Broad range of models has been developed reflecting different applications (eg. health, education, environmental monitoring), and emphasis on different aspects of maatauranga
- Jefferies and Kennedy (2009) identify three types of kaupapa Maori models currently used in the resource management space: cosmological (Atua-based) models, classification of time (Wa-based) models, and tikanga[15](values-based) models.

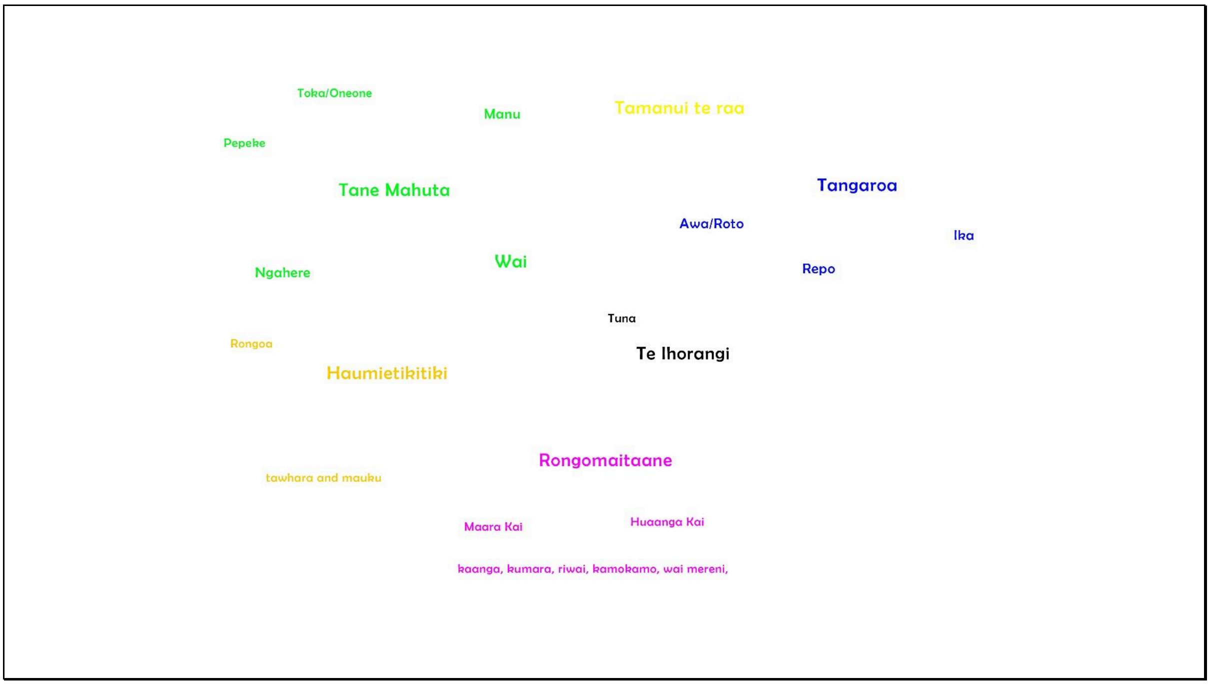
Exploring Atua frameworks

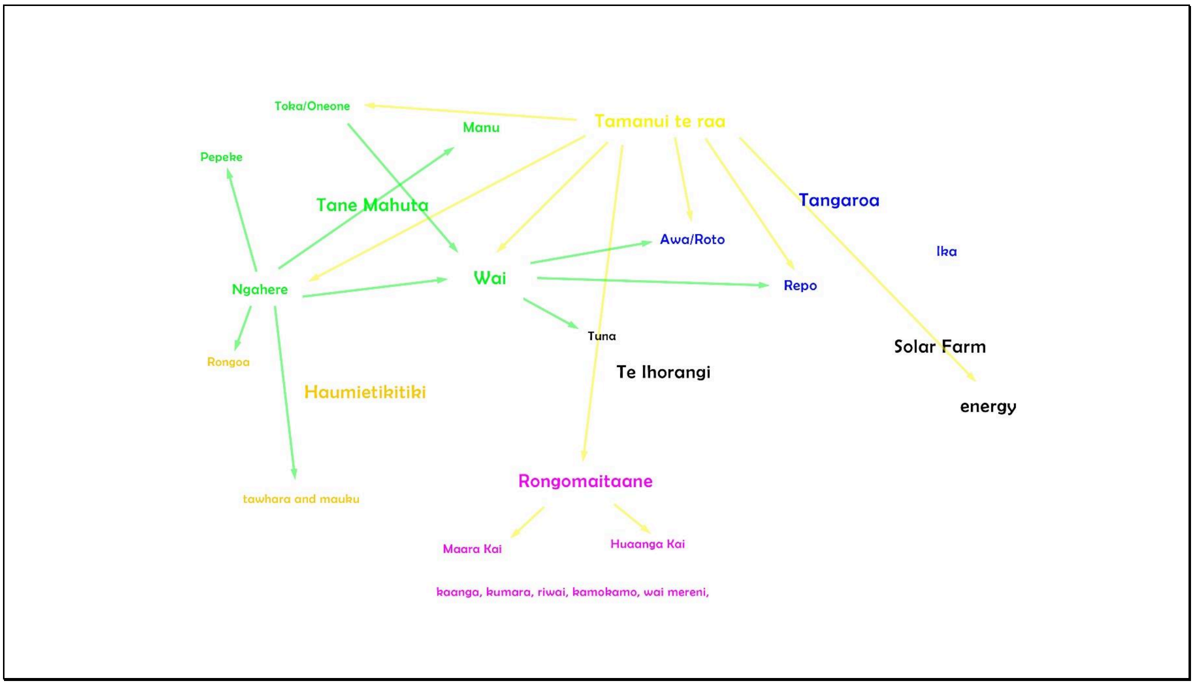
- Walker *et al,* 2021 “Atua frameworks have the potential to be an overarching point of reference within multiple spatial planning and resource management contexts.”

- Hopkins, 2018 - Atua are Te Ao Tawhito (of the old world) and are inherently, a framework for finding balance, rationale, order and perceptions of Te Ao Maaori (Maaori world) (O’Regan 1984) where all taaonga descend from Papatuaa-nuku and Ranginui-aa-tea.




Io Matua Kore
Ranginui-aa-tea = Papatu-aa-nuku
Tane Mahuta
Tamanui-te-raa
Tangaroa
Te Ihorangi
Rongomaitaane
Haumietikitiki
= Hine -tuparimaunga
= Punaweko
= Rehua
Te Ra
=Hine te Huhi
=Hine moana
=Ikatere
= Huru Te Aranga
Maara/hauaanga Kai
Kai aa Ngaahere
Manu
Ngahere
Repo
Roto/Awa
Ika
Tuna
Putoto = Takaaho
Kiwa= Parawhenuamea
Wai
Takotowai = Tuamatua
Rakahore = Hineukurangi
Pepeke
Toka/oneone


Toka/Oneone
Manu
Tamanui te raa
Pepeke
Tane Mahuta
Tangaroa
Awa/Roto
Ika
Ngahere
Wai
Repo
Tuna
Rongoa
Te Ihorangi
Haumietikitiki
Rongomaitaane
tawhara and mauku
Maara Kai
Huaanga Kai
kaanga, kumara, riwai, kamokamo, wai mereni,



Solar farming

Oneone
- Compaction of soil during solar farm construction
- Disturbance may lead to topsoil loss
- Panels affect soil temperature

Wai
- Large amounts of water required or cleaning
- Potential leaching of lead and cadmium from panels
- Heterogenous distribution of moisture in soil

Pepeke
- Polararisation can attract aquatic insects to lay eggs
- Non-polarising strips and non -reflective coating
- Terrestrial insects may benefit from reduced insecticide use

Solar farming

Manu
- Potential death through collision
- Lower bird density in very large arrays
- Ground nesting birds prefer to nest away from solar farms

Ngahere
- Vegetation removed, but forest often planted around arrays
- Within solar arrays woody species are a fire risk
- Potential for solar trees?

Maara
- Agrophotovoltaic/agrivoltaic systems
- High arrays requried to operate machinery
- Combination power+crops = higher/more stable returns

Greenhouses:

Advantages

Energy

Carbon

- More stable than open-air farming practices
- High returns from small portion of land

- Significant energy inputs required, mainly in winter
- Innovations
  - Heat pumps
  - Heat pump driven dehumidifiers
  - Thermal screens
- Government support for research in this field?

- Synergies: solar farming & greenhouse cultivation?

- Large carbon emissions
  → small producers liable for full cost

Greenhouses

Oneone
- Potential of degradation through excessive fertilization
- Changes in microbiome and its stability

Wai
- Less water needed due to reduced evaporation
- Potentially increased spread of fungal pests

Pepeke
- Survival and pollination efficiency decreased
- Pollinators require access to floral diversity

Greenhouses

Manu

- Birds may attempt to fly through glass
- Birds may attack their own reflection in a window

Ngahere

- Land cleared for greenhouse construction
- Restricted movement of birds, pollinators, native seeds

Greenhouse crops

Crop	Characteristics & size	Economics	Future trends & opportunities
Tomato	Largest crop >4,000 m^2	High capital costs Yield: 150-200 t/ha	Increasing demand for niche varieties
Capsicum	Highest energy demand >4,000 m^2	Returns: $300-350K/ha	
Cucumber	High energy demand High yield	Yield spread over year Premium prices in winter	
Lettuce	>2,000 m^2 (modern) Hydroponic systems	Lower returns: $110K/ha Lower heat/nutrient req.	
Berries	Low tech plastic tunnels Waikato/Hawke's Bay	Yields = 3x field yields	Local expertise available Blueberries: rapid growth

Potential benefits and impacts of the selected land uses - Tuna


https://www.aucklandzoo.co.nz/animals/new-zealand-longfin-eel


https://www.fishfarmingexpert.com/bio-marine-eels-ras/eel-production-going-swimmingly-for-35-years/1224497

Tuna farming - Things to consider

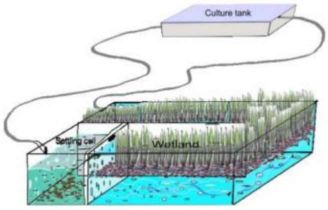
- Waikato-Tainui Fisheries Regulations 2011 allow to harvest tuna and stock paa tuna for a customary purpose only
- Consultation of Waikato-Tainui Trust Board needed if commercial exchange to other iwis considered
- Registration under Freshwater Fish Farming Regulations 1983 mandatory
- No commercial eel aquaculture exists in New Zealand and early attempts on 1980s failed
  - Test systems run by NIWA or Raglan Eels established
- Commercial eel cultivation systems developed for Japanese and European species and overseas eel produced as high-value species
- Bottleneck in eel aquaculture in New Zealand is the availability of wild glass eel because of regulations


http://raglaneels.com/

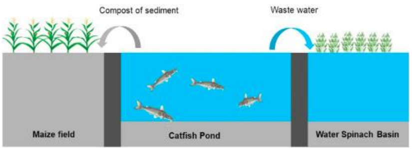

https://niwa.co.nz/te-k%C5%ABwaha/tuna-information-resource/pressures-on-new-zealand-populations/tuna-in-aquaculture/new-zealand

Impact of eel aquaculture
⇨ Wai

- Production of large volumes of wastewater rich in nitrogen, phosphorus, and suspended solids plus heavy metals, disinfectants or antibiotics and growth hormones
    - ➢ Clean-up: filtration and settling technologies (sludge as compost) or wetlands
    - ➢ Integration of multi-trophic aquaculture to balance nutrients surplus



Turcios & Papenbrock, 2014
https://www.sciencedirect.com/science/article/pii/S277242712100022X



Tung et al., 2021
https://www.sciencedirect.com/science/article/pii/S0045653520335268

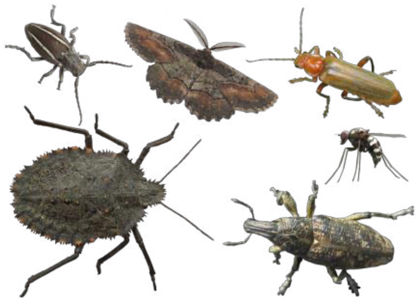
Impact of eel aquaculture
⇨ Ika

- High abundance of Koi carb in Lake Waikare
    - Could be provided as food source of eel aquaculture
    - **But**: bioaccumulation of contaminants in koi carb and transfer into aquaculture tuna need to be tested

Impact of eel aquaculture
⇨ Pepeke

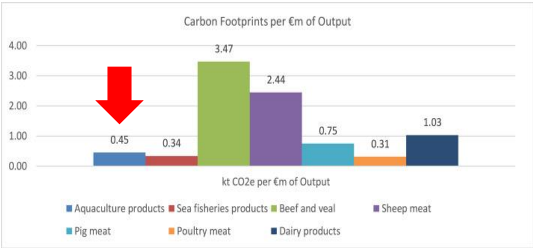
E/S/R Science for Communities

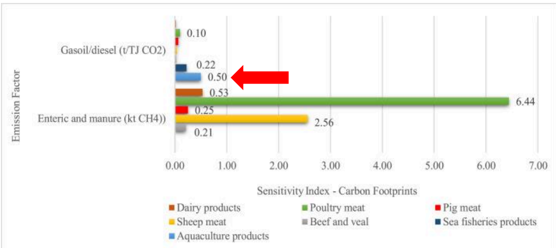
- Inconclusive
- Habitat restoration that comes with tuna is likely to also improve invertebrate habitat, and zooplankton being a source of food



Impact of eel aquaculture
⇨ Carbon and Energy

E/S/R Science for Communities





Tsakiridis et al., 2020
https://www.sciencedirect.com/science/article/pii/S0308597X19305561

Compared to other livestock production, aquaculture on the lower end of carbon emissions but still needs a considerably high amount of energy -> can be balanced off with using sustainable energy sources

Land use	Economic sustainability	Improved mauri	Create vibrant communities	Recover tikanga and kawa
Solar farming	✓✓✓	✓?	✓	✓?
Tuna	✓	✓✓	✓✓✓	✓✓✓
Greenhouses	✓✓✓	✓✓?	✓✓	✓?
Polyculture	✓✓	✓✓✓	✓✓✓	✓✓✓
Cropping and maara kai	✓✓	✓✓	✓✓✓	✓✓✓
Native vegetation	✓	✓✓✓	✓✓✓	✓✓✓

ESR
Science for Communities

Potential benefits and impacts of the selected land uses – Diverse systems



Impact of Polyculture systems
⇨ Wai

E/S/R Science for Communities

- Potential to decrease leaching of phosphorous or nitrogen due to enhanced uptake

- Improvements of soil structure stimulate water retention capacity
  - ➢ Higher resistance to drought and less irrigation needed

High productive pasture in Columbia in in dry phase
monoculture vs. polyculture

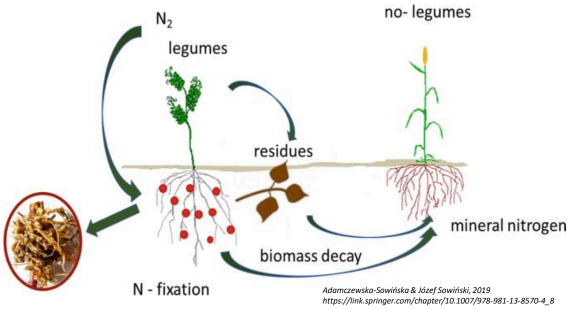
Impact of Polyculture systems
⇨ Oneone

E/S/R Science for Communities

Positive effects on

- Soil fertility,
- Physical soil characteristics and
- Soil microbial activity

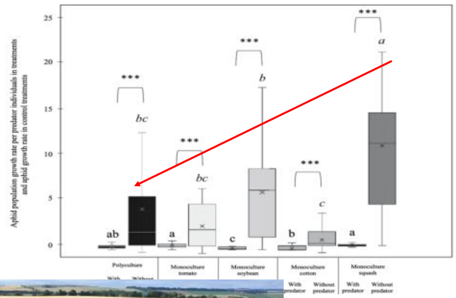
➢ Less fertilizer need to be added



Impact of Polyculture systems
⇨ Pepeke and Naghere

E/S/R Science for Communities

- Improvement of pest control (insects + weed)
- BUT: wrong crop combinations can also increase insect pest infestation



Simple:

Wildflower strip can significantly reduce insect pest density and crop damage

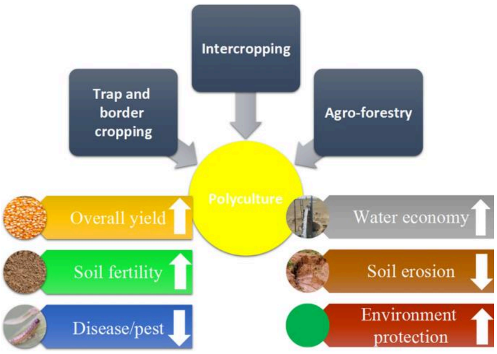
Impact of Polyculture systems
⇨ Manu

E/S/R Science for Communities

- Integration of living fences into the cropping system can strengthen biodiversity by providing a habitat
- Eyster et al., 2022: increase of bird diversity in woody perennial polyculture (agroforest) compared to corn or soy monoculture

Impact of Polyculture systems

E/S/R
Science for Communities

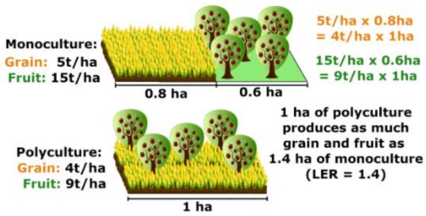


Bamboriya et al., 2022
https://link.springer.com/article/10.1007/s42398-022-00228-7

Cons:

Higher labour (costs)

Example calculation for Land Equivalent Ratio (LER)



https://www.vedantu.com/question-answer/what-is-polyculture-class-8-biology-cbse-6151e492f20c71210555f423

Diverse Systems – More examples:
Chinampas of Mexico City

- Creation of raised bed agricultural areas around canals used for aquaculture
- Fish waste at bottom of canals collected as fertilizer
- Stationary or floating gardens integrated -> high crop yield -> 4 to 7 harvests per year

E/S/R
Science for Communities

Agrivoltaic

E/S/R Science for Communities

Pros	Cons
• More **effective land use**. • **Increased generation** due to natural cooling of the solar panels by crop water evaporation • The shade from solar panels can **reduce stress** caused to **shade-tolerant plants** by high temperatures and UV rays • **Protection of crops against weather phenomena** such as hailstorms or strong winds • **Water savings** as solar panels will reduce the temperature of the land below them.	• **Higher cost** per kilowatt-hour generated due to larger capital expenditures • **Not suitable for shade-intolerant crops** • Can require significant changes in agricultural practices or machinery


Next2Sun GmbH in Germany

Toledo & Scognamiglio, 2021 Sustainability https://www.mdpi.com/2071-1050/13/12/6871


BayWa r.e. in the Netherlands

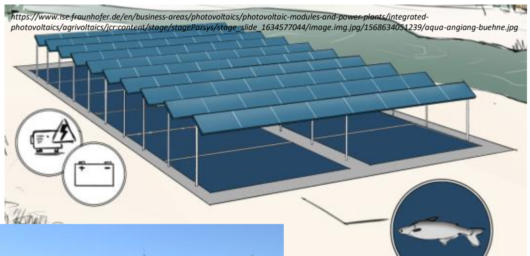
https://www.pv-magazine.com/2022/09/13/agrivoltaics-for-strawberries/

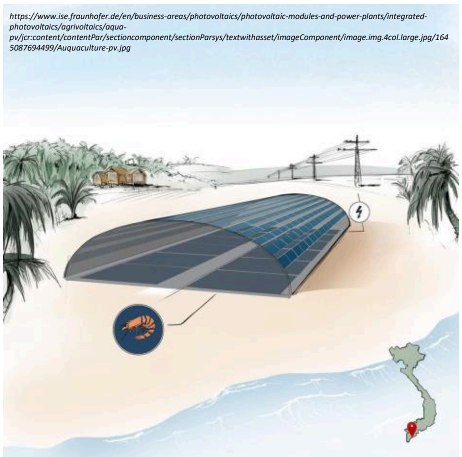

Fraunhofer ISE in Germany

Aquaculture Photovoltaics

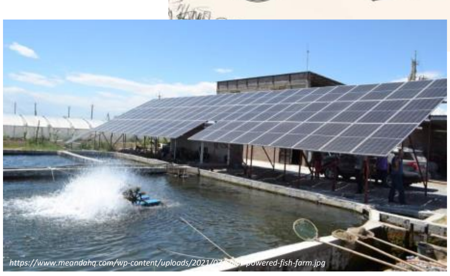
E/S/R Science for Communities

Fraunhofer ISE





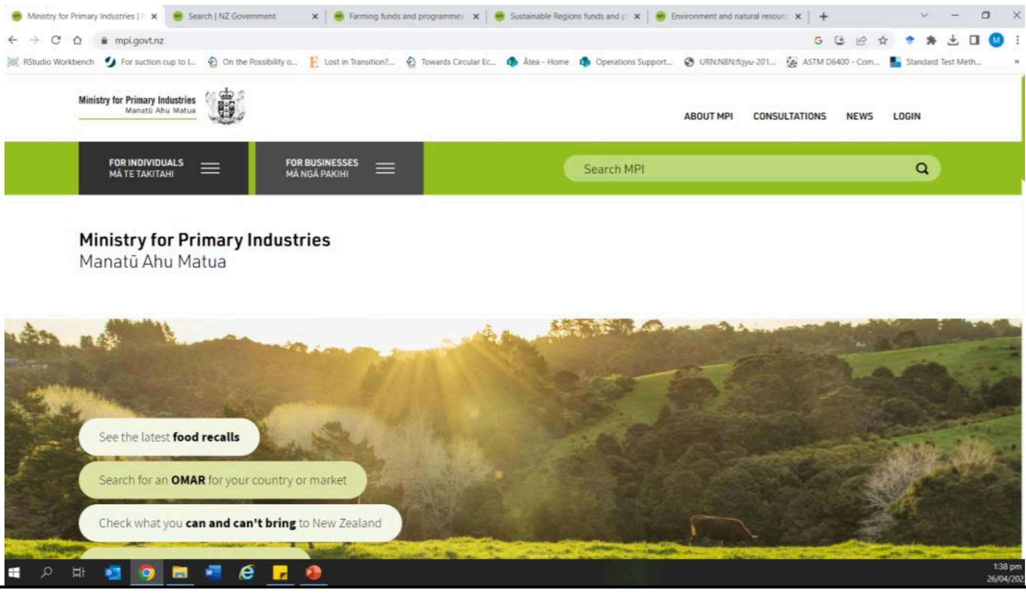
https://www.ise.fraunhofer.de/en/business-areas/photovoltaics/photovoltaic-modules-and-power-plants/integrated-photovoltaics/agrivoltaics/aqua-pv/jcr:content/contentPar/sectioncomponent/sectionParsys/textwithasset/imageComponent/image.img.4col.large.jpg/1645087694499/Auquaculture-pv.jpg

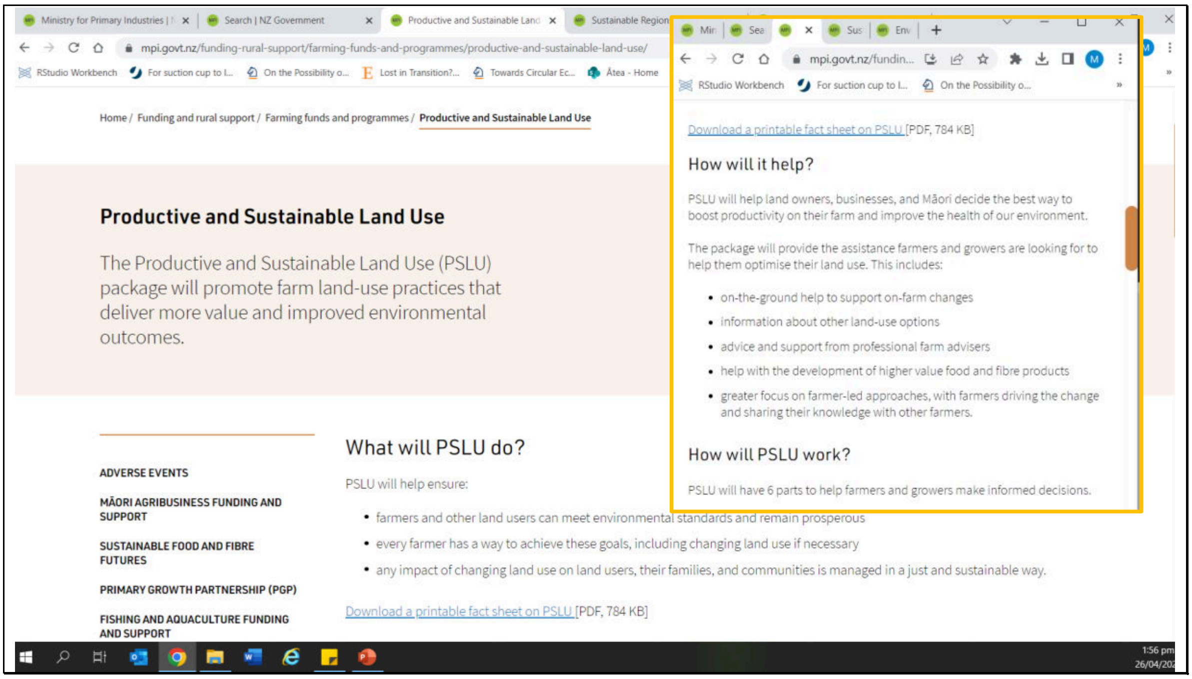


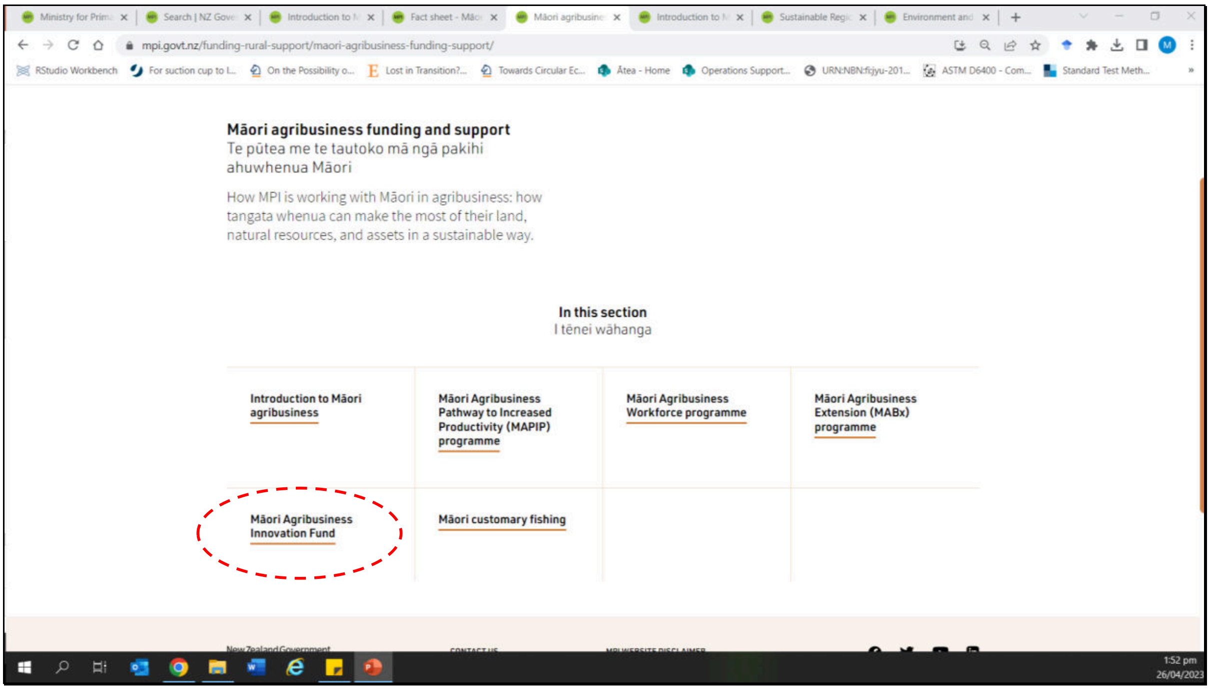
Fish farm in a village of Armenia

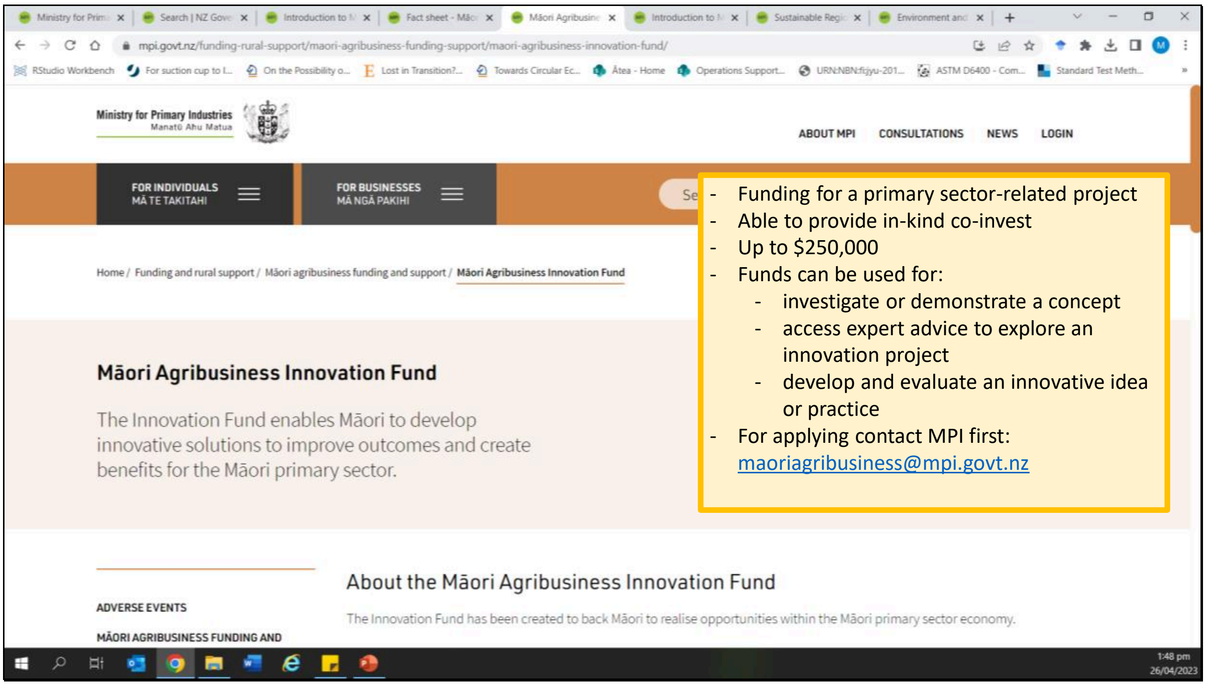
Land use	Economic sustainability	Improved mauri	Create vibrant communities	Recover tikanga and kawa
Solar farming	✓✓✓	✓?	✓	✓?
Tuna	✓	✓✓	✓✓✓	✓✓✓
Greenhouses	✓✓✓	✓✓?	✓✓	✓?
Polyculture	✓✓	✓✓✓	✓✓✓	✓✓✓
Cropping and maara kai	✓✓	✓✓	✓✓✓	✓✓✓
Native vegetation	✓	✓✓✓	✓✓✓	✓✓✓

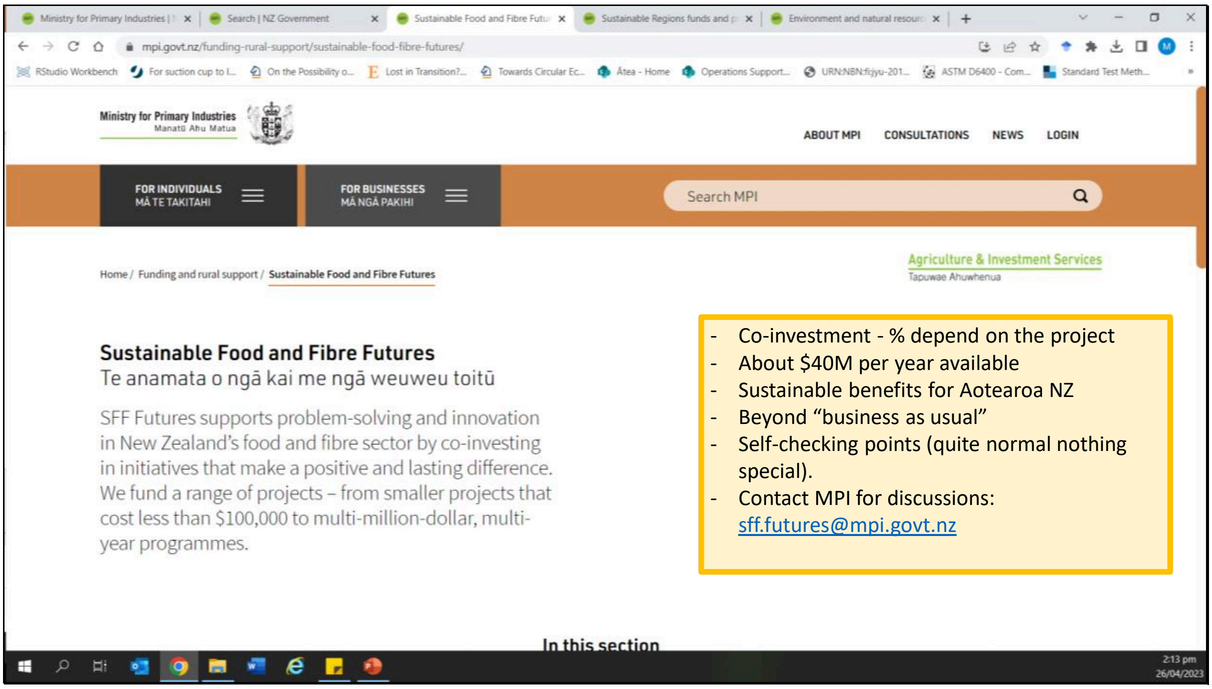
Moving forwards: some extra funds can help

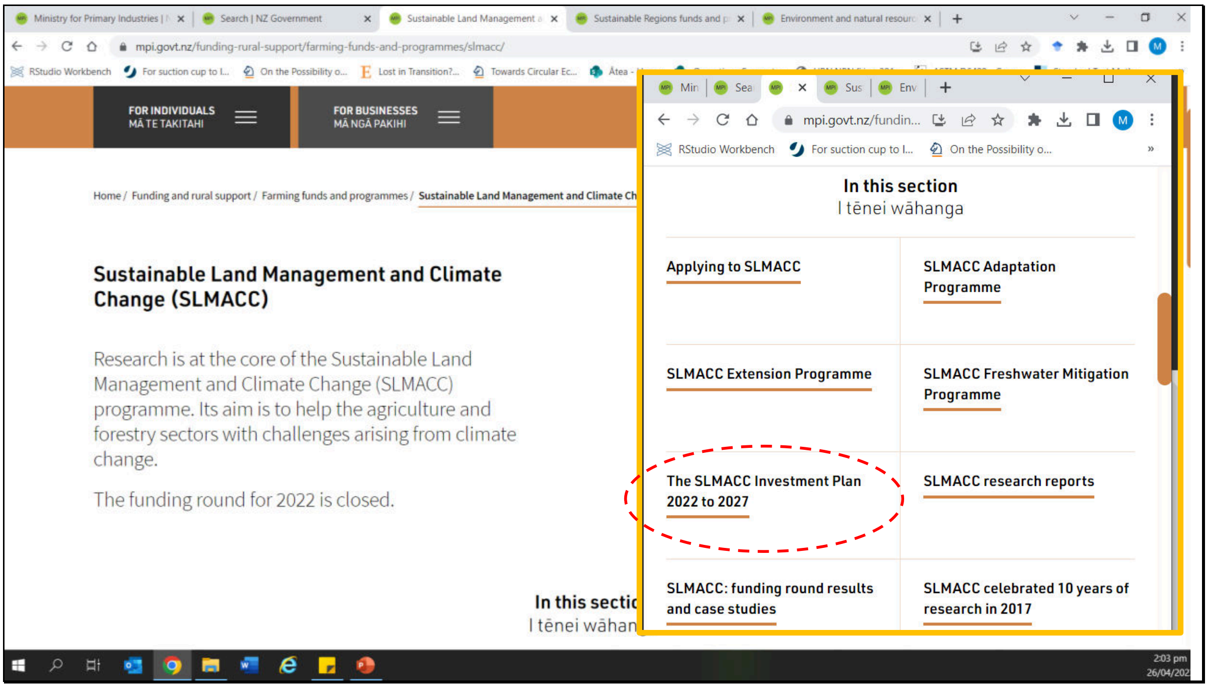



mpi.govt.nz/funding-rural-support/farming-funds-and-programmes/productive-and-sustainable-land-use/
Home / Funding and rural support / Farming funds and programmes / Productive and Sustainable Land Use
Productive and Sustainable Land Use
The Productive and Sustainable Land Use (PSLU) package will promote farm land-use practices that deliver more value and improved environmental outcomes.
ADVERSE EVENTS
MĀORI AGRIBUSINESS FUNDING AND SUPPORT
SUSTAINABLE FOOD AND FIBRE FUTURES
PRIMARY GROWTH PARTNERSHIP (PGP)
FISHING AND AQUACULTURE FUNDING AND SUPPORT
What will PSLU do?
PSLU will help ensure:
farmers and other land users can meet environmental standards and remain prosperous
every farmer has a way to achieve these goals, including changing land use if necessary
any impact of changing land use on land users, their families, and communities is managed in a just and sustainable way.
Download a printable fact sheet on PSLU [PDF, 784 KB]
How will it help?
PSLU will help land owners, businesses, and Māori decide the best way to boost productivity on their farm and improve the health of our environment.
The package will provide the assistance farmers and growers are looking for to help them optimise their land use. This includes:
on-the-ground help to support on-farm changes
information about other land-use options
advice and support from professional farm advisers
help with the development of higher value food and fibre products
greater focus on farmer-led approaches, with farmers driving the change and sharing their knowledge with other farmers.
How will PSLU work?
PSLU will have 6 parts to help farmers and growers make informed decisions.


mpi.govt.nz/funding-rural-support/maori-agribusiness-funding-support/
Māori agribusiness funding and support
Te pūtea me te tautoko mā ngā pakihi ahuwhenua Māori
How MPI is working with Māori in agribusiness: how tangata whenua can make the most of their land, natural resources, and assets in a sustainable way.
In this section
I tēnei wāhanga
Introduction to Māori agribusiness
Māori Agribusiness Pathway to Increased Productivity (MAPIP) programme
Māori Agribusiness Workforce programme
Māori Agribusiness Extension (MABx) programme
Māori Agribusiness Innovation Fund
Māori customary fishing


Ministry for Primary Industries
Manatū Ahu Matua
ABOUT MPI
CONSULTATIONS
NEWS
LOGIN
FOR INDIVIDUALS
MĀ TE TAKITAHI
FOR BUSINESSES
MĀ NGĀ PAKIHI
Home / Funding and rural support / Māori agribusiness funding and support / Māori Agribusiness Innovation Fund
Māori Agribusiness Innovation Fund
The Innovation Fund enables Māori to develop innovative solutions to improve outcomes and create benefits for the Māori primary sector.
- Funding for a primary sector-related project
- Able to provide in-kind co-invest
- Up to $250,000
- Funds can be used for:
- investigate or demonstrate a concept
- access expert advice to explore an innovation project
- develop and evaluate an innovative idea or practice
- For applying contact MPI first: maoriagribusiness@mpi.govt.nz
About the Māori Agribusiness Innovation Fund
The Innovation Fund has been created to back Māori to realise opportunities within the Māori primary sector economy.
ADVERSE EVENTS
MĀORI AGRIBUSINESS FUNDING AND


Ministry for Primary Industries
Manatū Ahu Matua
ABOUT MPI
CONSULTATIONS
NEWS
LOGIN
FOR INDIVIDUALS
MĀ TE TAKITAHI
FOR BUSINESSES
MĀ NGĀ PAKIHI
Search MPI
Agriculture & Investment Services
Tapuwae Ahuwhenua
Home / Funding and rural support / Sustainable Food and Fibre Futures
Sustainable Food and Fibre Futures
Te anamata o ngā kai me ngā weuweu toitū
SFF Futures supports problem-solving and innovation in New Zealand's food and fibre sector by co-investing in initiatives that make a positive and lasting difference. We fund a range of projects – from smaller projects that cost less than $100,000 to multi-million-dollar, multi-year programmes.
- Co-investment - % depend on the project
- About $40M per year available
- Sustainable benefits for Aotearoa NZ
- Beyond "business as usual"
- Self-checking points (quite normal nothing special).
- Contact MPI for discussions: sff.futures@mpi.govt.nz
In this section



SLMACC - Adaptation Programme

Social impacts, policy research, and the science around adaptation to climate change. It aims to:

- understand people's needs, including looking at barriers to behavioural change.
- develop tools and practices to enable adaptation to climate change.
- put adaptation into practice, providing examples that show how research can be used by different sectors and regions in practical ways.

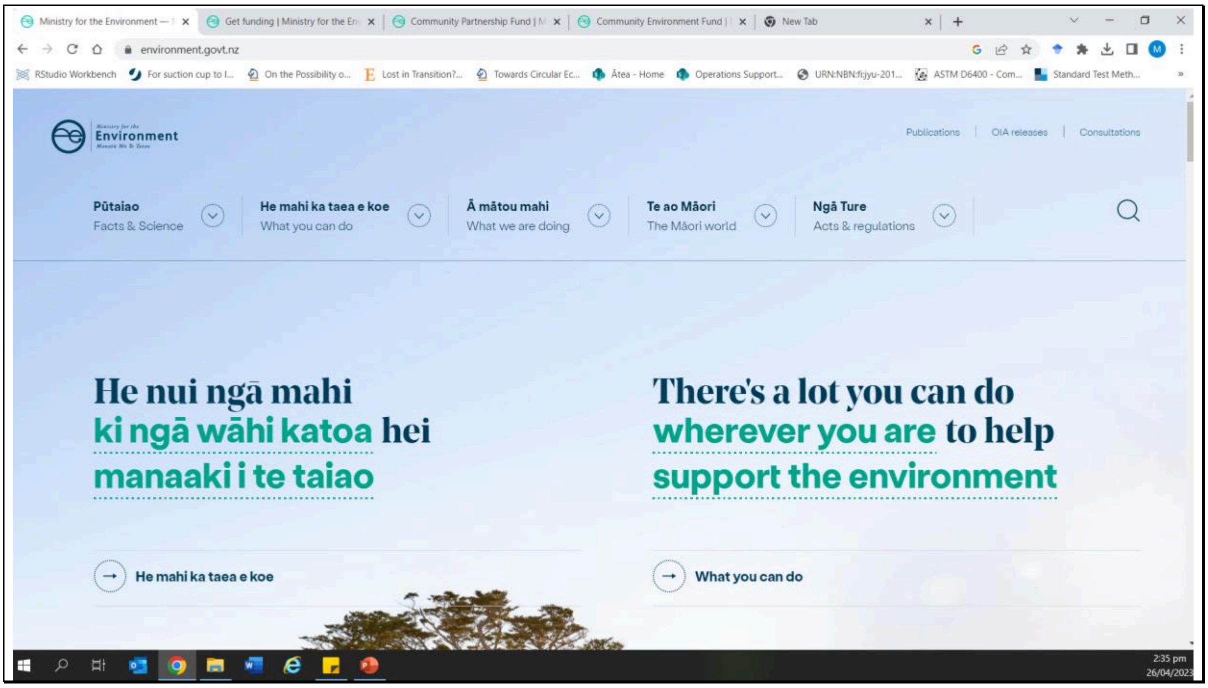
Each year, the programme has $2.26 million to fund scientific projects.

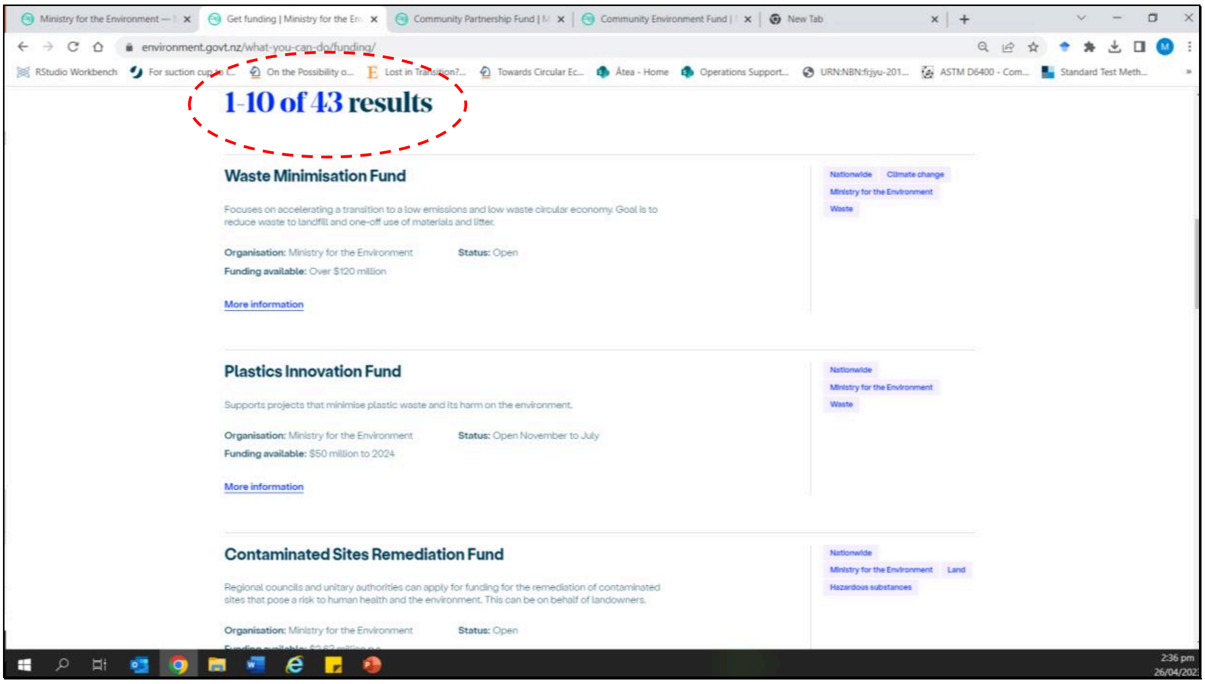
SLMACC - Extension Programme

Communicating research findings to farmers, growers, and other primary industry professionals. It aims to:

- directly influence engagement
- encourage implementation
- create lasting changes in behaviour.

The programme has up to $600,000 to fund extension projects each year.


Ministry for the Environment
Get funding | Ministry for the En
Community Partnership Fund
Community Environment Fund
New Tab
environment.govt.nz
Environment
Publications
OIA releases
Consultations
Pūtaiao
Facts & Science
He mahi ka taea e koe
What you can do
Ā mātou mahi
What we are doing
Te ao Māori
The Māori world
Ngā Ture
Acts & regulations
He nui ngā mahi ki ngā wāhi katoa hei manaaki i te taiao
There's a lot you can do wherever you are to help support the environment
He mahi ka taea e koe
What you can do
2:35 pm
26/04/2023


environment.govt.nz/what-you-can-do/funding/
1-10 of 43 results
Waste Minimisation Fund
Focuses on accelerating a transition to a low emissions and low waste circular economy. Goal is to reduce waste to landfill and one-off use of materials and litter.
Organisation: Ministry for the Environment
Status: Open
Funding available: Over $120 million
More information
Nationwide
Climate change
Ministry for the Environment
Waste
Plastics Innovation Fund
Supports projects that minimise plastic waste and its harm on the environment.
Organisation: Ministry for the Environment
Status: Open November to July
Funding available: $50 million to 2024
More information
Nationwide
Ministry for the Environment
Waste
Contaminated Sites Remediation Fund
Regional councils and unitary authorities can apply for funding for the remediation of contaminated sites that pose a risk to human health and the environment. This can be on behalf of landowners.
Organisation: Ministry for the Environment
Status: Open
Nationwide
Ministry for the Environment
Land
Hazardous substances
2:36 pm

- *What land uses or combination of them would provide long-term sustainability for the Nikau whaanau and the taiao in their rohe?*

- Enhancing Mauri of land and water through land use change: an exploration of potentials and effects using systems thinking and Waikato-Tainui methodologies at Nikau Farm in the Waikato region of Aotearoa New Zealand.

Land use	**Economic sustainability**	**Improved mauri**	**Create vibrant communities**	**Recover tikanga and kawa**
Solar farming	✓✓✓	✓?	✓	✓?
Tuna	✓	✓✓	✓✓✓	✓✓✓
Greenhouses	✓✓✓	✓✓?	✓✓	✓?
Polyculture	✓✓	✓✓✓	✓✓✓	✓✓✓
Cropping and maara kai	✓✓	✓✓	✓✓✓	✓✓✓
Native vegetation	✓	✓✓✓	✓✓✓	✓✓✓