Proposal information

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Investment area: 2023 Endeavour Fund - Research Programmes

Contracting organisation: University of Otago

New Zealand Business Number (NZBN):
9429041925324

Registration number:
245910

Year 1 funding requested:

$1,984,789.00 GST excl. amount	$297,718.35 GST amount	$2,282,507.35 Total amount

Total funding requested:

$9,923,945.00 GST excl. amount	$1,488,591.75 GST amount	$11,412,536.75 Total amount

Title:
Whatu raranga o ngā koiora – weaving cultural authority into gene-drives targeting wasps

Investment mechanism:
Research Programmes

Number of years funding requested:
5

Start and end dates:

01/10/2023	30/09/2028

Investment Signals

Support new or existing industries to be knowledge intensive (i.e., are characterised by workforces that are predominantly highly skilled, and which have the technology, tools and resources necessary to create higher value products and services).

Explain your selections (400 words)

We will develop culturally and ethically informed next-generation gene-drive tools to control invasive wasps. We will use the development of gene-drive technologies as an opportunity to weave in cultural self-determination to guide policy development. We do not aim to release gene-drives, but will provide the transformational knowledge needed for decision-makers to make culturally and scientifically informed decisions about a technology that may transform our productive sectors and safeguard our taonga biodiversity. Together with our technical advisory group and mana whenua representatives (Te Ropu Kahuwhā), we will explore the technical risks and benefits of gene-drive technologies; understand the values that underlie decision-making; investigate the opportunities for the inclusion of mātauranga Māori, and produce a set of recommendations, reflective of cultural authority, for their use, to guide policy development.

While this programme targets social wasps, the outcomes of this work will address broader questions about the ethics, cultural authority, risks, and benefits of gene-drive technologies that are potentially applicable to other pest species, and other biological technologies. This research will underpin the next generations of pest control in New Zealand by testing gene-drives to see if they are fit for purpose, determining boundaries and trade-offs for their use, and identifying key guiding principles needed for policy development. Weaving cultural authority into gene-drive technology will set the direction for new knowledge-intensive industries to assess this technology for pest species. There are few alternative technologies available to produce the step-change in pest control needed in New Zealand, but there are significant knowledge gaps about gene-drives that need to be filled before we can assess the technology for use here.

This project is focused on 1) closing the technical knowledge gaps in the development of gene drive technology, 2) understanding the richness and diversity of knowledge and views that Māori have for the development, design and use of these tools, and 3) providing key evidence on the risks, benefits, and efficacy of gene-drives to guide Tiriti-led science policy development and support a workable regulatory environment.

Our research is connected by Te Ao Māori values; kaitiakitanga, manaakitanga and kotahitanga which support interdisciplinary research between leading genetics, ecology, mātauranga, social research, and policy development to produce national strategic outcomes. We will develop culturally and ethnically informed gene-drive systems targeting wasps with clearly identified risks and benefits. This work will be carried out under controlled conditions and collaborating with world-leading international researchers.

Impact Category

Transform

Provide a brief explanation of how the proposal aligns to this category (400 words)

We will use the development of transformative pest control technologies for wasps to understand the risks and benefits of gene-drives, We will incorporate cultural perspectives, and produce clear guides for the ethical, safe and effective use of these technologies in New Zealand. This work will inform the development of future biological technologies, transforming our approach to generating and implementing them.

Invasive wasps cause severe economic and environmental damage in New Zealand. The cost to New Zealand of social wasps was estimated at $130 million/year in 2015 in a Department of Conservation and Ministry of Primary Industries report, and the impact of wasps on beekeeping, pollination and honey production is increasing and is amplified by climate change. Beekeeping added $425 million to the economy in 2021 in honey and an estimated $4 billion/year in pollination. The MPI/Landcare honeybee colony loss survey has, year-on-year, shown that approximately 12% of honeybee hive losses are due to wasp attacks.

Wasps damage our conservation estate, affecting tourism and the environment. They predate native arthropods, reducing food supplies for our native birds and attack those birds directly and threatening their recovery. Invasive wasps affect human health due to their aggressive nature and toxic stings, affecting the quality of experience for international tourism in our forests.

Gene-drives are challenging technologies. They challenge societal norms, values and cultural integrity. They are ethically contested with unresolved questions such as their 'good' and 'bad' uses, who decides what these uses are, and how available they are to people that may benefit. In the past, those who benefited from and decided to use such technologies were already advantaged. Marginalised groups, such as Māori and other indigenous and remote communities, have been disregarded and/or negatively impacted by such developments. We will thus weave cultural authority through the research, providing an exemplar of how other technologies are developed and deployed.

Technically, we will test gene-drives in containment to develop an understanding of a technology that may radically change how we control pests. Culturally, we will explore the diversity of perspectives and localized concerns. For decision-makers, we will gather key policy insights to guide the research into a balanced assessment of the suitability of this technology for New Zealand. These near-term impacts; tools for effective and long-term removal of pests, and the development of processes to guide ethical policy around complex technologies, will transform our primary industries, tourism, conservation estate and environment.

Research Keywords

- Pest control
- Reproductive Biotechnology
- Gene drive
- Te taiao
- Genetic technologies
- mātauranga Māori view in environmental management
- invasive species control
- Social wasps
- Insect genetics
- Genetically modified organisms
- Risk assessment

Contact people

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Funding proposal

Executive summary

(560 words)

Invasive pests damage agriculture, our conservation estate, and our health. Removing or suppressing these pests is expensive and complicated. Gene-drives, genetic methods to cause the extinction of pests, have been described as ‘silver bullet’ technologies. But are they? No gene-drive has been deployed anywhere in the world, none developed that would target key New Zealand pests, and it is unknown if gene-drives can be effective, safe, ethical, and economical. These knowledge gaps are barriers to the development of gene-drives and other novel biological tools. Understanding if we can build gene-drive systems that are safe, ethical and effective, and the concomitant development of policy, underpinned by Te Ao Māori values will support the deployment of novel biological tools. This is an opportunity to transform New Zealand’s ability to be resilient in the face of threats to our economy, environment and well-being.

We will fill these knowledge gaps by building gene-drives for a New Zealand pest; social wasps. **We hypothesise that we can build gene-drives that are effective, safe, and ethical.** We will test this using a tractable model wasp to determine the technically and culturally acceptable best gene-drive technologies and their safety and efficacy in containment. Wasps are exemplars that are nationally relevant but can be maintained in secure laboratories, providing insight into the general feasibility of gene-drives. We will weave in cultural authority, as defined by our mana whenua rōpu (Te Rōpu Kahuwhā), and regulatory needs, defined by our Technical Advisory group, to our gene-drive systems.

We will build on a nationwide survey of Māori participants that identified core values shaping attitudes to invasive species control. Through existing relationships with iwi and hapū in Northland, Bay of Plenty, Gisborne, Wairarapa and Whakatū we will establish Te Rōpu Kahuwhā providing opportunities to explore the richness of Māori perspectives on the impact of wasps, and the value and management of pollinators that share their ecosystems. It will help identify mātauranga Māori relevant to the development and use of gene-drives, allowing us to incorporate these ideals into gene-drive design.

With various gene-drive designs implemented in our test wasp system, we will implement the most effective and ethical in damaging invasive wasps, in containment. By testing these systems for efficacy, safety, and cultural acceptability, we will fill the knowledge gap that paralyses decision-making, and advance the cultural authority essential for use of these technologies in New Zealand. We will also identify key policy insights and guiding principles necessary for an ethical science response and cultural authority to manage invasive pests with new genetic technologies.

This project brings together experts on biosecurity, ecology, mātauranga and science interface [redacted] environmental sociology, mātauranga and Tiriti-led science policy [redacted] insect control [redacted] and insect genetics (Peter Dearden). Our team includes international experts, [redacted] (USA) and [redacted] (UK) as well as experts in pest control and regulation.

Removing invasive social wasps would reduce control costs (NZ$133 million/ year), trigger an annual NZ$62 million increase/year in the pastoral sector, and boost apiculture by NZ$58 million/year. More importantly, deciding to use gene-drives (or not) depends on high-quality knowledge about their suitability in New Zealand. We will fill this knowledge gap and develop a more ethical science response and policy pipeline for using novel biological tools. We aim to empower New Zealand to become more resilient managing multiple, interconnected threats to our economy, environment and well-being.

Vision Mātauranga

Will this proposal give effect to the Vision Mātauranga Policy? i.e. realise the potential of Māori people, knowledge, and resources

Yes

Explain your answer (500 words)

This programme is underpinned by ethical power-sharing as it provides the opportunity to weave cultural authority into the science leading to the development and deployment of gene-drives to manage invasive wasps. **Research Aim 1.1 Te Whatu Rangahau - Ngā Taonga Tuku Iho** builds on and adds value to previous research into Māori attitudes and acceptability of invasive species control in Aotearoa[1] and *Whakahonotia Nga Taonga Rerekē* – exploring Māori values and uses of ecological bio-control agents. This research is supported by an extensive network of Māori researchers, kaumatua, iwi and hapū members. This includes [redacted], a CoRE directed by [redacted], which has incorporated Māori values at its heart to protect and enhance the resilience of our productive lands; and [redacted], a Māori organisation with CEO [redacted] that is focused on biosecurity and biodiversity advocacy for Māori with an Iwi Chairs mandate to speak on biosecurity issues, including tool development and use.

[redacted] will oversee **CS1.1.1–1.1.3**. which will set the scene for interrogating previous survey results that quantitatively identified Māori values and viewpoints associated with gene-drives as a pest management tool. We will test these, kanohi ki te kanohi, with our mana whenua representatives on Te Rōpu Kahuwhā made up of our existing relationships and connections with iwi and hapū in Northland, Bay of Plenty, Wairarapa and Whakatū. This will help inform methodological approaches in **CS.1.1.1** to ensure sustained pathways of engagement and the inclusion of cultural authority in decision-making in **CS.1.1.2**; Understanding how wasps are valued and managed by Māori can complement the use of gene drives in wasps and **CS.1.1.3.** Identifying opportunities to include Te Ao Māori and mātauranga Māori relevant to the development and deployment of gene drives in wasps. We have identified a Māori PhD candidate [redacted]) who will deliver into **CS.1.1.3.** [redacted]. [redacted] We will be focusing on our existing relationships and connections with iwi and hapū in Northland, Bay of Plenty, Wairarapa and Whakatū. An unnamed Post-Doctoral Fellow will carry out focused participatory wānanga with these community groups to explore initial themes and key ethical considerations uncovered from the survey analyses of 1000 Māori participants[redacted].

[redacted] and a yet unnamed Māori policy analyst will oversee **CS. 1.1.4–1.1.6.** These CSs are focused on delivering an ethical science policy pipeline for the development and deployment of novel genetic tools. [redacted] is ideally placed to lead this crucial work.

What percentage of the total personnel costs are attributed to the named Māori project team members?

30

What percentage of the total personnel costs are attributed to the un-named Māori project team members?

10

What percentage of the project activity is led or co-led by Māori as co-designers, leaders or kaitiaki of the research?
30

What percentage of the proposed activities will use a Kaupapa Māori methodology?
20

What best describes the use of Mātauranga Māori in your project?
There is a balance between Mātauranga Māori and other science knowledge

Excellence

Science Excellence (1120 words)
New Zealand is beset with invasive pests.

Our isolation, unique biology, and our lack of predators have meant that many species brought here have become pests. In the past few years, 'Gene-Drive' technology has been proposed as a potential way of removing or suppressing pests[9-15]. This technology, or set of technologies since there are many versions, is challenging. It is technically hard to achieve, it is not clear how effective it will be in large pest populations, and it is controversial, for both scientists and the public[16,17,18]. One key problem is a technical knowledge gap. While we know how gene-drives **might** work, they have not been implemented beyond a small group of laboratory model species[11,19-21], closely related species[22], and mosquitos[12,15,23]. These species are not representative of the pests affecting New Zealand, leaving us unable to make informed decisions about gene-drive use. Furthermore, we lack basic information about social values that must underpin decisions on the use of such tools among key groups, identification of key ethical considerations, opportunities to include Te Ao Māori approaches, and key policies necessary for a culturally responsive process.

We will provide the technical confidence and ethical policy development process to decision-makers to be able to properly assess the use of these technologies. If gene-drives are shown to be effective and safe, then this will unlock the use of these technologies more broadly, providing potential access to a game-changing technology outside the lab. If gene-drives are shown to be neither safe, nor effective, then this project will definitively demonstrate this, allowing us to move on to others if desired. Without filling this knowledge gap, we will be lost in indecision, and lack an appropriate ethical process, to make use of these technologies if they prove successful and meet cultural and policy requirements

The exemplar pests we have chosen to target are invasive social wasps. These are damaging; affecting our agriculture, conservation estate and even our health[24-26]. Two of these wasps, the Common and the German wasp (*Vespula vulgaris* and *Vespula germanica*, respectively), have been in New Zealand for some time, with well-measured impacts. The European paper wasp (*Polistes dominula*) has just appeared in New Zealand[27,28] with high density in Nelson, but evidence of spread from Auckland to Alexandra[29]. Wasps grow rapidly, making them good gene-drive candidates, are relatively easy to contain, and are not major pests in their native range, meaning they are a problem requiring a uniquely New Zealand solution.

Wasp genetics is unusual[30] making transferring gene-drive technology from other species challenging. Modelling demonstrates that they would be affected by gene-drive systems[31-33]. Because of this we will generate and test gene-drive technologies in the well-studied[34], easy-to-grow and manipulate model wasp species[35,36] *Nasonia vitripennis*, for which genetic transformation technologies already exist[37-39]. Using this species as a rapid testbed for gene-drive technologies, we will take a stepwise, iterative, approach (**Figure 1**) to develop a gene-drive system, first developing and testing in *Nasonia*, then scaling up and transferring this technology to *Polistes*, and *Vespula* wasps in 5 years. In building gene-drive systems we will examine population genomics of invasive species to find 'private alleles'[31,40] as these will reduce the potential impact of our gene-drives escaping New Zealand.

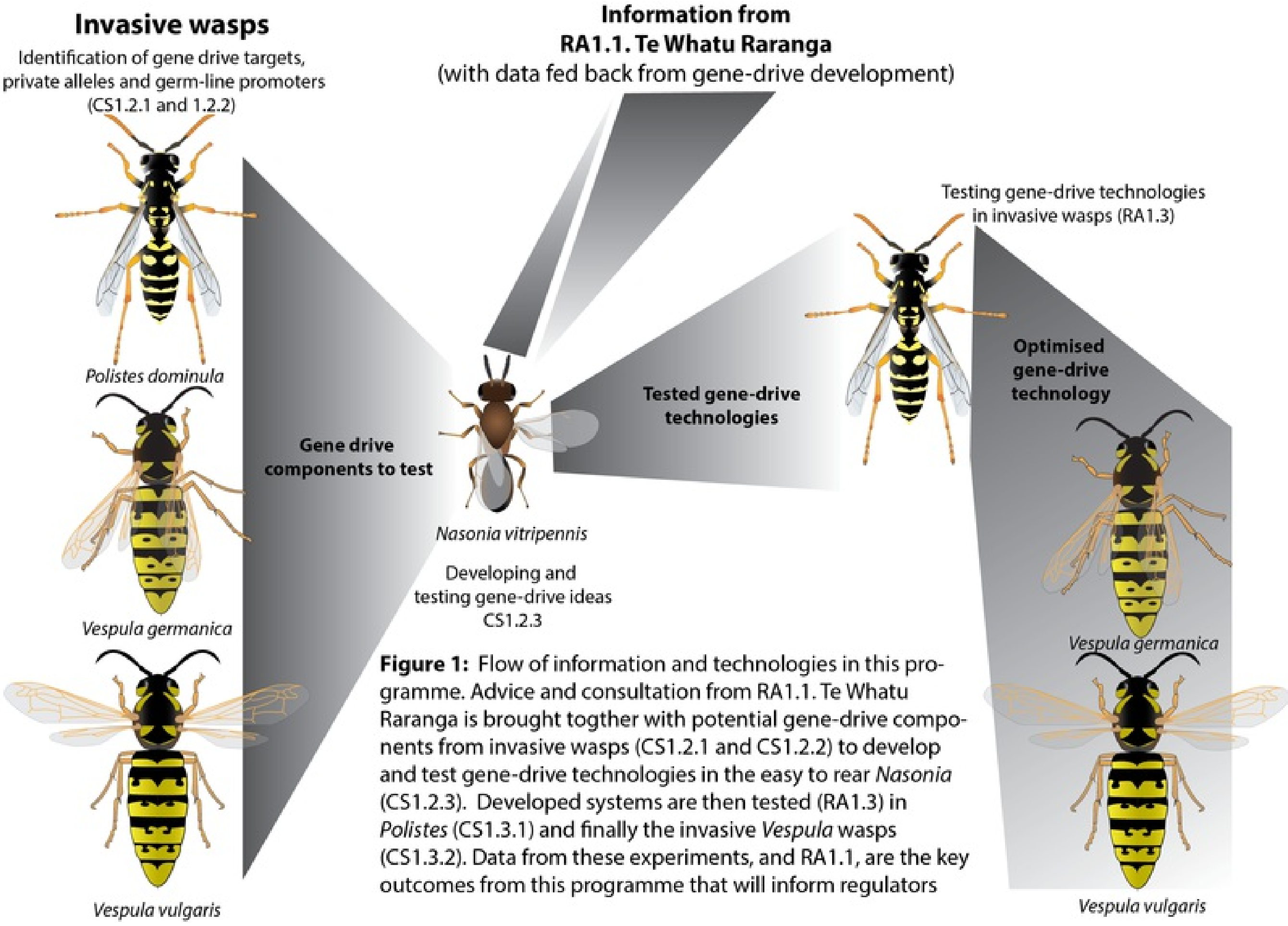

Figure 1: Flow of information and technologies in this programme. Advice and consultation from RA1.1. Te Whatu Raranga is brought togther with potential gene-drive components from invasive wasps (CS1.2.1 and CS1.2.2) to develop and test gene-drive technologies in the easy to rear *Nasonia* (CS1.2.3). Developed systems are then tested (RA1.3) in *Polistes* (CS1.3.1) and finally the invasive *Vespula* wasps (CS1.3.2). Data from these experiments, and RA1.1, are the key outcomes from this programme that will inform regulators

Based on experience in *Nasonia*, we will develop techniques to gene edit, and finally transform, our target species. We will extend our current research to develop gene-drive constructs based on the best international biosafety and efficacy advice available. Constructs will be deployed and tested for efficacy in relatively large populations of the target species in containment. Such a scale is only possible in small invertebrate species.

Committing to culturally-informed ethical research

Māori concerns around the development and use of novel biological tools and the opportunity to include mātauranga Māori are largely undescribed. Mechanisms for recognising and accounting for Te Ao Māori values in this space are critically underdeveloped. We will build on and add value to a national survey that captured the attitudes of 1000 Māori participants[1] to gene-drives and other pest control methods to identify how wasps are valued and what drives decisions around their management This will identify key ethical considerations and opportunities to include Te Ao Māori views and mātauranga Māori research.

Of critical importance to the outcomes and impacts of this programme are the use of Cultural Authority and Mana Ōrite Agreements recently developed for Bioprotection Aotearoa, Genomics Aotearoa and Te Whakahononga approach developed through Ngā Rākau Taketake (BHNSC). These will be used to guide the researchers and provide a mutual understanding of responsibilities for Te Ropu Kahuwhā to articulate to their communites. The purpose of a Cultural Authority Agreement is to provide clarity to all signing parties about the research being undertaken, agreed outcomes, and to recognize and provide for the relationship of mana whenua and their rohe. We will use the Mana Ōrite Agreement to legally formalize collaborations with Māori communities to recognise and provide for the relationship of Māori communities with their culture and traditions, with their ancestral forests, flora and fauna, lands, waters, sites, wāhi tapu, wāhi tupuna, wāhi whakahirahira, and other taonga.

International Expertise

We will draw on the expertise of key insect transgenesis and gene-drive experts to help us develop these systems. We have already worked with and have trained staff in two methods of gene editing in insects, using egg[41], and ovary injection[37,42]. We will also work closely with [redacted] (North [redacted]. Both [redacted] and [redacted] will provide insight and advice regarding the international development in the field, both from their work, and their network of collaborators, ensuring our approaches are world-class. This information will be fed into our consultation and design work.

Filling the knowledge gap

Debates about the use of new technologies are crucial to their effective deployment but need to be informed by real-world evidence about the risks and benefits of that technology. We risk having gene-drive technologies implemented overseas, leaving us with technologies not tailored to New Zealand society or pests, and without the opportunity to express self-determination. This programme aims to reduce this risk, by building capability, seeking to be culturally informed and ethical in its approach by embracing Te Ao Māori, and testing gene-drives for New Zealand's pests. This programme tackles arguably the biggest science-based issues and opportunities facing pest control in New Zealand. Our dual approach of gene-drive development research and the aims of RA1.1. Te Whatu Raranga will strengthen our commitment to leaving a legacy in the New Zealand science and innovation system.

Science Risk (280 words)

1) The technical development of gene-drive technologies is challenging. To ensure the best success we will use a wasp model system, *Nasonia vitripennis*, where many of the underpinning technologies required to build a gene-drive are available, including transgenesis[38,39,42]. We have modified and implemented these technologies in the Dearden lab. We have engaged world experts in this area ([redacted] and [redacted]) to ensure we use leading approaches.

2) Transferring gene-drives from model systems to *Polistes* and *Vespula* wasps is key to understanding their efficacy in invasive wasps. To support this, we have a world expert on these wasps in the team [redacted]). Work will be undertaken to develop the technology and skills needed to make these wasps transgenic as gene-drives are tested in *Nasonia*.

3) Making gene-drive technologies suitable to the New Zealand environment requires a great deal of information about cultural needs, the ethical dilemmas of these technologies and implications for social license, the needs of regulators to make decisions, and the contents of policy. To ensure cultural authority is woven authentically through this programme our team includes world experts [redacted], to support ecology aspects and bring Te Ao Maori values into science research, [redacted], to support understanding of science-informed - and development of Tiriti-led science policy. We also have existing Cultural Authority Agreements and Mana Ōrite Agreements that demonstrate our commitment to being culturally responsive researchers. We have a technical advisory group with members from key stakeholders and regulators, EPA, MfE, DOC, and Predator Free 2050 LTD. Input from these experts will ensure our gene drive technology is responsive to and suitable for, the Aotearoa-New Zealand environment

Team Excellence (560 words)

Peter Dearden is an insect geneticist with experience in working with hymenopteran/ haplodiploid insects including bees[43,44] and wasps[45-47]. He has experience in insect transgenesis[48,49] and gene editing and has a track record of research on insect germ-cells- critical to transgenesis[50-52]. Peter has published in arthropod genomics[53-55], including leading the sequencing of the Common and German wasp genomes[45]. Peter is involved in a range of community engagement, including discussions about gene-drives and gene editing for the Royal Society Te Aparangi Gene Editing Panel[56], and received the Callaghan Medal for Science Communication in 2014.

[redacted]

[redacted] ti [redacted]

[redacted]

International Advice will be provided by [redacted] and [redacted].

[redacted]

[redacted]

Postdoctoral, Postgraduate and support: This programme will be supported by four postdoctoral researchers, two PhD students, a project manager and a research coordinator. Two postdocs will lead gene-drive development, one will be [redacted], [redacted] One postdoc will work on the Vision Matauranga aspects. An international search for the remaining postdocs will be carried out. One PhD student ([redacted]) will work on mātauranga Māori informed research and one on wasp genomics.

Technical Advisory Group and mana whenua representation through Te Rōpu Kahuwha: We will be advised on regulatory matters by a group containing [redacted] (Predator Free 2050), [redacted] (Plant and Food Research), [redacted] (EPA), [redacted] (DOC), [redacted] (EPA), and cultural matters from representatives from five iwi/hapū (Northland, Eastern Bay of Plenty, Gisborne, Wairarapa, Whakatū).

Team Risk (280 words)

Project management: This programme will be led by Peter Dearden, who has successfully led MBIE programmes(Future Bees), and is co-director of Genomics Aotearoa and deputy director of Bioprotection Aotearoa. Peter will be supported by a research coordinator to ensure team and advisory group meetings occur and are effective. Team meetings will be held by video conference to avoid unnecessary travel, with a Kanohi ki te kanohi strategy meeting each year.

Early Career mentoring: Early-career researchers will be mentored by their supervisors (all of whom are experienced) as well as being engaged in team meetings and discussions. The research coordinator and project manager will support the delivery of mentorship.

Availability of staff: The availability of students and postdocs may be a problem for this project, though many of the key positions are already named. The University of Otago's genetics programme is a good source of students for these kinds of projects, and Bioprotection Aotearoa also attracts students and staff internationally. We will build flexibility into these roles as much as possible to make them attractive.

Cultural responsiveness: Cultural responsiveness is crucial to this project, and will be managed by the leadership, led by [redacted]. Regular cultural competency training will be undertaken by staff and students.

Succession: Succession planning is important to the future of this work, its implementation, and New Zealand in general. Employment of 4 postdoctoral researchers is at the heart of succession planning as these will be key individuals who will provide future capacity and leadership. As part of their mentoring, they will have opportunities for student supervision, cultural competency, strategic planning, as well as deliberative career planning to ensure their future success as leaders

Impact

Benefit to New Zealand (1120 words)

1) The New Zealand public and decision-makers need risk and benefit data to fill the knowledge gap for gene-drives.

As genetic technologies continue to develop internationally it is necessary for New Zealand to make decisions about using them in health, agriculture, and pest control. Consideration of hypothetical ideas without scientific data risks entrenching poor policy decisions which may be difficult to undo. For example, the publication of survey results from a Biological Heritage National Science Challenge (BHNSC) team[16] and others[18] shows that significant proportions of the public are pro- or anti-technologies for pest control that are still yet to be developed. Such discussions in the absence of data have significantly reduced value and utility.

This work will generate data on risk and benefits for a potentially game-changing method of pest control, providing a factual basis on which to discuss this challenging technology.

2) New Zealand's economy and conservation estate will benefit from wasp removal or suppression.

The economic impact of Vespula wasps in New Zealand has been carefully assessed[70]. Wasps cause an annual direct cost of NZ$133 million to the economy[70]. Wasps compete with honeybees. Removing wasps would increase the pollination rate of clover, reducing fertilizer (with climate-change implications) and reseeding, resulting in a NZ$62 million/year increase to the pastoral sector[70].

Wasps exclude honeybees from collecting beech honeydew which could be used by the apicultural industry to an annual value of NZ$57.8 million/year[70]. Wasps destroy beehives with just under 12% of hive losses attributed to wasps in 2022[71] directly affecting Mānuka honey production.

High resource availability in New Zealand has allowed huge populations of wasps, with massive ecological impact[24]. *Vespula* wasps are omnivorous and eat honeydew, nectar, insect prey, vertebrates, and carrion[72]. Up to 4.8 million prey items, including bees, per hectare per season are estimated to enter *Vespula* nests in New Zealand[73] causing vast primary industry and ecological damage. Wasps make our native forests less attractive to tourists, especially in Nelson and Buller (Whakatū). These impacts are increasing with climate change.

The impact of *Polistes* is being measured in New Zealand[74-76]. In other countries, they cause a significant proportion of wasp stings, and in Colorado, *Polistes* causes economic impacts to vineyards and other fruit-based businesses[77], indicating the potential for impact on our own viticulture and horticulture industries.

Given the damage to our apiculture and agriculture, tourism and conservation estate, removal, or suppression of wasp populations would have immediate and significant positive effects on industry and the environment, with spill-over benefits to health.

We commissioned research from [redacted] as to the economics of a commercially deployed wasp gene-drive system in New Zealand which shows they are economically feasible[redacted]. The last knowledge gap is to discover if a gene-drive system can be developed that is culturally acceptable, safe, and effective. This programme will fill that gap.

3) Pest control in New Zealand is obviously not only about wasps.

The Predator Free initiative, controversies about using 1080 and other poisons, and the increased need for safe environments for our critically endangered species indicate the need for new, effective, and safe forms of pest control. Pest management costs billions of NZD$ per year in New Zealand[79], with the cost of invasive species internationally at $163 billion US$ annually (2017 figure)[80]. Gene-drives might be a breakthrough technology to ameliorate these costs, but like all technologies needs to be tested and either, triaged as un-useful, or proven effective and safe and thus used.

This programme, while focused on wasps, will provide valuable data and direction for the use of gene-drives in other species or show that we must look elsewhere for solutions to our pest problems. Either outcome would benefit New Zealand and steer us towards the development of the technologies we need.

4) Providing opportunities for Te Ao Māori and mātauranga to be included in gene-drive development and deployment provides a pathway to culturally responsive research and power sharing.

This programme is underpinned by ethical power-sharing as it provides the opportunity to develop kaupapa Māori methods in the science behind developing and deploying gene drives for wasps. **Research Aim 1.1 Te Whetu Rangahau - Ngā Taonga Tuku Iho** will add value to previous research into Māori attitudes[1] on pest control in New Zealand. Much of this survey data has yet to be analysed for further insights (**Fig 2**). This programme will provide the opportunity to uncover the richness in perspectives, such as localized concerns. Exploring the relationship between mātauranga and Te Tiriti o Waitangi with mana whenua in Te Rōpu Kahuwhā will add these nuances and identify appropriate controls that may make the use of gene-drives acceptable. This approach will provide a future guide for policymakers and regulators, who lack the information to recognise what culturally embedded research is and how it can feed into a Tiriti-led science policy approach.

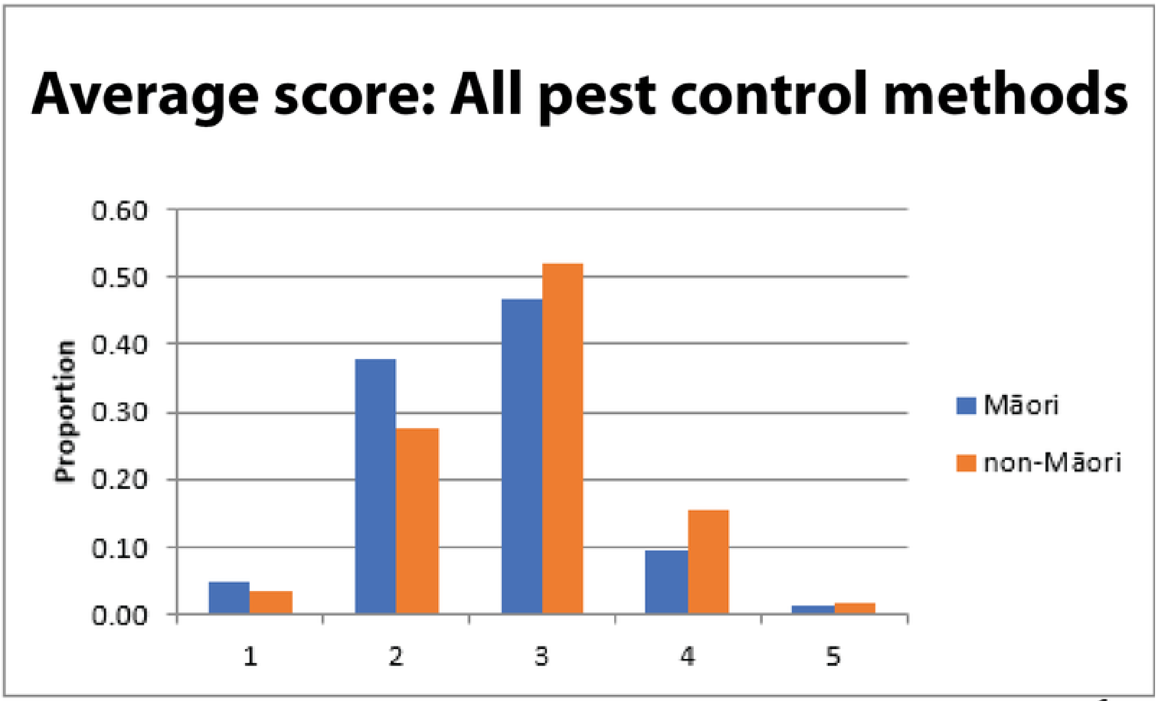

Figure 2 Māori and non-Māori have different attitudes to pest control methods[1].
Most respondents scored moderately for 'Pest Control Attitudes'. For this variable the distributions of the scores for Māori and non-Māori differed, with Māori in general being less comfortable with some pest control methods (particularly poison bait spread by aircraft, selective breeding resulting in infertile males and genetic editing resulting in most offspring being male).
Scoring key: (5) I have no concerns at all about this method (4) I am uncomfortable with this method but will accept it as long as appropriate controls are in place (3) I am comfortable with this method as long as appropriate controls are in place (2) Should only be used as a last resort (1) Should never be used under any circumstances.

5) New Zealand needs experts in gene-drive technologies.

Gene-drive, and similar pest control technologies, are being developed for different species in the rest of the world. In some cases, deployment will be relatively soon[81]. Without technical capability and capacity in New Zealand, we will be unable to deal with problems with this technology, or to stop such technology from being, accidentally or not, deployed in New Zealand. New Zealand has been discussed by overseas scientists as the ideal location to test their gene-drive technologies[82], putting us at risk of being the pawns in the international development of this technology without building our own capacity and capability, or addressing our own environmental concerns. We firmly believe that the development of this technology needs to be carried out in New Zealand to effectively address the concerns of the New Zealand public, Māori, and end-users. This is too important a technology for us to be merely bystanders without self-determination; to make this work we need to develop the skills to build, assess, deploy, and, if necessary, mitigate, these technologies ourselves.

This programme will build experience in both senior and early-career scientists ensuring that we have experience in detecting, controlling, and implementing these technologies.

6) This proposal aligns with MBIE investment signals.

This proposal brings together national and international experts in pest control, genetics, regulation, policy development and mātauranga Māori to address a key problem that limits future growth, controlling our pest species. The data produced by developing and testing gene-drives in an Aotearoa-New Zealand context will either unlock this technology more broadly or demonstrate its limitations. Either outcome will help us generate new technologies, or workable solutions for the control of pests. The research provides a pathway for Māori, Māori knowledge, and key ethical considerations to shape the invention of next-generation pest control and will provide a pathway for similar input into other novel technologies. Finally, this programme underpins the development of new knowledge-intensive pest-control industries.

Benefit to New Zealand Risk (280 words)

The aim of this programme is to develop the data required to support, or not, the use of gene-drives in New Zealand. By developing gene-drive systems in New Zealand, and building in Māori, public, policy, and regulator concerns to those gene-drive systems we aim to understand if it will be possible to use gene-drives in New Zealand. These near-term benefits of our research are not at risk.

Data around the benefit scales of *Vespid* wasp removal in New Zealand is well established, though that of *Polistes* is less well understood. Careful research has identified the impacts of wasps in primary production situations, and the ecological effect of wasps in our conservation estate. Estimation of the removal of wasps is thus solid but does not consider unexpected ecosystem changes caused by wasp removal. We must consider the unknown efficacy of a gene-drive system. Our research may indicate that gene-drives may only suppress populations of wasps, with an unclear ecological and economic impact. Because of this, we have ensured we have ecological and modelling expertise, linked to Te Rōpu Kahuwhā, on our team.

The data from this research programme will fill the data gaps in models of gene drive efficacy and economics. This will allow better prediction of these technologies' risks and benefits, from both scientific and economic perspectives.

The risks around benefits to New Zealand from this project are all about the safety, efficacy, socially-contested use, and economic costs of gene-drive systems. This knowledge is the key outcome of the research programme. Addressing these questions will benefit New Zealand through a better understanding of the potential use of gene drives for pest control.

Implementation Pathway(s) (1120 words)

In this proposal, we aim to develop, in containment, ethical, culturally informed, next-generation tools for the suppression of three species of invasive social wasps. The research proposed will be world-leading but also address an issue of key concern to New Zealand - supporting the eradication of a pest that negatively impacts our economy, environment, and health. The key aim of this project is to fill the knowledge gap which is stopping New Zealand from either implementing or discarding, gene-drives as a pest control strategy. By filling the key knowledge gap on the safety and efficacy of these technologies, and by bringing Te Ao Māori values, mātauranga, and regulator needs into the development process, we aim to inform the key question; is this technology right for New Zealand?

Successful implementation of the outcomes from this programme will produce a well-informed, tested process that delivers a workable regulatory environment for genetic technologies. As noted, we do not intend the deployment of a wasp gene-drive system as part of this programme. The development of technical knowledge, the understanding of the perceptions and values of Māori, including any mātauranga, and the requirements of regulators ensure a robust process to decide which pest control technology is for us. Our advisory and focus groups will allow us to stress-test this process safely.

The next users of the data we generate, and the technologies we invent, will be the regulators, policy analysts, decision-makers and mana whenua that provide cultural authority, that control the use of new technologies in New Zealand. Such groups sit in multiple areas in local (Regional and City Councils, Pest Management Agencies) and national government (EPA, Ministry for the Environment, Ministry of Primary Industries etc). By working closely with an advisory group drawn from experts in this area, as well as working with those bodies directly during the development of our technologies (**CS1.1.5**), we will ensure a strong, culturally informed, trusted relationship. Such a relationship will allow us to interact with regulators as trusted scientific advisors, allowing them to have confidence in our outputs to guide decision-making and support Tiriti-led science policy.

Final end-users of gene-drive technologies, if technically and culturally appropriate, and after robust policy and decision-making based on the data we produce in this programme will be pest control companies, such as [redacted], with whom we have had preliminary discussions. Our analysis shows gene-drive technology delivery could be economic for such companies. End-users in our conservation estate include agencies such as DOC, who are involved in our technical advisory group.

The data from this programme will potentially provide new tools for wasp control, as directed by the MPI National Policy Direction for Pest Management (2015), which drives the pest control activities of Regional Councils and Pest Management agencies. It will provide potential solutions for DOC policies and programmes (such as 'Wasp Wipeout'), targeting wasps in high-value native ecosystems, and inform Predator Free 2050, which recognises the need for new pest control technologies. This work will also feed into the Manaaki Whenua-led Wasp Tactical Action Group.

Gene-drive technologies will face barriers, from many different groups. We aim to understand what values drive decision-making around the development and use of gene-drives and will provide a forum to share knowledge and receive feedback. We recognize that the development and use of genetic technologies vary widely in public perceptions and attitudes, and we have created a space to collate these localized concerns. This proposal aims to carry out the research to describe and quantify those areas of concern and the trade-offs with the use of gene-drives as a management and control tool for invasive wasps.

A significant barrier is the absence of cultural authority and ethical guidelines to develop and use gene-drive technologies. Our most important response to this is that we are enabling Māori, specifically mana whenua cultural authority, agency to decide on gene-drive design, and that we are limiting our testing of gene-drive ideas in containment. Building on our previous work (funded by the RSNZ[9] and BHNSC[16,66]), and focusing on iteratively weaving cultural authority into gene-drive development, we can build in key aspects of gene-drive technology that will address cultural and ethical concerns. While this is occurring, we will also identify tikanga and insights from mātauranga Māori, including more recent kaupapa Māori tools[83], that can help guide the team to understand the context in which gene-drives may be used. Importantly, work in this area will inform the development of gene-drives but is independent of those working on developing the technology, to control conflicts of interest.

Gene-drives face crucial regulatory and policy barriers. The aim of this programme is to develop gene-drive systems that will provide the specific knowledge, data and understanding required by the public to discuss these technologies as well as that needed for regulators, government, and decision-makers to support their decision to implement or not. We will weave into this research routes to the cultural authority crucial for implementation, and ensure Māori agency in planning gene-drive designs. We will also examine current policies and develop Te Triti-informed policies to support the generation and use of gene drives, determining where there are barriers and using the output from our research to find solutions. We will work with our Technical Advisory Group to canvass the concerns and opinions of the EPA, MfE, MPI, DOC and the Parliamentary Commissioner for the Environment to generate an understanding of what sorts of gene-drive technologies are more likely to pass regulatory and public opinion hurdles. These outcomes will inform the development of gene-drive constructs allowing us to mitigate against regulatory issues and clear the path to future implementation. Our international advisors will provide access to their networks and knowledge to ensure we know the key new technologies being developed before publication.

Understanding, and finding mitigation for, risks in future implementation is the most important aspect of this proposal, and it will be informed by discussions with our Technical Advisory Group (DoC, PF2050 LTD, P&FR, MPI and EPA) and mana whenua representative (Te Ropu Kahuwhā) as to what information they would need to see for decision-making. While this is an unusual approach to an implementation pathway, we feel that because it is a highly socially contested technology, and a technically challenging tool, generating the data such that a discussion and decision can be informed, is the main role of research.

Implementation Pathway(s) Risk (280 words)

Freedom to operate.

The ideas behind the use of gene-drives to suppress pests date back to 2003[84], when it was proposed that a homing endonuclease gene could be modified for this purpose. This research is freely available. A great deal of gene-drive technology has been published, providing the basis for this research programme. There are no patents of gene-drive systems in wasps, and none that would affect our freedom to operate (searches via Google Patents, World Intellectual Property Organisation and US Patents and Trademark office). The final plans for an Aotearoa-New Zealand-compliant gene-drive would be developed in this proposal incorporating mitigation of concerns from mana whenua, policymakers and decision-makers. During this process, we will continue to monitor to see if IP issues arise.

There is patent protection around using the CRISPR-cas9 enzyme in gene editing for commercial purposes, though this is disputed. This intellectual property protection will not affect the research described in this programme but might affect the use of a gene-drive commercially. Licensing the technology is available and the best way to access it.

Barriers and enablers.

The key barriers to this programme are the lack of cultural authority and clear recommendations for policy analysts and end-users. This programme authentically weaves through cultural authority informed by robust science, structured workshops and an understanding of global policy. This provides insights into the development of an ethical process that captures concerns and opportunities. Working with Te Rōpu Kahuwhā will identify opportunities for mātauranga and Te Ao Maori values to be embedded into the design and use of genetic technologies. This provides the enabling cultural authority needed to ensure the implementation of this research programmme.

Team Impact (560 words)

Dearden, [redacted], and [redacted] have track records in delivering impact. [redacted] and [redacted] and have worked on public and Māori consultation around novel biological tools including gene drives producing published findings foundational to this programme [redacted]. Dearden and [redacted] have worked together on wasp control [redacted] and beekeeping, developing new solutions for wasp control, and new disease and management practices for beekeepers. They were also authors of the key publication discussing the use of gene-drive technologies in New Zealand [redacted].

[redacted] Her research has a wide impact through ensuring benefits to, and connection with Māori communities and through her leadership roles in academia and high-level strategic policy guidance. [redacted]

[redacted] has worked effectively at the interface between science, community, and policy, and is an outstanding leader in the development of Tiriti-led science policy. [redacted] make her uniquely able to deliver impact from this programme through community, regulators and policymakers.

Peter Dearden has worked with the beekeeping industry developing genetic tests for bee breeding currently used in the industry[85,86]. He continues working with industry to develop genome-informed breeding strategies[85,86] to improve bee health and performance. Peter is the Director of Genomics Aotearoa and has a track record in public engagement, and has worked with, and published with EPA staff[87].

[redacted]

[redacted] brings an understanding of the New Zealand research and regulatory system having worked here for some years. [redacted] is a thought leader in the safety and efficacy of gene drives in agriculture [redacted].

[redacted]

Our Technical Advisory Group provide deep links to industry and experience in the regulation of novel genetic technologies

Post-contract Outcomes for New Zealand (280 words)

2-years

Data from our gene-drive systems inform public debate, and decision-maker discussions around gene-drive technology, not only for wasps but for other invasive pests. New Zealand has the capability in the science system to implement gene-drives or to recognise their effects if imported accidentally. The development of ethical power-sharing research linked to Tiriti-led policy in this programme will be followed by others wishing to understand the deployment of novel technology in New Zealand.

Wasp biology knowledge developed in this programme will be used to develop new mitigation methods to complement or replace gene-drive. Discussions about gene-drive commercialisation, if it is effective and safe, will be proceeding.

5 Years

If gene-drive technologies are approved, a commercial entity using this research will be in place, and wasp numbers reduced.

Our research approach will be used by others wishing to address complex challenging technologies as it will be viewed as an exemplar as how to carry out authentic research into values and cultural considerations as a route to understanding and deploying complex technology

If gene-drive technologies are not safe and effective, removing this as an option will re-focus research into new pest control strategies.

10 Years

If gene-drive technologies are approved wasp numbers could now be suppressed ([redacted]). Better pollination will be reducing greenhouse gas emissions, tourism to our honeydew beech forests will increase and honeydew will be the new Mānuka honey, providing rich income streams for apiculture.

If gene-drives are not safe and effective, new tools, developed following our approach, will be being implemented and tested at this time, many of them built on the knowledge and technologies for wasps developed in this programme.

Project plan

Work Programme

Sequence	Short title	Type	Start date	End date	Realisation date
1	Understanding the risks and benefits of gene-drives for pest control by developing them for invasive wasp species	Impact statement	01/10/2023	30/09/2028	
1.1	Te Whatu Rangahau - Ngā Taonga Tuku Iho	Research aim	01/10/2023	30/09/2028	
1.1.1	Understanding Māori values that underpin decision-making on the use of gene-drives.	Critical step	01/10/2023	30/09/2025	
1.1.2	Understanding how invasive wasps are valued and managed by Māori.	Critical step	01/01/2024	01/01/2026	
1.1.3	Including Te Ao Māori and mātauranga Māori in the development and deployment of gene drives in wasps.	Critical step	01/10/2024	30/09/2027	
1.1.4	Understanding the policy environment for gene technologies in New Zealand.	Critical step	01/10/2024	30/09/2028	
1.1.5	Identifying policy design and enactment necessary for science informed, culturally responsive, ethical policy.	Critical step	01/10/2023	30/09/2025	
1.1.6	Development of a Tiriti led science policy pipeline for the use of gene-drives.	Critical step	01/10/2023	30/09/2028	
1.2	Developing Gene-drive Technologies.	Research aim	01/10/2023	30/09/2027	
1.2.1	Identifying gene-drive targets in wasps.	Critical step	01/10/2023	30/09/2025	
1.2.2	Identifying germ-line promoters in wasps.	Critical step	01/10/2023	30/09/2025	
1.2.3	Testing gene-drive constructs in Nasonia	Critical step	01/10/2023	30/09/2027	

1.2.4	Mid-term evaluation	Critical step	01/08/2026	30/09/2026	
1.3	Deploying Gene-drive Technologies in invasive wasps in containment.	Research aim	01/10/2025	30/09/2027	
1.3.1	Implementing gene-drive technology in Polistes.	Critical step	01/10/2023	30/09/2028	
1.3.2	Implementing gene-drive technologies in Vespid wasps.	Critical step	01/10/2023	30/09/2028	

Impact statement 1

Impact statement 1

Impact statement title
Understanding the risks and benefits of gene-drives for pest control by developing them for invasive wasp species

Impact statement (140 words)
[redacted]

[redacted]

Start date:
01/10/2023

End date:
30/09/2028

Impact statement leader:
[redacted]

Impact statement 1 > Research aim 1.1

Research aim title
Te Whatu Rangahau - Ngā Taonga Tuku Iho

Research aim statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2028

Impact statement 1 > Research aim 1.1 > Critical step 1.1.1

Critical step title
Understanding Māori values that underpin decision-making on the use of gene-drives.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2025

Impact statement 1 > Research aim 1.1 > Critical step 1.1.2

Critical step title
Understanding how invasive wasps are valued and managed by Māori.

Critical step statement (140 words)
[redacted]

Start date:
01/01/2024

End date:
01/01/2026

Impact statement 1 > Research aim 1.1 > Critical step 1.1.3

Critical step title
Including Te Ao Māori and mātauranga Māori in the development and deployment of gene drives in wasps.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2024

End date:
30/09/2027

Impact statement 1 > Research aim 1.1 > Critical step 1.1.4

Critical step title
Understanding the policy environment for gene technologies in New Zealand.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2024

End date:
30/09/2028

Impact statement 1 > Research aim 1.1 > Critical step 1.1.5

Critical step title
Identifying policy design and enactment necessary for science informed, culturally responsive, ethical policy.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2025

Impact statement 1 > Research aim 1.1 > Critical step 1.1.6

Critical step title
Development of a Tiriti led science policy pipeline for the use of gene-drives.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2028

Impact statement 1 > Research aim 1.2

Research aim title
Developing Gene-drive Technologies.

Research aim statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2027

Impact statement 1 > Research aim 1.2 > Critical step 1.2.1

Critical step title
Identifying gene-drive targets in wasps.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2025

Impact statement 1 > Research aim 1.2 > Critical step 1.2.2

Critical step title
Identifying germ-line promoters in wasps.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2025

Impact statement 1 > Research aim 1.2 > Critical step 1.2.3

Critical step title
Testing gene-drive constructs in Nasonia

Critical step statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2027

Impact statement 1 > Research aim 1.2 > Critical step 1.2.4

Critical step title
Mid-term evaluation

Critical step statement (140 words)
[redacted]

Start date:
01/08/2026

End date:
30/09/2026

Impact statement 1 > Research aim 1.3

Research aim title
Deploying Gene-drive Technologies in invasive wasps in containment.

Research aim statement (140 words)
[redacted]

Start date:
01/10/2025

End date:
30/09/2027

Impact statement 1 > Research aim 1.3 > Critical step 1.3.1

Critical step title
Implementing gene-drive technology in Polistes.

Critical step statement (140 words)
[redacted]

Start date:
01/10/2023

End date:
30/09/2028

Impact statement 1 > Research aim 1.3 > Critical step 1.3.2

Critical step title
Implementing gene-drive technologies in Vespid wasps.

Critical step statement (140 words)

[redacted]

Start date:
01/10/2023

End date:
30/09/2028

Research plan, method & specialist resources

Research Plan (560 words)

We aim to understand the risks and benefits of gene-drives for pest control by developing them for invasive wasp species. In this programme we develop gene-drive systems, identify opportunities to include mātauranga Māori and develop a Tiriti-led policy framework. This information to provide cultural authority and fill the gap in our knowledge; **are gene-drives suitable for New Zealand pest management?**

Gene-drives spread infertility or other effects through a population by copying and pasting a gene-drive 'construct' such that all offspring of a carrier inherit it. A diagram of a wasp gene-drive system, compared to normal inheritance, is shown in **Figure 3**.

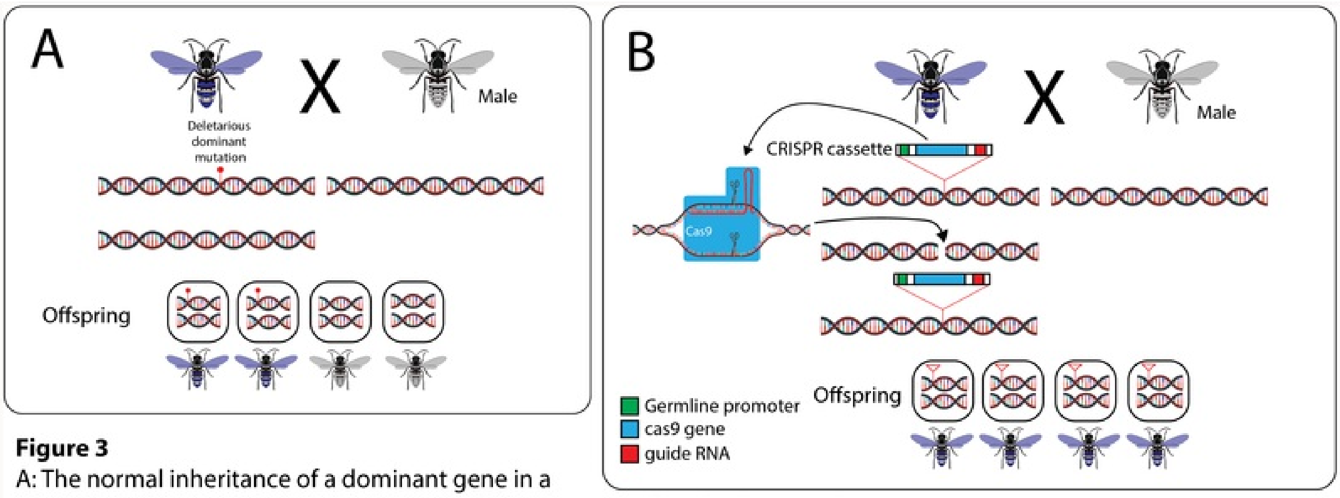

Figure 3
A: The normal inheritance of a dominant gene in a haplodiploid species (males have one set of chromosomes, females have two).
B: Inheritance of a gene drive system. Here a gene drive cassette containing a Cas9 gene and guide RNA that guide it to its site of insertion is inherited by all offspring when the Cas9 gene is activated in the germline.
This ensures the gene drive cassette spreads through the population even if it causes deleterious effects on fertility.

Te Whatu Rangahau - Ngā Taonga Tuku Iho (RA 1.1) builds on previous research into Māori attitudes and acceptability of invasive species control in Aotearoa[1]. In complex conversations such as gene-drives, we need to carry out a deliberative process to understand a diverse range of perspectives of mana whenua. Understanding the values that inform decisions among mana whenua, is crucial to weaving in cultural authority of developing new and novel biological control tools (**CS1.1.1-1.1.3**). With Te Rōpu Kahuwhā and wider mana whenua groups, we will test these findings to understand opportunities to include Te Ao Māori values and mātauranga. We will also define what the boundaries and trade-offs would be with the development and use of gene-drives proposed for example see[12,15,21,22,69,88–98]. This will provide policy analysts with clear recommendations for the use of gene drives in a regulatory environment (**CS1.1.4 – 1.1.6**).

Generating gene-drives in a wasp species (RA 1.2) will require the development of cutting-edge biotechnology tools. To ensure these are developed rapidly we will use a tractable model wasp, *Nasonia*, in which we have considerable experience[46,47], as a test system, and transfer developed technologies to *Polistes* and *Vespula* wasps (**RA1.3**).

During the development of gene-drive technologies, and informed by Te Rōpu Kahuwhā (**RA1**), we will [redacted] Targetting these will allow us to 'personalise' our gene-drive for New Zealand wasps. We will conduct national and international genomic surveys for genetic variation in our three pest wasp species. [redacted]

Having narrowed down acceptable gene-drive mechanisms, using input from Te Rōpu Kahuwhā (**RA1.1**), we will design and test gene-drive systems in *Nasonia*, and test them on small- and medium-scale populations (in containment)(**CS1.2.3**). In **RA1.3 Deploying Gene-drive Technologies in invasive wasps** we will identify those that work and transfer the best technologies to *Polistes*(**CS1.3.1**). Finally, we will transfer the safest and most effective technology to *Vespula* wasps in containment (**CS1.3.2**).

Our technical risks are mitigated by using *Nasonia* as our genetic workhorse, finding technologies that work in this easy-to-rear and contain system, and by drawing on the expertise of our international advisors.

Methods (1680 words)

[redacted]

[redacted]

[redacted]

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[redacted]

Specialist Resources (560 words)

Insects and Insect rearing

This project critically depends on access to the four key insect species and rearing them in the lab. Both the Dearden and [redacted] labs have experience in culturing and manipulating all four species of wasp from this project and collecting new colonies from the environment. *Nasonia* culture is routine in the Dearden Lab. *Polistes* culture is relatively straightforward, and both labs have grown *Polistes* in containment. Growth of *Vespula* species is more difficult, but effective culture conditions, and ways of closing the life cycle in the lab, have been developed in the [redacted] Lab.

High-Performance Computing and Genomic data

The Dearden and [redacted] labs have produced high-quality genome sequences for both *Vespula* species[45], and this data is available for this research programme (and indeed international open access). A draft *Polistes* genome is available internationally, and the Dearden lab has recently upgraded this to a high-quality assembly and re-annotated it to improve its usefulness. This information will eventually be made open access but is currently available to this programme through the Dearden lab.

High-performance computing to support the population genomics work in this project will be provided by the University of Otago either through bespoke servers at the Department of Biochemistry or through the National eScience Infrastructure (NeSI). The tools for analysing this data are being developed by Genomics Aotearoa through their high-quality genomes project and are available containerised for use from the Genomics Aotearoa GitHub site or Docker/Singularity repositories.

Biotron

Testing the efficacy of gene-drives on a larger scale may require access to larger containment facilities than available at the University of Otago. We will use the NZ Biotron sited at Lincoln University, which has the space and containment requirements for these experiments. Costs for the use of this facility are factored into the programme budget. Access to the Biotron is available through the Department of Agricultural Science, Lincoln University, and is a part of the [redacted] CoRE infrastructure directed by [redacted].

Microinjection

Transformation of insects usually requires microinjection. Microinjection facilities are specialised for insect microinjection. Appropriate facilities for both adult and embryo injection are available at the University of Otago and can be moved into containment for the generation of transgenic insects.

Covid restrictions

If Coronavirus regulations are active during this programme then we have all the capabilities required for video-conferencing such that national and international collaboration will not be affected. Workshops and meetings with Māori participants in the work will need to be Kanohi ki te kanohi producing some risk if the pandemic intensifies. If international staff are hired we will seek to support their immigration as essential workers. We have routinely carried out lab work at Level 3 and Red level and Peter Dearden is classed as an essential worker for the University of Otago to maintain animal rearing if Level 4 restrictions apply.

Funding requested

Impact statement funding

Understanding the risks and benefits of gene-drives for pest control by developing them for invasive wasp species

Start date	Months	Funding			Total annual funding
01/10/2023	12	$1,984,789.00 GST excl. amount	$297,718.35 GST amount	$2,282,507.35 Total amount	$2,282,507.35
01/10/2024	12	$1,984,789.00 GST excl. amount	$297,718.35 GST amount	$2,282,507.35 Total amount	$2,282,507.35
01/10/2025	12	$1,984,789.00 GST excl. amount	$297,718.35 GST amount	$2,282,507.35 Total amount	$2,282,507.35
01/10/2026	12	$1,984,789.00 GST excl. amount	$297,718.35 GST amount	$2,282,507.35 Total amount	$2,282,507.35
01/10/2027	12	$1,984,789.00 GST excl. amount	$297,718.35 GST amount	$2,282,507.35 Total amount	$2,282,507.35
	Total:	$9,923,945.00 GST excl. amount	$1,488,591.75 GST amount	$11,412,536.75 Total amount	**$11,412,536.75**

Project budget

[redacted]

Additional budget information

Project team

Year 1 FTE figures

Name	Organisation	Role	Include CV in print	IS 1
Peter Dearden	University of Otago	Key researcher, Science leader	✔	0.30
[redacted]	Lincoln University	Key researcher, Leader	✔	0.15
[redacted]	Victoria University of Wellington	Key researcher	✔	0.15
[redacted]	University of York	Key individual	✔	0.05
[redacted]	North Carolina State University	Key individual	✔	0.05
[redacted]	Te Tira Whakamātaki	Key individual	✔	0.15
[redacted]	Plant and Food Research	Key individual	✔	0.05
[redacted]	Predator Free 2050 Ltd	Key individual	✔	0.05
[redacted]	EPA	Key individual	✔	0.05
[redacted]	Environmental Protection Agency	Key individual	✔	0.05
Post-doctoral Fellow 1 (Otago)	University of Otago	Post-doctoral researcher		1.00
[redacted]	University of Otago	Post-doctoral researcher		1.00
Post-Doctoral Fellow 2	Victoria University of Wellington	Post-doctoral researcher		1.00
Post-Doctoral Fellow 3	Lincoln University	Post-doctoral researcher		1.00
[redacted]	Lincoln University	Student		1.00
PhD student (TBA)	Victoria University of Wellington	Student		1.00

Programme Manager	University of Otago	Other		0.50
[redacted]	University of Otago	Contract manager		0.00
			Sub total	**7.55**

Year 2 FTE figures

Name	Organisation	Role	Include CV in print	IS 1
Peter Dearden	University of Otago	Key researcher, Science leader	✔	0.30
[redacted]	Lincoln University	Key researcher, Leader	✔	0.15
[redacted]	Victoria University of Wellington	Key researcher	✔	0.15
[redacted]	University of York	Key individual	✔	0.05
[redacted]	North Carolina State University	Key individual	✔	0.05
[redacted]	Te Tira Whakamātaki	Key individual	✔	0.15
[redacted]	Plant and Food Research	Key individual	✔	0.05
[redacted]	Predator Free 2050 Ltd	Key individual	✔	0.05
[redacted]	EPA	Key individual	✔	0.05
[redacted]	Environmental Protection Agency	Key individual	✔	0.05
Post-doctoral Fellow 1 (Otago)	University of Otago	Post-doctoral researcher		1.00
[redacted]	University of Otago	Post-doctoral researcher		1.00
Post-Doctoral Fellow 2	Victoria University of Wellington	Post-doctoral researcher		1.00

Post-Doctoral Fellow 3	Lincoln University	Post-doctoral researcher		1.00
[redacted]	Lincoln University	Student		1.00
PhD student (TBA)	Victoria University of Wellington	Student		1.00
[redacted]	University of Otago	Contract manager		0.00
Programme Manager	University of Otago	Other		0.50
			Sub total	**7.55**

Year 3 FTE figures

Name	**Organisation**	**Role**	**Include CV in print**	**IS 1**
Peter Dearden	University of Otago	Key researcher, Science leader	✔	0.30
[redacted]	Lincoln University	Key researcher, Leader	✔	0.15
[redacted]	Victoria University of Wellington	Key researcher	✔	0.15
[redacted]	University of York	Key individual	✔	0.05
[redacted]	North Carolina State University	Key individual	✔	0.05
[redacted]	Te Tira Whakamātaki	Key individual	✔	0.15
[redacted]	Plant and Food Research	Key individual	✔	0.05
[redacted]	Predator Free 2050 Ltd	Key individual	✔	0.05
[redacted]	EPA	Key individual	✔	0.05
[redacted]	Environmental Protection Agency	Key individual	✔	0.05

Post-doctoral Fellow 1 (Otago)	University of Otago	Post-doctoral researcher		1.00
[redacted]	University of Otago	Post-doctoral researcher		1.00
Post-Doctoral Fellow 2	Victoria University of Wellington	Post-doctoral researcher		1.00
Post-Doctoral Fellow 3	Lincoln University	Post-doctoral researcher		1.00
[redacted]	Lincoln University	Student		1.00
PhD student (TBA)	Victoria University of Wellington	Student		1.00
[redacted]	University of Otago	Contract manager		0.00
Programme Manager	University of Otago	Other		0.50
			Sub total	**7.55**

Year 4 FTE figures

Name	Organisation	Role	Include CV in print	IS 1
Peter Dearden	University of Otago	Key researcher, Science leader	✔	0.30
[redacted]	Lincoln University	Key researcher, Leader	✔	0.15
[redacted]	Victoria University of Wellington	Key researcher	✔	0.15
[redacted]	University of York	Key individual	✔	0.05
[redacted]	North Carolina State University	Key individual	✔	0.05
[redacted]	Te Tira Whakamātaki	Key individual	✔	0.15
[redacted]	Plant and Food Research	Key individual	✔	0.05

[redacted]	Predator Free 2050 Ltd	Key individual	✔	0.05
[redacted]	EPA	Key individual	✔	0.05
[redacted]	Environmental Protection Agency	Key individual	✔	0.05
Post-doctoral Fellow 1 (Otago)	University of Otago	Post-doctoral researcher		1.00
[redacted]	University of Otago	Post-doctoral researcher		1.00
Post-Doctoral Fellow 2	Victoria University of Wellington	Post-doctoral researcher		1.00
Post-Doctoral Fellow 3	Lincoln University	Post-doctoral researcher		1.00
[redacted]	Lincoln University	Student		1.00
PhD student (TBA)	Victoria University of Wellington	Student		1.00
[redacted]	University of Otago	Contract manager		0.00
Programme Manager	University of Otago	Other		0.50
			Sub total	**7.55**

Year 5 FTE figures

Name	Organisation	Role	Include CV in print	IS 1
Peter Dearden	University of Otago	Key researcher, Science leader	✔	0.30
[redacted]	Lincoln University	Key researcher, Leader	✔	0.15
[redacted]	Victoria University of Wellington	Key researcher	✔	0.15
[redacted]	University of York	Key individual	✔	0.05

[redacted]	North Carolina State University	Key individual	✔	0.05
[redacted]	Te Tira Whakamātaki	Key individual	✔	0.15
[redacted]	Plant and Food Research	Key individual	✔	0.05
[redacted]	Predator Free 2050 Ltd	Key individual	✔	0.05
[redacted]	EPA	Key individual	✔	0.05
[redacted]	Environmental Protection Agency	Key individual	✔	0.05
Post-doctoral Fellow 1 (Otago)	University of Otago	Post-doctoral researcher		1.00
[redacted]	University of Otago	Post-doctoral researcher		1.00
Post-Doctoral Fellow 2	Victoria University of Wellington	Post-doctoral researcher		1.00
Post-Doctoral Fellow 3	Lincoln University	Post-doctoral researcher		1.00
[redacted]	Lincoln University	Student		1.00
PhD student (TBA)	Victoria University of Wellington	Student		1.00
[redacted]	University of Otago	Contract manager		0.00
Programme Manager	University of Otago	Other		0.50
			Sub total	**7.55**

Key relationships

End users

Impact statements in your application

Number	Title
IS 1	Understanding the risks and benefits of gene-drives for pest control by developing them for invasive wasp species

Organisation	IS 1
Ministry for the Environment	✔
Environmental Protection Authority	✔
Ministry for Primary Industries (MPI)	✔
Parliamentary Commissioner for the Environment	✔
Department of Conservation	✔
Regional Councils	✔

International collaborations/partnerships

Organisation	Organisation country:	Researcher/project name:
[redacted]	United States of America (the)	[redacted]
[redacted]	United Kingdom of Great Britain and Northern Ireland (the)	[redacted]
[redacted]	United States of America (the)	[redacted]

We will build relationships with [redacted] and his lab as the world-leading centre on Nasonia genetics. We will share technologies with this group, ensuring that we are connected to the development of new GM technologies for this species, and able to bring them to New Zealand.

Our international advisors [redacted] will provide information on the international best practice around gene-drives, and keep us informed of the progress of other experiments in this area. We expect to integrate their advice into our research teams, via multiple VC meetings through the program, and through exchange visits to each other's labs (including the PhD and postdoctoral researchers). [redacted] are outstanding researchers in this area and this programme will ensure New Zealand has continued access to their expertise. [redacted]

If you have excluded co-funding from consideration in your research, tell us why.

The aim of this project is to fill a knowledge gap in our understanding of the potential use for gene drives in New Zealand. As such knowledge must be independent and transparent, and more importantly, seen to be independent, we feel that co-funding for this project is not appropriate.

Subcontracting

Impact statement

Understanding the risks and benefits of gene-drives for pest control by developing them for invasive wasp species

Subcontracting organisation:	Subcontracting status:	Year 1	Year 2	Year 3	Year 4	Year 5
[redacted]						
[redacted]						
[redacted]						
[redacted]						
[redacted]						
	[redacted]					

Supporting information

Intellectual property management

(560 words)

The key outcomes of the programme are the cultural agency to use gene-drives and data that support public discussion about gene-drives and their use. To deliver non-biased, independent, accessible data and advice, the normal routes to commercialisation, involving either patenting or commercial secrecy must be avoided. The researchers involved should not have a financial stake in the project. We commit to publication in open access journals and open access to the data generated in this project such that it can be used to inform the debate.

The science team will be supported by University of Otago's Research & Enterprise Office and Otago Innovation Limited, Lincoln University Research Office, Wellington UniVentures and the Research Development Office at Victoria University of Wellington, who will provide ongoing strategic advice with respect to the management of confidential information, IP management and ways to ensure open access to our data and technologies.

IP management principles:

Prior to the commencement of this project, an IP Advisory Group will be established, comprising representatives of all research partners. In addition to these, independent, external advisors with expertise in IP management and knowledge transfer will be provided for ongoing consultation.

The roles of this committee are to: provide oversight on the development of IP (including from an indigenous knowledge perspective); protect the mātauranga Māori used in this project and meet regularly to review the activities and IP management; and ensure that any new IP generated is leveraged so as to ensure benefits to New Zealand.

The research teams already has, and will continue to, implemented Cultural Authority Agreements to ensure that all research and research outcomes and their use in relation to this programme are agreed upon by all involved and affected parties.

All Intellectual Property will be managed by the University of Otago, in collaboration with the research partners and the IP advisory group. The parties will maintain a register for all background and new Intellectual Property in relation to the project. The parties will meet as required but no less than twice a year to review all IP activities.

Should any new IP be commercialised, the parties agree that management of commercialisation will be led, in collaboration with all partners, by the party that is in the best position to do so.

All background IP brought to the project, including Mātauranga Māori, will continue to belong to the respective collaborative partners who created it.
Background IP of relevance to the project shall be made available for use in the project research and for non-commercial purposes.

Any application of rights must be consistent with the MBIE requirement that, as it is investing on behalf of NZ, the IP must be made available to end-users in NZ.

Special ethical and regulatory requirements

(280 words)

Development of gene-edited or transgenic *Nasonia*, *Vespula* or *Polistes* wasps in containment will require permission from the Environmental Protection Agency. We have applied for that permission through the University of Otago Institutional Biological Safety Committee, and received permission for *Nasonia* at this time. We expect permission for *Polistes* and *Vespula* will take some months to be approved. Costs for those applications have already been met.

Initial experiments will be carried out in an already-built insect facility in the Biochemistry Department University of Otago. This facility, while currently PC2 invertebrate containment, is built to PC3 standard and can be upgraded depending on the ruling of the EPA. Larger scale experiments will be carried out at the Biotron at Lincoln University.

Proposal Glossary

Your glossary should not exceed two sides of an A4 page. Do not include references, hyperlinks or images.	
Word/acronym / abbreviation/te reo Māori	**Full description/translation**
Allele	A genetic variant
Apiculture	Beekeeping
BHNSC	Biological Heritage National Science Challenge
Common Wasp	Vespid social wasp invasive to New Zealand (*Vespula vulgaris*)
Containment	Held in an EPA and MAF approved containment facility
Diploid	Containing two sets of chromosomes
DOC	Department of Conservation
EPA	The Environmental Protection Agency
Gene-drives	Genetic technologies that can drive an inserted piece of DNA through a population, even if that DNA causes deleterious effects to the organism (eg reduced fertility)
Gene-editing	A technology developed to make targeted mutations or insertions in the DNA of a live organism. Gene-editing uses Cas9 enzyme and guide RNAs to cause to double-strand break in DNA at a specific location
Genetically modified (GM)	A general term for an organism whose DNA has been experimentally modified in a heritable way
German Wasp	Vespid social wasp invasive to New Zealand (*Vespula germanica*)
Haplodiploid	Description of the situation where males and females have different ploidy. Usually males are haploid and females are diploid
Haploid	Containing one set of chromosomes
hapū	A division of a Māori people or community.
heterozygous	Containing one copy of a modified allele
homozygous	Containing two copies of a modified allele
IBSC	Institutional Biological Safety Committee
Iwi	"People" or "nation", and is often translated as "tribe", or "a confederation of tribes"
Kaupapa Māori	Principles and ideas which act as a base or foundation for action. A kaupapa is a set of values, principles and plans which people have agreed on as a foundation for their actions.
Kawa	Māori cultural practices
Mātauranga Māori	A Māori way of being and engaging in the world using kawa (cultural practices) and tikanga (cultural principles) to understand the world.
MBIE	Ministry of Business Innovation and Employment
MPI	Ministry of Primary Industries
Nasonia vitripennis	A parasitic haplodiploid wasp used extensively in fundamental genetics research
NeSI	National E-science Infrastructure
Polistes	Polistine social wasp, often called paper wasps, invasive to New

	Zealand. New Zealand has three introduced, invasive paper wasp species, *Polistes dominula*, *P. chinensis* and *P. humilis.*
Private alleles	Genetic variants found in only some subset of a population of organisms
ReMOT-control Crispr	A newly discovered technique that uses a yolk protein to transport Cas9 and guide RNA to the ovary where gene editing occurs on eggs and oocytes, thus modifying the next generation
RSNZ	Royal Society Te Apārangi
Taiao	World, Earth, natural world, environment, nature, country.
Tikanga	Māori cultural principles
Transformation	The process by which an organism becomes Genetically modified
Transgenesis	making an organism containing an inserted piece of DNA
Vision Mātauranga (VM)	An MBIE policy that aims to unlock the innovation potential of Māori knowledge, resources and people to assist New Zealanders to create a better future
VUW	Victoria University of Wellington

[redacted]
10. Esvelt, K. M., Smidler, A. L., Catteruccia, F. & Church, G. M. Concerning RNA-guided gene drives for the alteration of wild populations. *Elife* **3**, e03401 (2014).
11. Gantz, V. M. & Bier, E. Genome editing. The mutagenic chain reaction: a method for converting heterozygous to homozygous mutations. *Science* **348**, 442–4 (2015).
12. Gantz, V. M. *et al.* Highly efficient Cas9-mediated gene drive for population modification of the malaria vector mosquito Anopheles stephensi. *Proc. Natl. Acad. Sci.* **112**, E6736–E6743 (2015).
13. Noble, C., Olejarz, J., Esvelt, K. M., Church, G. M. & Nowak, M. A. Evolutionary dynamics of CRISPR gene drives. *Sci. Adv.* **3**, e1601964 (2017).
14. Unckless, R. L., Clark, A. G. & Messer, P. W. Evolution of resistance against CRISPR/Cas9 gene drive. *Genetics* **205**, 827–841 (2017).
15. Windbichler, N. *et al.* A synthetic homing endonuclease-based gene drive system in the human malaria mosquito. *Nature* **473**, 212 (2011).
[redacted]
17. National Academies of Sciences, E. & Medicine. *Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty, and Aligning Research with Public Values*. (The National Academies Press, 2016).
18. Kathlene, L., Munshi, D., Kurian, P. & Morrison, S. L. Cultures in the laboratory: mapping similarities and differences between Māori and non-Māori in engaging with gene-editing technologies in Aotearoa, New Zealand. *Humanit. Soc. Sci. Commun.* **9**, 100 (2022).
19. Grunwald, H. A. *et al.* Super-Mendelian inheritance mediated by CRISPR–Cas9 in the female mouse germline. *Nature* **566**, 105–109 (2019).
20. Min, J., Noble, C., Najjar, D. & Esvelt, K.M. Daisyfield gene drive systems harness repeated genomic elements as a generational clock to limit spread. *BioRxiv*, 104877 (2017).
21. Yan, Y. & Finnigan, G. C. Development of a multi-locus CRISPR gene drive system in budding yeast. *Sci. Rep.* **8**, 17277 (2018).
22. Buchman, A., Marshall, J. M., Ostrovski, D., Yang, T. & Akbari, O. S. Synthetically engineered Medea gene drive system in the worldwide crop pest *Drosophila suzukii*. *Proc. Natl. Acad. Sci.* **115**, 4725–4730 (2018).

23. Adolfi, A. *et al.* Efficient population modification gene-drive rescue system in the malaria mosquito Anopheles stephensi. *Nat. Commun.* **11**, 1–13 (2020).
24. Beggs, J. The ecological consequences of social wasps (Vespula spp.) invading an ecosystem that has an abundant carbohydrate resource. *Biol. Conserv.* **99**, 17–28 (2001).
25. Clapperton, B. K., Alspach, P. A., Moller, H. & Matheson, A. G. The impact of common and German wasps (Hymenoptera: Vespidae) on the New Zealand beekeeping industry. *N. Z. J. Zool.* **16**, 325–332 (1989).
[redacted]
27. Ministry of Primary Industries. European Paper Wasp. (2016).
28. Ridout, A. Scientists hunt down a Nelson invader with a sting in its tail. *The Nelson Mail* (2018).
29. iNaturalistNZ. European Paper Wasp. (2023).
30. de la Filia, A. G., Bain, S. A. & Ross, L. Haplodiploidy and the reproductive ecology of Arthropods. *Curr. Opin. Insect Sci.* **9**, 36–43 (2015).
[redacted]
32. Li, J. *et al.* Can CRISPR gene drive work in pest and beneficial haplodiploid species? *Evol. Appl.* **13**, 2392–2403 (2020).
33. Liu, Y. & Champer, J. Modelling homing suppression gene drive in haplodiploid organisms. *Proc. R. Soc. B* **289**, 20220320 (2022).
34. Werren, J. H. & Loehlin, D. W. The parasitoid wasp *Nasonia*: an emerging model system with haploid male genetics. *Cold Spring Harb. Protoc.* **2009**, pdb. emo134 (2009).
35. Beukeboom, L. & Desplan, C. Nasonia. *Curr. Biol.* **13**, R860 (2003).
36. Lynch, J. A. The expanding genetic toolbox of the wasp *Nasonia vitripennis* and its relatives. *Genetics* **199**, 897–904 (2015).
37. Chaverra-Rodriguez, D. *et al.* Targeted delivery of CRISPR-Cas9 ribonucleoprotein into arthropod ovaries for heritable germline gene editing. *Nat. Commun.* **9**, 1–11 (2018).
38. Li, M. *et al.* Generation of heritable germline mutations in the jewel wasp *Nasonia vitripennis* using CRISPR/Cas9. *Sci. Rep.* **7**, 1–7 (2017).
39. Li, M., Bui, M. & Akbari, O. S. Embryo microinjection and transplantation technique for *Nasonia vitripennis* genome manipulation. *JoVE J. Vis. Exp.* e56990 (2017).
40. Sudweeks, J. *et al.* Locally Fixed Alleles: A method to localize gene drive to island populations. *Sci. Rep.* **9**, 1–10 (2019).
41. Roth, A. *et al.* A genetic switch for worker nutrition-mediated traits in honeybees. *PLoS Biol.* **17**, (2019).
42. Chaverra-Rodriguez, D. *et al.* Germline mutagenesis of *Nasonia vitripennis* through ovarian delivery of CRISPR-Cas9 ribonucleoprotein. *Insect Mol. Biol.* **29**, 569–577 (2020).
43. Duncan, E. J., Hyink, O. & Dearden, P. K. Notch signalling mediates reproductive constraint in the adult worker honeybee. *Nat. Commun.* **7**, 12427 (2016).
44. Duncan, E. J., Leask, M. P. & Dearden, P. K. Genome Architecture Facilitates Phenotypic Plasticity in the Honeybee (*Apis mellifera*). *Mol. Biol. Evol.* **37**, 1964–1978 (2020).
[redacted]
46. Taylor, S. E. & Dearden, P. K. The *Nasonia* pair-rule gene regulatory network retains its function over 300 million years of evolution. *Development* **149**, dev199632 (2022).
47. Taylor, S. E. *et al.* The *torso-like* gene functions to maintain the structure of the vitelline membrane in *Nasonia vitripennis* , implying its co-option into *Drosophila* axis formation. *Biol. Open* bio.046284 (2019) doi:10.1242/bio.046284.
48. Duncan, E. J., Benton, M. A. & Dearden, P. K. Canonical terminal patterning is an evolutionary novelty. *Dev. Biol.* **377**, 245–261 (2013).
49. Karunaraj, P. *et al.* Noggin proteins are multifunctional extracellular regulators of cell

signaling. *Genetics* **221**, iyac049 (2022).
50. Chang, C., Dearden, P. & Akam, M. Germ Line Development in the Grasshopper *Schistocerca gregaria*: *vasa* As a Marker. *Dev. Biol.* **252**, 100–118 (2002).
51. Dearden, P. Germ cell development in the Honeybee (*Apis mellifera*); *Vasa* and *Nanos* expression. *BMC Dev. Biol.* **6**, 6 (2006).
52. Dearden, P. K., Grbic, M. & Donly, C. *Vasa* expression and Germ Cell Specification in the Spider mite *Tetranychus urticae*. *Dev. Genes Evol.* **212**, 599–603 (2003).
53. International Aphid Genomics Consortium (include P. K. Dearden). Genome sequence of the pea aphid Acyrthosiphon pisum. *PLoS Biol.* **8**, e1000313 (2010).
54. The Honey Bee Genome Sequencing Consortium. Insights into social insects from the genome of the honeybee *Apis mellifera*. *Nature* **443**, 931–949 (2006).
55. Chipman, A. D. *et al.* The First Myriapod Genome Sequence Reveals Conservative Arthropod Gene Content and Genome Organisation in the Centipede Strigamia maritima. *PLoS Biol.* **12**, e1002005 (2014).
56. Royal Society Te Aparangi Gene editing panel. *Gene Editing in Pest Control*. (2019).

[redacted]

70. MacIntyre, P. & Hellstrom, J. An evaluation of the costs of pest wasps (Vespula species) in New Zealand. *Int Pest Control* **57**, 162–163 (2015).
71. Brown, P. *Report on the 2022 New Zealand Colony Loss Survey*. (2022).
72. Richter, M. R. Social wasp (Hymenoptera: Vespidae) foraging behavior. *Annu. Rev. Entomol.* **45**, 121–150 (2000).

73. Harris, R. J. Diet of the wasps *Vespula vulgaris* and *V. germanica* in honeydew beech forest of the South Island, New Zealand. *N. Z. J. Zool.* **18**, 159–169 (1991).
74. McGruddy, R. A. *et al.* Invasive paper wasps have strong cascading effects on the host plant of monarch butterflies. *Ecol. Entomol.* **46**, 459–469 (2021).
75. Howse, M. W. *et al.* The native and exotic prey community of two invasive paper wasps (Hymenoptera: Vespidae) in New Zealand as determined by DNA barcoding. *Biol. Invasions* **24**, 1797–1808 (2022).
76. McGruddy, R., Howse, M. W., Haywood, J., Toft, R. J. & Lester, P. J. Nesting ecology and colony survival of two invasive *Polistes* wasps (Hymenoptera: Vespidae) in New Zealand. *Environ. Entomol.* **50**, 1466–1473 (2021).
77. Cranshaw, W. S., Larsen, H. J. & Zimmerman, R. J. Notes on Fruit Damage by the European Paper Wasp, *Polistes dominula*(Christ) (Hymenoptera: Vespidae). *Southwest. Entomol.* **36**, 103–105, 3 (2011).
[redacted]
79. Goldson, S. L. *et al.* New Zealand pest management: current and future challenges. *J. R. Soc. N. Z.* **45**, 31–58 (2015).
80. Diagne, C. *et al.* High and rising economic costs of biological invasions worldwide. *Nature* **592**, 571–576 (2021).
81. Swetlitz, I. In a remote West African village, a revolutionary genetic experiment is on its way — if residents agree to it. *STAT* (2017).
82. Esvelt, K. M. & Gemmell, N. J. Conservation demands safe gene drive. *PLoS Biol.* **15**, e2003850 (2017).
83. Moylan, S. He kete hauora taiao: A Bicultural Ecological Assessment Framework. (2021).
84. Burt, A. Site-specific selfish genes as tools for the control and genetic engineering of natural populations. *Proc Biol Sci* **270**, 921–8 (2003).
85. Petersen, G. E. L. *et al.* Genotyping-by-sequencing of pooled drone DNA for the management of living honeybee (*Apis mellifera*) queens in commercial beekeeping operations in New Zealand. *Apidologie* **51**, 545–556 (2020).
86. Petersen, G. E. L., Fennessy, P. F., Amer, P. R. & Dearden, P. K. Designing and implementing a genetic improvement program in commercial beekeeping operations. *J. Apic. Res.* **59**, 638–647 (2020).
87. Inwood, S.N., *et al.* Opportunities for modern genetic technologies to maintain and enhance Aotearoa New Zealand's bioheritage. *N. Z. J. Ecol.* **44**, (2020).
88. Gantz, V. M. & Bier, E. The mutagenic chain reaction: a method for converting heterozygous to homozygous mutations. *Science* **348**, 442–444 (2015).
89. Chae, D. *et al.* Chemical controllable gene drive in *Drosophila*. *ACS Synth. Biol.* **9**, 2362–2377 (2020).
90. Champer, J. *et al.* A CRISPR homing gene drive targeting a haplolethal gene removes resistance alleles and successfully spreads through a cage population. *Proc. Natl. Acad. Sci.* **117**, 24377–24383 (2020).
91. Champer, S. E. *et al.* Computational and experimental performance of CRISPR homing gene drive strategies with multiplexed gRNAs. *Sci. Adv.* **6**, eaaz0525 (2020).
92. Del Amo, V. L. *et al.* A transcomplementing gene drive provides a flexible platform for laboratory investigation and potential field deployment. *Nat. Commun.* **11**, 352 (2020).
93. Del Amo, V. *et al.* Small-molecule control of super-Mendelian inheritance in gene drives. *bioRxiv* 665620 (2019).
94. Dhole, S., Lloyd, A. L. & Gould, F. Tethered homing gene drives: a new design for spatially restricted population replacement and suppression. *Evol. Appl.* **12**, 1688–1702 (2019).
95. Dhole, S., Vella, M. R., Lloyd, A. L. & Gould, F. Invasion and migration of spatially self-limiting gene drives: A comparative analysis. *Evol. Appl.* **11**, 794–808 (2018).
96. Kandul, N. P. *et al.* Assessment of a split homing based gene drive for efficient knockout of multiple genes. *G3 Genes Genomes Genet.* **10**, 827–837 (2020).

97. Noble, C. *et al.* Daisy-chain gene drives for the alteration of local populations. *Proc. Natl. Acad. Sci.* **116**, 8275–8282 (2019).
98. Prowse, T. A., Adikusuma, F., Cassey, P., Thomas, P. & Ross, J. V. A Y-chromosome shredding gene drive for controlling pest vertebrate populations. *Elife* **8**, e41873 (2019).
99. Dance, A. Core Concept: CRISPR gene editing. *Proc. Natl. Acad. Sci.* **112**, 6245–6246 (2015).
100. Li, Z. et al. Identification of transcription factor binding sites using ATAC-seq. Genome Biol. 20, 1–21 (2019).
101. Bentsen, M. et al. ATAC-seq footprinting unravels kinetics of transcription factor binding during zygotic genome activation. Nat. Commun. 11, 4267 (2020).
102. Karabacak Calviello, A., Hirsekorn, A., Wurmus, R., Yusuf, D. & Ohler, U. Reproducible inference of transcription factor footprints in ATAC-seq and DNase-seq datasets using protocol-specific bias modeling. Genome Biol. 20, 1–13 (2019).
103. Wilson, M. J., Havler, M. & Dearden, P. K. *Giant*, *Krüppel*, and *caudal* act as gap genes with extensive roles in patterning the honeybee embryo. *Dev. Biol.* **339**, 200–211 (2010).
104. Champer, J. *et al.* A toxin-antidote CRISPR gene drive system for regional population modification. *Nat. Commun.* **11**, 1–10 (2020).
105. Dearden, P. K., Duncan, E. J. & Wilson, M. J. RNA interference (RNAi) in honeybee (*Apis mellifera*) embryos. *Cold Spring Harb Protoc* **2009**, pdb prot5228 (2009)

Classifications