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Views of conservation volunteers and environmental specialists on genetic technologies for pest control in Aotearoa New Zealand

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Pests such as invasive exotic wasps and rats are a serious threat to Aotearoa New Zealand's native species, and the country has been working toward the New Zealand government's target of eliminating rats, possums, and mustelids by 2050. Since current control methods lack the efficiency and scalability to eradicate mammalian predators and pest invertebrates like wasps, gene technologies are being considered and developed as additional methods of control. Social studies to gauge public perceptions on these novel technologies have also been conducted, with a strong emphasis on Indigenous viewpoints and the importance of societal compacts, particularly Te Tiriti o Waitangi (Treaty of Waitangi). Conservation volunteers and environmental specialists are uniquely experienced and positioned to inform decisions on which technologies are developed and how, but 1) what are their views on genetic technologies for pest control and 2) how do they expect gene technology for pest control to be discussed and developed? To help answer these two questions, we conducted a new analysis of a dataset of 8,199 nationwide survey responses, 23 in-depth surveys of wasp control volunteers, and 18 interviews with rat and wasp control volunteers and environmental experts, using Q-methodology. All of the conservation volunteers, scientists, academics, and environmental professionals expect that risks associated with the technology are carefully and fully identified and mitigated against. A majority cautiously supports gene technologies for their potential to more effectively control pests. A significant minority supports gene technologies for pest control under certain conditions, most significantly if Māori as Tiriti partners are also supportive. A smaller minority has doubts and concerns about gene technologies for pest control and raises important considerations for scientists and policy-makers alike. Addressing all of these concerns, supported by Tiriti-based decision-making processes, will facilitate consensus-based discussions and decisions on genetic technology use.

KEYWORDS

pest control, volunteers, environmentalists, Māori, genetic technologies, Q-methodology, wasps, rats

Introduction

Ship rats (*Rattus rattus*) and Norway rats (*Rattus norvegicus*) were introduced to Aotearoa at the time of European settlement in the 1800s and are widespread in mainland Aotearoa. Rats eat bird eggs and chicks and substantially reduce the population survival of many native birds. Elimination efforts that create safe havens have been critical for ensuring the survival of some taonga (treasured, native) species. Rats have successfully been eradicated from some small offshore islands and mainland eco-sanctuaries (Innes et al., 2023) and more recently an urban peninsula (Motukairangi-Miramar) in the capital city Wellington. This rat elimination work has involved coordinated effort, countless volunteer hours, and ongoing community vigilance to prevent reinvasion. To scale the positive effects of this pest control on the mainland islands, in 2016, the government instituted the target of a Predator-Free New Zealand (PF2050) by the year 2050 (Predator Free 2050 Ltd, 2018). This seeks the eradication of rats, possums, and mustelids, which also predate on native birds and consume their food sources.

Introduced invertebrates are not included in this nationwide eradication attempt, but some are arguably as damaging to native environments. German (*Vespula germanica*) and common (*Vespula vulgaris*) wasps were accidentally introduced to Aotearoa in the 20th century. As "New Zealand's most abundant, widespread and damaging pest" (Lester et al., 2013:56), *Vespula* wasps compete with taonga species by feeding on honeydew and consuming vast quantities of insects (Lester and Beggs, 2019). Vespex® (containing the poison fipronil) is a highly targeted wasp bait and is currently the primary and most effective wasp control measure in Aotearoa (Lester and Beggs, 2019). The application of Vespex® is limited however, requiring user certification and being labor-intensive, weather-dependent, seasonal, and impractical for use over large areas (Lester et al., 2013). According to unpublished records, thousands of volunteers play a crucial role in Vespex® field operations each summer. Despite these biosecurity efforts and strong aspirations of local communities for wasp eradication (Howse et al., 2024), wasps continue to degrade te taiao (the natural environment), as well as hampering the work of conservation workers and volunteers (Palmer and Mercier, 2021) in dealing with other pests. Pest inundation also erodes the relationship between te taiao and Māori people as kaitiaki (environmental guardians) (Waitangi Tribunal, 2011; Black et al., 2019).

PF2050 is likely to be "unachievable with current or even near-future technologies" (Linklater and Steer, 2018:2) and therefore requires a "breakthrough science solution" (Predator Free 2050 Ltd, 2018:29). Could that breakthrough involve genetic technologies (gene tech), which are highly targeted and, in theory, have the potential to self-propagate at landscape scale? Scientific research is under way in Aotearoa to answer that question, developing gene tech for pest control, in tandem with social research into peoples' perspectives on and expectations of gene tech. For instance, PF2050 Ltd and Genomics Aotearoa are funding researchers to experiment with techniques that could produce population suppression in rats, through single-sex offspring selection (SSOS). The National Science Challenge: BioHeritage "Novel tools, technologies & strategies" team experimented with gene drive to control exotic wasps (Dearden et al., 2018). Uniquely, both research programs include teams of Māori social scientists, who are contributing social, cultural, and political considerations to technological developments (Palmer et al., 2022).

Gene drive as described by Palmer and Mercier (2021) is a genetic modification (GM) that is inherited by all offspring. Rather than following typical Mendelian inheritance, all offspring inherit the modified gene from the modified parent. In the case of rats, SSOS could be achieved by copying an existing, naturally occurring gene complex, referred to as the "t complex," from mice to Norway rats, or through the use of the CRISPR gene drive (Leitschuh et al., 2018). Gene drive could be used to rapidly spread a gene that suppresses female fertility throughout a population (Dearden et al., 2018). Similarly, SSOS could tip the rat population balance increasingly male, decreasing the likelihood of generational procreation (Leitschuh et al., 2018).

Responsible science also involves the public in discussions regarding the development of new technologies (Royal Society Te Apārangi, 2019). Conversations regarding if, when, and how new gene tech is used in conservation should be started early, allowing "interested communities and conservationists [to] help guide the development of local drive systems" (Esvelt and Gemmell, 2017:5). Furthermore, "empowered engagement" is one of several key emerging principles that facilitate awareness, "public acceptance," and thus good governance over emerging technologies (Hartley et al., 2022:39). Inclusivity and consideration of diverse ways of seeing and knowledge systems, such as those held by Indigenous peoples globally, requires significant shifts, including "respectful conversation and deeper consideration of the fact that the same environment might mean different things to different people" (Wissing and Webb, 2023:345). Governance instruments such as UNDRIP and treaties must also be taken into account.

Identifying a lack of principles to guide ethical governance for emerging technologies, Hartley et al (2022:37) seek to address "the governance gap for conservation gene drive." Esvelt and Gemmell (2017:4) argue that "now is the time to be bold in our caution" because "history suggests that safety engineering becomes a primary concern only after a well-publicized disaster." Indigenous values and principles are also guiding (Hudson et al., 2021) and informing research platforms such as Genomics Aotearoa, who state that a goal is "research undertaken by, for and with Māori and embedding Māori management of indigenous genomics research practice and data." (Genomics Aotearoa, 2024).

GM is often met with apprehension due to concern over "unintended consequences." While gene drive appears to be a relatively efficient and inexpensive technology compared to other options, a key argument against its use is the (global) implications if modified wasps were to disperse back to their native range (Dearden et al., 2018). In this case, "gene drives could lead to unwanted global extinction of a species if the modified organism spreads widely" (Lester et al., 2020:1). There is also a risk that the target species will rapidly evolve an ability to suppress the drive system (Wedell et al., 2019). While a modified gene jumping across species is generally accepted as impossible, a real concern is that the reduction in rat numbers would allow a surge in other pest species, such as mice, in the event of rat or stoat eradication (Bridgman et al., 2018). A further consideration is the possibility of the intentional release of a GM control beyond Aotearoa's shores, as was the case with the

deliberate introduction of calicivirus responsible for rabbit hemorrhagic disease (Esvelt and Gemmell, 2017). Other "unintended consequences" extend beyond the environment, such as reduced business revenue from the wasp-related industry (MacIntyre and Hellstrom, 2015); however, a detailed discussion of these sociopolitical and economic issues is beyond the scope of this paper. As gene drive research is relatively new and genetically modified organisms with a gene drive system have not yet been released (Frieß et al., 2023; Wedell et al., 2019), there is, as yet, insufficient knowledge regarding these technologies to allow full, specific consideration of all the risks (MacDonald et al., 2022). Crucially however, special consideration of the potential for GM to impact Māori and their rights to and relationships with taonga is required under Te Tiriti o Waitangi (the Māori text of the Treaty of Waitangi—the nation's founding covenant between settlers and Māori) (Satterfield and Roberts, 2008). The Treaty of Waitangi principles provide the foundational underpinning for any future regulatory arrangements of genetic technologies in Aotearoa (Everitt-Hinks and Henaghan, 2019). In Aotearoa, the development and use of novel gene technologies for wasp control require special consideration under Te Tiriti. With regard to invasive species control, the government's PF2050 response to invasive species has been criticized for failing to recognize "rights to, and ownership of, decision-making over the environment guaranteed within the Treaty" (Peltzer et al., 2019:425–426); by contrast, the efforts of Aotearoa's hundreds of volunteer environmental groups and other conservation volunteers in the protection of te taiao are broadly recognized (Hardie-Boys, 2010; Peters et al., 2015; Ross, 2009). Thus, while wasp and rat eradication in Aotearoa New Zealand (Aotearoa) may be made technically possible through novel gene technology, the development and application of gene tech requires not only their viability but also their visibility and that they are culturally acceptable and socially and politically supported, and even then "…with the current technology and social support, eradication isn't always possible" (Lester, 2022:139).

What is the level of public knowledge and support for genetic technologies in Aotearoa? Perspective, perception, attitude, and acceptance studies undertaken over the past decades show low to medium levels of support for gene tech depending on the application. A recent nationwide survey of more than 8,000 people (MacDonald et al., 2020:904) showed that the use of gene drive as a pest control strategy in Aotearoa had "moderate (32%) levels of public support" when compared with other novel controls (Trojan female, 42% and pest-specific toxin, 52%). However, support levels varied significantly when "subgroups" were identified, such as Māori. Black et al. (2021) found a higher level of uncertainty about gene drive among Māori participants, through "do not know" responses. They noted that the greatest influences on Māori decision-making were community and whānau (family group) wellbeing, suggesting holistic-minded decision-making, leading to a more cautious approach than taken by Pākehā populations. Studies involving informed Māori students (Mercier et al., 2019), Māori businesses (Palmer and Mercier, 2021), and spiritually affiliated Māori (King Hunt, 2023) all highlighted the need for further discussion on all aspects of GM, not just the technical science. Māori also expressed varying levels of trust in science and the government (Mercier et al., 2019; Black et al., 2021) noting historic and contemporary breaches of the Te Tiriti. Māori also expected decision-making processes to support the Tiriti principle of rangatiratanga or self-determination (Palmer et al., 2020; Satterfield and Roberts, 2008).

While volunteer willingness to "contribute their time and expertise to … initiatives aimed at increasing the effectiveness of wasp control" (Lester et al., 2013:60) could prove crucial in any national effort to control wasps, there is little in the literature (locally or internationally) about environmental specialists and conservation volunteer perspectives toward emerging pest control gene technologies or their attitudes toward Tiriti-led governance. Heimann and Medvecky (2022), drawing upon the nationwide survey data of MacDonald et al. (2020), revealed that 13.2% of mammalian predator control volunteers "have no concerns" about gene drive to control pest mammals and 46.5% of the volunteers are "reasonably comfortable with the method as long as appropriate controls are in place," but data were not collected to explain these views.

Most volunteer perspectives research to date focuses on what motivates volunteers to get involved and examines their contribution (Halpenny and Caissie, 2003; Liarakou et al., 2011). A 2022 Department of Conservation (DOC) annual report (Department of Conservation, 2022) reported that 373 volunteers have given the equivalent of 36,923 working days to community conservation efforts over the last 35 years. This number is very conservative given other estimates in the literature (Heimann and Medvecky, 2022; Jones, 2021) and may be due to DOC limiting their count to volunteer activities directly under their supervision. The actual number of volunteers involved is more likely to be closer to Handford's (2011) estimate of between 25,000 and 45,000 or 600 community groups (Ross, 2009). The contribution of volunteers is not only important for biodiversity purposes, rather:

> …volunteers are also direct links to the communities in which they live, and can be conduits through which to engage more New Zealanders in conservation issues (Heimann and Medvecky, 2022:1).

As the "boots-on-the-ground," volunteer communities have valuable, first-hand experience of pest issues and their "participation and engagement in pest species issues has been linked to support of management options in some studies" (MacDonald et al., 2020:906). Volunteer involvement can therefore be a key driver in avoiding "campaign fatigue," which is needed if support through to eradication is to be maintained (Lester, 2022; Howse et al., 2024). Furthermore, volunteers will remain central to pest control efforts regardless of the technology they oversee, due to the development and implementation time needed for new control methods and strategies. Also, close to the issues are those who value Aotearoa's taonga and are developing research-based specialist knowledge in ecological systems and pest control.

Thus, involving this group helps identify different areas of potential difficulty, impact, and risk, perhaps beyond even what can be foreseen by scientists developing genetic technologies.

Because conservation volunteers and environmental specialists are uniquely experienced and positioned in relation to pest control, this research seeks their input into two key questions:

1. How do environmentalists and conservation volunteers view potential genetic technologies for pest control in Aotearoa New Zealand?
2. How do environmentalists and conservation volunteers expect to see genetic technologies for pest control discussed and developed in Aotearoa New Zealand?

This research recognizes the important contribution that volunteers make to conservation and, as Māori researchers, considers Te Tiriti as the foundation of our research, drawing on the foundational relationship of Māori to te taiao.

Materials and methods

This study uses three distinct methods and datasets to explore the research questions. The Aotearoa "nationwide survey" was conducted in 2017 (BioHeritage 2.6, 2019; MacDonald et al., 2020) and captured data on public attitudes toward pest control and gene technologies. We identified, extracted, and analyzed data attributable to conservationist volunteers, also differentiating between Māori and Pākehā (New Zealand European) perspectives. To explain and enrich these quantitative survey findings, we conducted two qualitative studies. "Wasp Wipeout," led by a postgraduate student of Victoria University of Wellington, comprises a free-text online survey with 23 conservation volunteers. "Rats and Wasps," led by final year engineering students from Worcester Polytechnic Institute (WPI), Massachusetts, comprises interviews with 18 environmental scientists and researchers, pest control volunteers, and biosecurity workers (see Hemmerling et al., 2023). For this article, we refer to people across both latter studies as environmental specialists, to denote this mix of academic, laboratory, practice, and field-based specialist knowledge.

Nationwide survey

Details of data collection for the survey of 8,199 New Zealanders are available elsewhere (MacDonald et al., 2020). We analyzed responses from two questions in the open dataset. For question 21: *Please rate your level of agreement with the following statements about pests that have been introduced to New Zealand and the methods for controlling them*, we extracted data from participants identifying as either Māori (1,015 respondents) or Pākehā/New Zealand European (6,721 respondents). This question included the statement "Treaty obligations should guide decisions about eradicating pests." We further selected participants from this subset who self-identified as regular trappers of mammalian pests (possums and rats) and compared their rankings of options in question 15: *There are a number of ways to control species that are considered to be pests. Please indicate your general attitude towards the pest control methods listed below*. This question listed current methods and genetic technologies under development.

Wasp Wipeout

Wasp Wipeout was conducted using a "Māori-led, Māori-lensed" methodology and comprises a Qualtrics survey with 23 conservation volunteers across Aotearoa. We offer the descriptor "Māori-led and Māori-lensed" to account for research led by Māori, influenced by Māori approaches, on a topic of importance for Māori, but not necessarily focused on Māori participants. Co-author Jones managed the National Wasp Wipeout Programme led by Conservation Volunteers New Zealand (CVNZ) in partnership with DOC from December 2020 to December 2021 and drew on this network for participants. Ethics approval was obtained from Te Herenga Waka – Victoria University of Wellington's Human Ethics Committee (HEC#30376).

Methodological orientations

The Waka Hourua (double-hulled sailboat) framework was used recently by the Environmental Protection Agency to weave together mātauranga (Māori knowledge) and science, two distinct knowledge systems (Jones et al., 2020). Waka hourua can also describe the research practice of different disciplines being lashed together to work toward a common goal. In this research, we line up a Māori worldview, brought by ourselves as Māori researchers (including aspirations envisaged by Te Tiriti), alongside the views of environmental specialists (contributions of predominantly non-Māori participants). Whanaungatanga (kinship) (influenced by King Hunt, 2023; Mercier et al., 2019; Palmer and Mercier, 2021) and manaakitanga (care) approaches helped co-author Jones to (re) establish trust-based relationships with the participants. The "nationwide survey" contained short pop-up explanations of biotechnologies like gene drive; however, MacDonald et al. (2020) reflect that the presentation of scientific evidence can lead to greater hesitancy, concern, and even entrenchment and polarization of views. To avoid this, Jones worked with co-author Lester to prepare explanations of the technologies on PowerPoint slides. These were shared with participants during three whanaungatanga sessions that Jones hosted along with a representative from CVNZ. All participants (whether they attended the session or not) received a summary sheet about the technologies. This was worded to provide sufficient scientific information in clear, accurate, concise language; participants should feel informed enough to answer the survey but not overwhelmed with scientific jargon.

Participants

Survey participants completed the survey with the knowledge that responses would be aggregated and published confidentially. Of the 23 completed survey responses, 63% identified as Pākehā, 26% as NZ European, 7% as Māori, and 4% (one person) as Other. The

locations where the participants complete wasp control were widely distributed across Aotearoa (Figure 1). Participants were collectively responsible for the management of approximately 4,600 Vespex® bait stations.

An invitation to participate in Wasp Wipeout was shared with volunteers registered in the national Wasp Wipeout Programme via CVNZ and DOC; therefore, the exact number invited to participate is not known. For this study, "volunteers" are defined as persons involved in unpaid wasp control efforts on (or for the primary benefit of) public conservation land.

Survey design

Co-authors Jones and Palmer designed the survey drawing on Jones' experience engaging with volunteers. We included multichoice and tick-all-that-apply questions, with options for participants to explain their selections further. Engaging manaakitanga and being mindful of survey fatigue, open-field questions were optional and questions succinct and short. Written responses were received from all participants for almost every question in the survey.

We included two forced Likert ranking exercises. The first queried why wasp control was important to the participants. The second sought their level of agreement or disagreement with a number of statements regarding current methods and the future of wasp control.

Given the sample size, the responses reported here are indicative and not representative of the whole wasp control volunteer community.

FIGURE 1
Google map of Aotearoa New Zealand showing the locations (approximately) where participants complete the wasp control.

Analysis and reporting

Participants were not identifiable to the researchers. For analysis, we assigned an alphabetical code indicating how the participant self-identified and added this to their Qualtrics survey number: P—paid worker, V—volunteer, U—unpaid worker, K—kaimahi aroha, and I—interested but not involved. We reported quotes from survey open text boxes against these codes to illustrate the numerical results.

Rats and Wasps

"Rats and Wasps" uses Q-methodology, which invites participant reflection upon and responses to an issue through a concourse of statements presenting diverse ideas and positions on that issue. For complex areas of inquiry, this relieves cognitive and emotional labor on participants, allowing them to discuss ideas they may not have otherwise thought of, felt were relevant, or had the courage to raise themselves. WPI researchers Horowitz, Hemmerling, Kanli, and McDonald with King Hunt and Mercier co-developed a concourse of 34 statements, all on some aspect of "gene-based pest control" and participants considered and ranked all statements. Q-methodology factor analysis revealed ranking patterns, enabling us to identify three factors, or groupings of participants with a similar outlook. Approval for this research was obtained from Worcester Polytechnic Institute's Institutional Review Board.

Methodological orientation

Q-methodology enables the exploration of a much wider range of views than traditional, semistructured interviews allow. Participants read a large number of statements—representing real-world positions on an issue—decide whether they agree or disagree with those positions, and rank them by the strength of their dis/agreement. Q is a useful method for topics that are new, controversial, or difficult to articulate or discuss, as they empower participants to voice their personal standpoints through working with pre-prepared statements that represent a broad range of societal views. Q-methodology also surfaces rich individual participant details. We briefly sketch our methods here, available in full elsewhere (Hemmerling et al., 2023).

Participants and participation

We invited participants by emailing invitations to 89 people. Interviews were conducted with 18 individuals, by an interview facilitator and a note-taker. The participant group includes experts, such as scientists, in the field of conservation (n_{EX} = 4), pest control volunteers (n_{VL} = 9), research professors/lecturers (n_{AC} = 3), or those with an affinity for the environment (n_{EN} = 2). Of the participants, 11% identified as Māori, 56% as Pākeha/Kiwi/European, and 33% as European/Caucasian.

The interview session consisted of a welcome and explanation of the study, a consent form with demographic information, introductory questions, an explanation of SSOS and gene drive, the Q-methodology sorting exercise, and a structured set of follow-up questions about their Q-sort. Interviews lasted an hour on

average. All participants signed consent forms stating their data be published confidentially.

We designed the introductory questions (such as "Are pest species like rats or wasps a problem where you come from?") to gauge participants' involvement in pest control. We then asked, "Are you familiar with the sex selection (SSOS) method or the gene drive method?": if no, a brief, scripted explanation of the two "forms of genetic modification" was given and any questions were answered. If we could not provide an answer, we responded: "We are not experts in the field, but we will note that question and pass it along to the scientists." The Q-sort was performed next, following the process described by King Hunt (2023). Follow-up questions were asked to deepen our understanding of how and why participants ranked the statements.

Generating a concourse of statements

To capture broader perspectives on gene-based pest control, we did a content analysis of news media and other public platforms, identifying viewpoints from public conversations on pest control and genetic modification. Content analysis identified themes, shown in Table 1, and we drafted statements for the Q-methodology concourse to align with these themes. We built from statements in previous Q-methodology studies (Mercier et al., 2019; King Hunt, 2023).

Participant ranking of statements to create unique Q-sorts

Participants were given 34 statements to read and sort into piles of "agree," "disagree," and "neutral." We then asked participants to place statements on a pyramid-shaped ranking grid according to how strongly they agree or disagree with each statement. The grid scale went from strongly disagree (−4) at the left to strongly agree (+4) at the right, with zero in the middle signifying neutral. Statements were printed with an identifying number on the back that enabled subsequent data analysis. The numerical grid pattern made by the individuals' placement of 34 statements constitutes the participant's unique Q-sort.

Follow-up questions with participants enabled them to explain their answers at the strong agree and disagree ends, which statements "jumped out," which statements were difficult to place, and to suggest any issues not covered by the 34 statements.

We audio-recorded and transcribed interviews. Each interviewee was assigned an identifying number. For reporting, we assigned a letter code, indicating the participant's expertise: EX—professional expert in conservation, VL—conservation volunteer, AC—researcher or lecturer, and EN—environmentalist. Two letters for participant identifiers in "Rats and Wasps" distinguish them from "Wasp Wipeout's" single-letter identifiers.

We input numerical results from Q-sorts into the software program PQMethod and performed factor analysis with the QPCA option using the Varimax rotation method. This data reduction method automatically finds underlying connections between all participant Q-sorts through statistics and presents these as correlation matrices (Baker, 2016). PQMethod identified several consensus statements across the 18 participants and three factors or groupings of like Q-sorts. The PQROT add-on program was then used to manually that check each Q-sort was in the most appropriate factor, based on the similarities of their distinguishing statements. We considered the cluster of statements and made qualitative judgments about the overall perspective each factor represents.

TABLE 1 Themes found through media content analysis and represented in Q statements that we devised.

Themes	Significance of theme
Religion	Recognizes a system of beliefs and acts of worship. Ideas of spirituality acknowledge a sense of connection to something greater than oneself.
Power	Recognizes humans' drive for control and strength. Includes the capability to influence nature and people.
Ethics	Recognizes moral principles and defines right from wrong behavior. Includes ideas of trust, ideals, and virtue.
Environment	Recognizes concerns about nature and effects on nature. Entails both living and non-living things in the ecosystem.
Safety	Recognizes health, wellbeing, and protection from dangers. Includes prevention of risks and hazards.
Economy	Recognizes financial, business-related, and monetary concerns. Encompasses gaining benefits or profiting from an endeavor.
Knowledge	Recognizes facts, experiences, and knowledge acquisition. Includes information about particular topics.
Social	Recognizes relationships between others. Includes connections humans have with society or a particular group.

Theme colors are applied in Tables 2, 3.

Results

We begin with the analysis of data from the nationwide survey. Then, findings from Wasp Wipeout and Rats and Wasps are presented separately before being integrated into the Discussion.

Nationwide survey

Figure 2 presents the averaged rankings from 7,736 survey participants from nationwide survey data (BioHeritage 2.6) to the question "Q15 Please rate your level of agreement with the following statements about pests which have been introduced to New Zealand and the methods for controlling them." Overall, the 1,015 Māori and 6,721 NZ European/Pākehā respondents have similar attitudes to different aspects of pest control. Both most strongly *agree* that "we should plant native plants to protect native species," "we should kill rats, possums, and stoats to protect native species," "pest species are a significant conservation problem," "native species have greater rights than non-native species," and "investment in pest control benefits future generations." Both most strongly *disagree* that "there is enough pest control being done already" and that "pest control is less important than other conservation issues." The greatest divergence between Māori and NZ European is seen in whether "Treaty obligations should guide

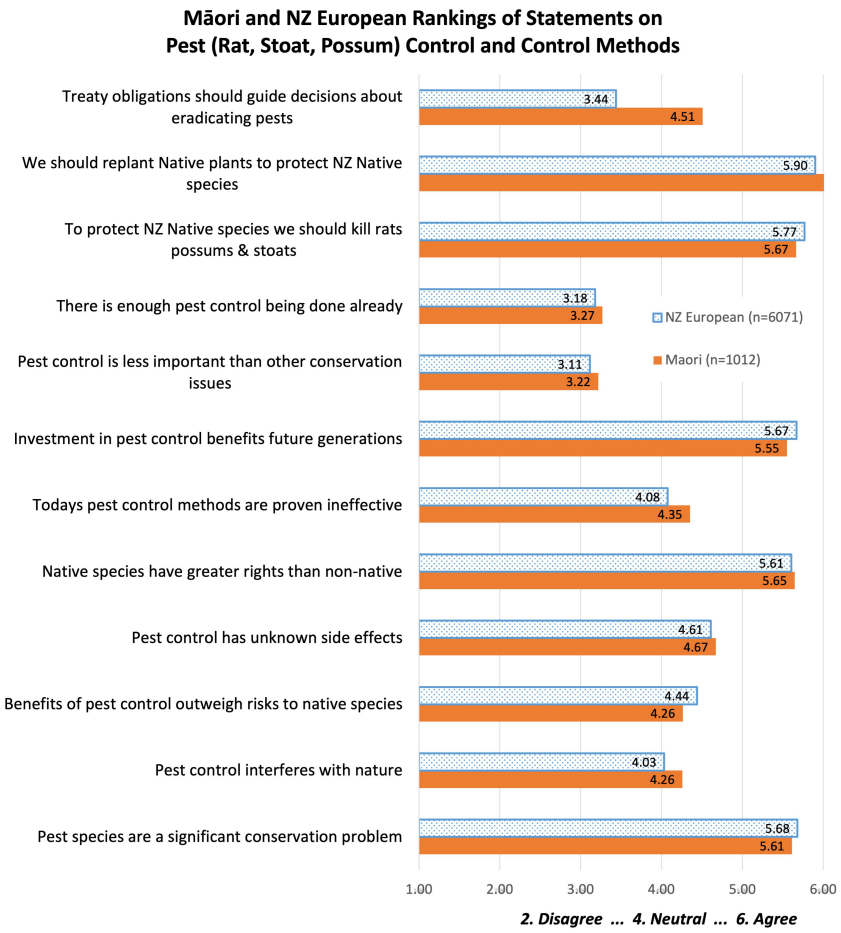

FIGURE 2
Contrast of 1,015 Māori and 6,721 NZ European survey respondents' averaged rankings to statements on pest control; data from BioHeritage Project 2.6. A rating of 1 correlates to strongly disagree, 4 to neutral, and 7 strongly agree.

decisions about eradicating pests." Māori slightly agree on average, and NZ European slightly disagree.

We further queried the Māori and NZ European participants in the database to more closely analyze responses to the question "Q21 Please indicate your general attitude towards the pest control methods listed below." Although some discussion has been published (Black et al., 2021), we identified a subgroup of 1,426 respondents who report being involved in "trapping or controlling rats, stoats, and/or possums" at least every 2–3 months and as "trappers," which can thus be considered volunteer or professional conservationists. One hundred ninety-eight of these are Māori (19.5% of all Māori respondents) and 1,228 are NZ European (18.3% of all NZ European respondents). We also identified and extracted data from 51 Māori who trap intensively (at least weekly).

Participants rated—on a scale from 5: "No concerns" to 1: "Should never be used"—their attitude to four currently used pest controls and five controls under development, including genetic technologies such as gene drive and trojan female. Figure 3 displays the average of non-Māori and Māori trapper responses across the options. A total of 3.5% of the Māori trappers and 20.7% of Māori selected 6 "I don't know" to option 1, hunting. This indicates a strong positive attitude toward hunting among Māori trappers, compared with Māori generally, 20% of whom are uncertain. The responses from 6: "I don't know" were omitted from score calculations.

Figure 3 shows that Māori trappers have lower levels of comfort with all pest control methods compared to NZ European trappers. Figure 3 also reveals that the more regular involvement Māori have with trapping, the higher the level of comfort with all pest control options. On average, participants are most 4: "Comfortable, as long as appropriate controls are in place" with hunting and trapping. Participants, Māori and NZ European alike, are least comfortable with "poison by air," their averages aligning with 2: "Should only be used as a last resort." Novel genetic technologies are seen as more acceptable than aerial poison drops, clustering around 3: "Uncomfortable, but will accept as long as appropriate controls are in place."

Subtracting the number of participants who choose option 6: "I don't know" leaves what we term a "net response" to each pest control option. Interestingly, the "net response" decreased quite steadily as participants engaged with subsequent control options in question Q21. Thus, as participants progressed through control options 1 to 4, then 5 to 9, considering and ranking as they went,

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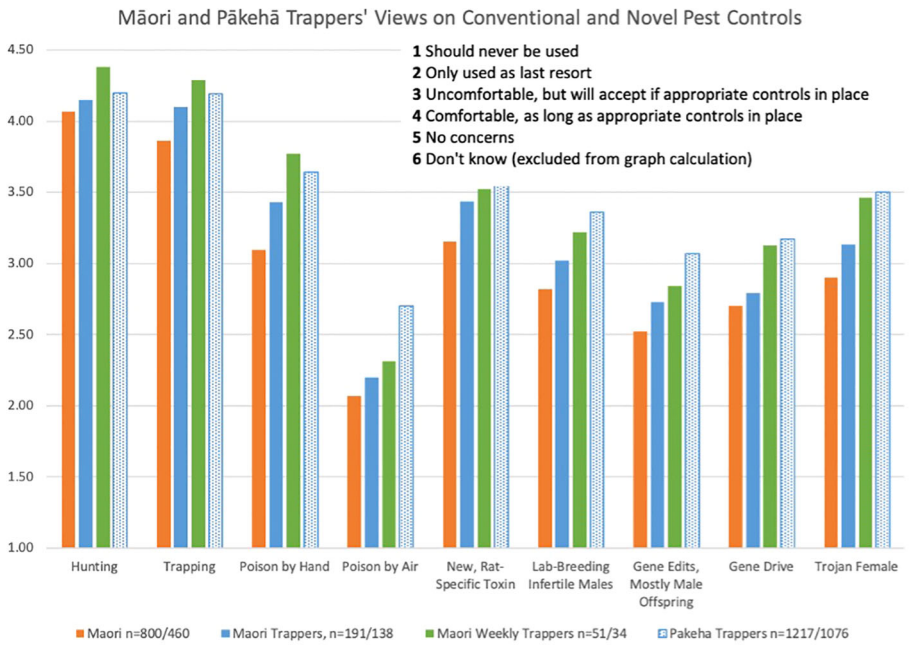

FIGURE 3
Comparison of Māori and NZ European (Pākehā) trappers' attitudes to four conventional and five novel pest controls; data from BioHeritage Project 2.6. Respondents selected *6. I don't know* were excluded from the averages, leaving a net response *n*. The legend displays net responses received as *n* = maximum/minimum for each type of participant. A steadily decreasing net number of responses reveals increased participant uncertainty as the novel control types became more genetically intensive and complex.

uncertainty levels increased, with steadily decreasing net responses (see the minimum and maximum responses in Figure 3) and steadily increasing numbers of "I don't know" responses across all groups. NZ European trappers were more confident to rank their attitude to novel pest controls than Māori. The lowest net response of NZ European trappers was 88% for option 8, gene drive, compared with the lowest net response of Māori trappers being 56% for option 9, trojan female technique. "I don't know" proportions increased to a high of 30% of all trappers and 44% of Māori. The biggest increase in uncertainty among all respondents was between options 7 "gene edits, mostly male offspring" and 8 "gene drive." This perhaps indicates that even a brief explanation of the intended outcome of the novel control (for option 7, the three words "mostly male offspring") helps to determine attitude. The "national survey" did not contain any questions that could answer research question 2.

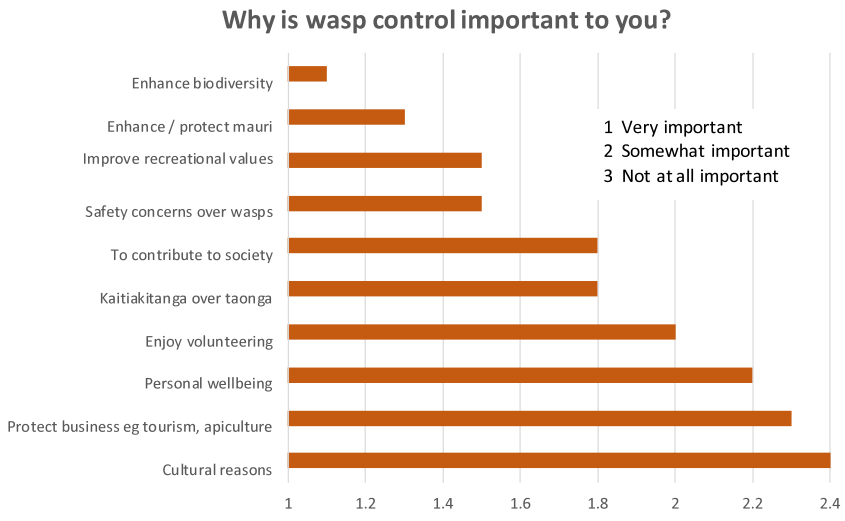

FIGURE 4
Averaged Likert rankings of 10 reasons why conservation volunteers consider wasp control to be important.

Wasp Wipeout

Background

The majority of Wasp Wipeout's 23 survey participants complete wasp control on public conservation land (42%), and most respondents (81%) have been involved in wasp control for between 6 months and 5 years. When asked about control methods they currently use, more than half (53%) selected Vespex®, while other poisons, smoking the nest out, and pouring petrol into the nest were also chosen as options.

Key results

When asked why wasp control is important (Figure 4), "to enhance biodiversity outcomes" was the reason most often ranked "very important" of the 10 statements provided. Despite all question respondents being non-Māori, the second most important reason overall was to "enhance mauri" (lifeforce), with 70% selecting "very important."

A total of 62% participants strongly agree that "new technologies are required to control or eradicate invasive wasps": "bring it on if you can! Need all the tools we can get!" (P23). Of the participants, 58% either strongly agreed or agreed that "current control methods are unsuitable for controlling wasps on a long-term basis." Participants (15%) who disagreed or strongly disagreed with this felt that "current wasp control methods are appropriate" (P18).

There were 48% of participants who strongly agreed and 38% who agreed with the statement that "genetic modification (such as gene drive) wasp control technology is/could be/should be considered" an option. There were 14% who neither agreed nor disagreed, and no one disagreed with this statement, indicating a cohort-wide willingness to discuss genetic technologies for wasp control, despite GM "challenging" personal views. Of the participants, 38% agreed that "management of wasps is becoming harder year-on-year," 14% didn't know, and 20% disagreed. "Climate change and more erratic weather over the summer" (P9) supported the view that "controlling wasps using Vespex® alone was becoming more challenging."

When asked which characteristics would be most important if a new wasp control tool "were to be made available," 79 selections were made (Figure 5).

A tool that "is safe for other wildlife" was most selected (21 times) although V19 expressed that while a solution with "minimal environmental impact" would be ideal, "the unfortunate reality is compromise to get some wins rather than every win at the risk of losing all."

"Highly effective success rate in killing wasps" was the second-most popular choice (19 selections). The third-most desired characteristic (15 selections) was "cost-effectiveness." Participants prefer control methods that "will allow time and money (resources) to be focused on other aspects of care within our environment" (V/P25). "Will be adopted industry-wide" was selected 11 times, perhaps signifying that standard practice is important to a nationwide community like conservation volunteers.

New biotechnologies requiring "some level of personal involvement" was selected four times, supported by an assertion that "if the pest control allows more people and communities to take hands on [approach] we will have more success" (V/K8). "Non-toxic and pesticide free" was also only selected four times. Participants are adept at handling poisonous baits so removing them as an option is not desirable to most.

No one saw "non-genetic modification" as desirable. All four Wasp Wipeout seminar attendees either strongly agreed or agreed with the need for new technologies. No one selected organic as desirable, although V/K8 expressed uncertainty about new technologies and a preference for organic treatment: "My knowledge of new and developing controls are limited. Without knowing the solutions being tested, an effective easily distributed organic solution would be top."

One alternative suggestion, that the tool be "suitable for landscape scale control, e.g., aerially applied, biological, or multi season efficacy" (P/I13), reveals that some believe current tools such as Vespex® are not viable long-term.

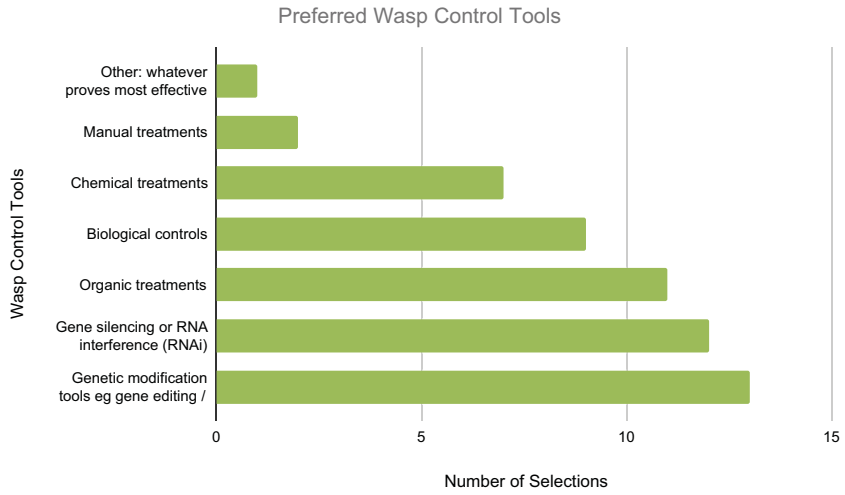

FIGURE 5
Conservation volunteers' most desired characteristics of new biotechnological tools for wasp control.

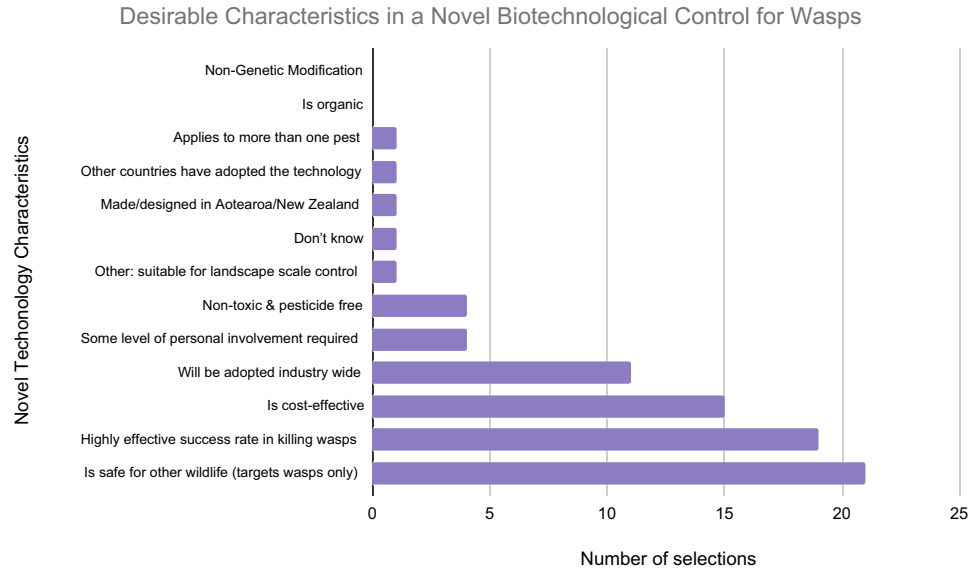

FIGURE 6
Conservation volunteers' preference (based on the number of selections) for six types of wasp control tools and one additional tool suggested by a participant.

Participants were asked which wasp control tools (both available and in development by researchers) are most appealing (Figure 6). "Genetic modification tools such as gene editing or gene drive" was most selected (13 times), supporting earlier responses: "current tools are too resource intensive" (P/I13) and no one desiring that novel tools be non-GM. However, later in the survey, several participants utilized the open text box to explain further their positionality on non-GM control methods.

"Gene silencing or RNA interference" was the next most frequently selected option (12 times). V/U20 only selected "Genetic modification…" and "Gene silencing…" options, explaining that "many of the others have been tried with little success." BioHeritage is investigating RNAi to control invertebrate pests such as varroa mite (*Varroa destructor*).

"Organic treatments" was selected 11 times and appeared many times in free text boxes. A degree of uncertainty due to insufficient knowledge is also evident in statements such as "I would need to read more about this and its impacts" (I17). V26 offered "whatever proves more effective" as an alternative suggestion, revealing the nature and type of control tool is less important than the outcome.

Relating to how decisions should be made on gene technologies, 53% either strongly agreed or agreed with the statement that the "perspectives of unpaid workers need more representation in discussions about new pest control methods":

> In my personal life I am not fond of genetic modification, but seeing the prolific spread of wasps in the Bush I visit every summer, I believe at some point even just an objective and educated conversation about the risks vs rewards for gene editing should be had (V19).

> Including [volunteers] in the discussion from early in the development would help build understanding and hopefully more buy into slightly more challenging ideas like GM (V7).

We now explore participants' preferences further by characterizing them as three overarching attitudes: optimistic, some concerns, and a preference for non-GM controls.

Optimistic

An optimistic attitude toward novel gene technologies sees them as "the only way to get good national coverage of wasp control over the long term and if reinvasion occurs" (V/P25), alongside a sense of desperation for "any way that works to rid the forest of the pests" (P11). Features noted among participants that expressed this attitude include experiencing volunteer fatigue and a sense that current tools are no longer as effective. Limited time, budget, and resources were also key arguments for gene technologies, I17 highlighting the need for "tools that aren't reliant on volunteers to put out every year and hopefully the tools are long lasting." V/U20 stated that "people are only prepared to do [wasp control] for a few years" and strongly supported GM technology.

Some concerns

Participant concerns regarding genetic technologies for wasp control included the pace of development, insufficient consideration of risk, and uncontrolled spread of genetically modified wasps:

> Tight time frames for eradication might make the decision makers lean toward a biotechnological solution such as gene editing or similar, though this does seem unsettling. I hope this is carried out very carefully (V/U20).

> I'm concerned about the potential for genetically modified wasps to escape NZ shores and impact other countries (V14).

Other participants outlined the conditions under which their concerns about gene technologies would be allayed, such as its effectiveness and understanding and controlling its impact:

> I am honestly concerned about harmful consequences and slips (e.g. what if it gets out of NZ). However, generally I am for it if it helps and is controlled and generally safe (V/K8).

Use non-GM options

Participants preferring non-GM options perceived alternative controls to be more available and safe:

> Gene technology too far away, chemical treatments available (P23).

> Ideally it's an organic treatment with low risk for nature and other animals, current and future use and avoids harmful consequences (V/K8).

When asked how novel technology would impact their future involvement as a volunteer, participants were positive about novel controls reducing their need to do wasp control:

> Hopefully [novel gene technologies] would put me out of a job, but if needed … then I would be happy to be involved (V7).

> Just getting them out of the country is what we all want. No one goes after wasps as a matter of choice (V10).

Many participants expressed their support and personal commitment to ongoing conservation efforts with 47% of participants saying that more effective wasp control would allow them to "get on and do other conservation tasks" (P16). On the other hand, one participant suggests that the use of gene technologies would potentially have a negative impact on their future involvement as a volunteer because they are "not comfortable with novel technologies" (V15).

Rats and Wasps

The Q-methodology interviews with 18 conservation volunteers and environmental specialists identified the following:

A. 34 statements relating to "genetic technologies for pest control" that collectively represent a broad range of societal views on this topic;
B. consensus statements across all 18 participants in Rats and Wasps;
C. three factor groupings of participants, their distinctive perspectives on gene tech for pest control with expansion upon development expectations and issues by genetic technologies for pest control. These results are presented in the next three sections.

A. Concourse of statements

Content analysis assisted us to produce a concourse of statements and group them across eight key themes. Most concerns relate to the Environment (seven statements), followed by Safety (five statements), and Social (five statements) themes. Knowledge, Ethics, and Economy themes had four statements each, with five statements spread across Power and Religion themes.

During interviews, participants were asked if they had views other than those on the concourse of statements. Topics suggested, regarding gene technologies, included science communication and more on the advantages of gene-based pest control compared with traditional methods:

> In the backyard is a reasonable place to manage the problem. But in other areas really remote, the tools that exist do not really solve the problem, and that way we can see the different implications [from] gene-based pest control methods in comparison to other methods (EX7).

Aotearoa, including the government, needs to continue resourcing future conservation efforts, with social license. Topics suggested by participants on how the technologies are developed in the future included demonstrating safety, needing expanded discussion comparing gene-based and traditional pest control methods, and more on the social dimensions of decision-making:

> Slightly absent here, I think, is the discussion around scientists and this discussion around Treaty partners … I think we need more leadership and continuity of leadership around … Predator Free 2050. This is not necessarily something for the scope of your work, but … we need a social license to go ahead (VL5).

Another added that inclusive discussions are key to making collective decisions:

> I have a strong interest in the wide range of people who live in NZ being properly, thoroughly, respectfully engaged in a way that allows them to really define the terms of this conversation. So not just "do you agree with this?" and "On what terms do

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> you agree with is?", but really allowing them to build their own perspectives on those debates (AC3).

With confirmation from the 14 other participants that their main concerns are captured in our 34 concourse statements, we next identified key similarities and differences in participants' views on those statements.

B. Consensus statements

A consensus statement is one that all participants roughly agree with, regardless of their factor grouping. The PQMethod software identified five consensus statements alongside factor group analysis, as shown in Table 2. Also revealing commonly held beliefs across the 18 participants, consensus analysis identifies statements that do not contribute to factor group distinctions.

Groups showed the strongest consensus and agreement (positive *Z*-scores) with the statement "the government should invest more funding into gene-based pest control," with EN12 urging "What will we do if we don't fund? We will lose our native species." All moderately agreed that "genetic techniques like gene-based pest control minimize off-target effects." A slight agreement was seen in "gene-based pest control would enhance Māori guardianship over the environment," with EX1 (Māori) of group 1 noting this "depends on the future whether Māori would have more say over some of these topics … it is an opportunity to enhance guardianship." Meanwhile, AC3 (Pākehā) of group 2, who advocates for stronger Te Tiriti partner contribution, placed "Māori perspectives in the middle column purely because I am not the person who can make those statements."

All groupings disagreed (negative *Z*-scores) with the statement "gene-based pest control would contribute to the food web collapsing," with EN15 calling this "rubbish" and EX1 "a very extreme reaction." Groupings were relatively neutral about the statement "climate change would push the population of pest species to require a gene-based pest control solution in the future." This remark may explain this apparent ambivalence: "Climate change is real, but humans are creating problems. So, this statement is taking the blame off humans and putting it on climate change" (VL9).

C. Factor groupings and narratives

The PQMethod software identified and extracted distinguishing statements for each factor, as summarized in Table 3. Here, we only present distinguishing statements in the agree and disagree ranges with *Z*-scores greater than |0.9|.

Z-score and Q-sort values for each distinguishing statement, comparison between each factor, and composite Q-sorts are reported elsewhere (Hemmerling et al., 2023).

The following three subsections are each led by a heading that labels and describes each group, giving an overview of the group's shared perspective. Each group's distinguishing statements are then presented as subheadings, when necessary accompanied by a modifier in square brackets [] to convey their negative position in relation to the statement. The group's positions are briefly discussed.

Group 1: support for gene-based controls (n_1 = 8)

The eight participants in factor group 1 generally supported gene-based pest control technologies. All the participants in group 1 felt that the goal of PF2050 was not achievable with current methods. Group 1 leaned toward accepting gene-based technology, as they believed something beyond "business as usual" is needed to achieve PF2050.

Gene-based pest control is a crucial step toward a PF2050 [statement #14]

Participants strongly agreed that gene-based technologies are needed to achieve PF2050. For example: "I absolutely agree … we've got 27 years left to run on this objective. With the current tools we have, we are not going to get there" (VL5). Of the current pest control methods, "trapping can do a lot, but it is a perpetual workload" (VL5), and a stop-gap measure to which a step-change of adding novel techniques is needed to achieve PF2050. A strong consensus agreement with this statement underscores the importance to this group of adopting gene-based pest control if a predator-free Aotearoa is to be achieved.

Gene-based pest control would help Aotearoa lead the world in achieving pest eradication [statement #6]

Participants strongly agreed, noting that:

TABLE 2 Consensus statements and *Z*-score values for each factor.

Statement identifying number	Consensus Statement	*Z*-score for factor 1	*Z*-score for factor 2	*Z*-score for factor 3
13	Climate change would push the population of pest species to require a *gene-based pest control* solution in the future.	0.31	0.07	−0.00
18	*Gene-based pest* control would contribute to the food web collapsing.	−1.10	−0.88	−1.43
23	Genetic techniques like *gene-based pest control* minimize off-target effects.	0.84	0.22	0.60
25	The government should invest more funding into *gene-based pest control.*	1.20	0.72	0.76
33	*Gene-based pest control* would enhance Māori guardianship over the environment.	0.68	0.24	0.16

Z-scores indicate how many standard deviations the statement is from 0 or the neutral position. A positive *Z*-score represents agreement and a negative score disagreement. Refer to Table 1 for explanations of the theme colour codes.

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TABLE 3 Factor groupings and *Z*-scores for distinguishing statements of the Q-methodology.

Factor number	Q-sorts	Distinguishing statement	ID no.	*Z*-score for factor 1	*Z*-score for factor 2	*Z*-score for factor 3
1	5, 7, 10, 12, 14, 16, 17, 18	*Gene-based pest control* would be a crucial step towards a Predator-Free 2050.	14	**2.02**	0.45	0.80
		Gene-based pest control would help Aotearoa lead the world in achieving pest eradication.	6	**1.85**	0.70	0.92
		Gene-based pest control would enhance the Aotearoa economy.	24	**1.48**	0.85	0.40
		Gene-based pest control would take too long to eradicate the pests from Aotearoa.	27	**−1.14**	−0.04	−0.05
		Religion and spirituality offer guidance on *gene-based pest control.*	1	**−1.17**	0.82	0.43
		Gene-based pest control should only be used inside the laboratory.	20	**−1.41**	−0.15	−0.36
		Gene-based pest control is part of a hidden agenda.	26	**−1.57**	−2.24	0.70
		Gene-based pest control is an example of humans "playing god".	5	**−1.57**	−0.12	1.90
2	1, 3, 6, 11, 13	Treaty/Tiriti partners should agree on *gene-based pest control* before it is used.	7	0.29	**2.10**	0.32
		Matauranga Māori (Māori knowledge) counts in the decision to use *gene-based pest control.*	2	0.71	**1.54**	0.64
		My opinion counts in the decision whether to use *gene-based pest control.*	32	0.12	**0.93**	−0.12
		I am not knowledgeable enough to decide if *gene-based pest control* should be implemented.	30	0.47	**−0.95**	1.63
		Gene-based pest control in Aotearoa would lead to the global extinction of the pest species.	17	−0.32	**−1.52**	−0.12
		Gene-based pest control is part of a hidden agenda.	26	−1.57	**−2.24**	0.70
3	2, 4, 9	*Gene-based pest control* is an example of humans "playing God."	5	−1.57	−0.12	**1.90**
		I am not knowledgeable enough to decide if *gene-based pest control* should be implemented.	30	0.47	−0.95	**1.63**
		Gene-based pest control is a technical fix for broader social, cultural, and spiritual issues.	3	−0.23	−0.16	**1.30**
		Pest trapping gives me more personal satisfaction than *gene-based pest control* would.	34	−0.59	−1.00	**0.95**
		I trust the government to only implement *gene-based pest control* if a majority of people agree.	11	−0.42	0.51	**−1.71**
		Scientists communicate effectively about *gene-based pest control.*	29	0.29	−0.70	**−1.75**
		I trust scientists to develop ethical *gene-based pest control.*	22	0.82	0.62	**−1.91**

The bold *Z*-score values indicate the factor that distinguished the statement.
Refer to Table 1 for explanations of the theme colour codes.

> We have already seen it with products like Good Nature traps, people have adopted it in other parts of the world. This will be no different. I think the rest of the world is looking at New Zealand … can they do it? And if they can, why wouldn't you copy it? (VL10).

Aotearoa has a unique opportunity to prove these concepts are possible on a relatively small island nation that might not be achievable in other small countries because of geological location (EX16).

A biosecurity officer believes that other parts of the world might learn from and replicate Aotearoa's use of gene-based pest control to their benefit, but in the introductory part of the interview, noted "a concern is if [genetically modified rats] were to get out of NZ because these pest species might be native to other places and vital to ecosystems of other countries" (EX16).

Gene-based pest control would enhance the Aotearoa economy [Statement #24]

Every participant in group 1 registered moderate–strong agreement with this statement, expecting gene-based technology could be economically beneficial: "Arguably, I think we already do lead the world, but this would be a good step and is tied up with the boost of the economy" (VL5). VL5 highlighted other potential benefits of gene-based pest control, such as early adopter advantages from being world-leading. EX16 also noted that Aotearoa's current knowledge and skill base in pest control has been exported successfully with the potential to grow further with gene-based technologies.

Gene-based pest control is [not] an example of humans "playing God" [statement #5]

Most group 1 participants strongly disagreed with statement #5. A Christian in the group noted:

> I don't think pest control is 'playing God'. It's actually taking proactive steps to try to get rid of the problem … And you don't need to be a scientist to see that it's a problem (VL17).

VL18 stated "I'm an atheist, there is no God. It's just an example of us controlling our environment that we live in. I'm happy with that." A non-grouped participant and dog handler remarked that "as soon as we start editing genetics, I think we are playing creationism. I don't personally believe in God, but I do believe in creation" (EN15).

Gene-based pest control is [not] part of a hidden agenda [statement #26]

Participants showed moderate–strong disagreement with the idea that pest control was a corporation or government's hidden agenda, with VL14 explicitly pooh-poohing the idea as "conspiracy." EX16 notes that there are "far too many conspiracy theories in NZ as it is, so I'm not going to jump onto that bandwagon." However, EX7 acknowledged that this is an issue for other "groups in NZ who are very concerned about different types of toxins or poison." A group 3 participant noted the "agenda" to be straightforward:

> The people that are researching it, they are genuinely interested in the science, or they are genuinely interested in trying to get rid of these pests and they recognize that these pests don't belong in New Zealand. They were never here and only in recent times have they come here. I don't think there is any hidden agenda (VL2).

Gene-based pest control should [not] only be used inside the laboratory [statement #20]

Participants also showed moderate–strong disagreement with statement #20, with VL18 exclaiming "there's absolutely no point in doing it if you are only going to use it in the laboratory" and VL14 noting "That's not going to do much at all. Is it?".

Gene-based pest control would [not] take too long to eradicate pests from Aotearoa [statement #27]

Participants moderately disagreed with statement #27, suggesting a positive expectation that gene-based pest control might NOT take as long as traditional methods. The only group participant to comment was unsure where to place the statement, noting potential for "unintended consequences, for example you could have harm to native species as a consequence as we do now with our current pest control methods" (EX7).

Religion and spirituality [do not] offer guidance on gene-based pest control [statement #1]

Group 1 participants moderately disagreed with statement #1. A common sentiment was "I don't discount religion, but it has nothing to do with pest control" (VL5). Others similarly acknowledged spirituality, but saw focus as needed:

> Any issue is complicated enough without adding religion and spirituality. When you add religion and spirituality to matters which are already complex, it becomes unnecessarily complicated. I completely disagree with placing all my trust in science, but I also don't believe religion needs to be in this discussion (VL17).

Overall, participants in group 1 were distinctive in their views that gene-based pest control is critical to achieve PF2050, a nationwide eradication effort that, moved beyond the laboratory, would see Aotearoa leading the world in pest control, and this would enhance the economy. Non-technical and non-physical perspectives are irrelevant to debates on gene tech for pest control, and group 1 disagree with any suggestion of hidden agendas or conspiracies behind gene-based pest control.

Group 2: support for gene-based controls as long as Tiriti partners agree (n_2 = 5)

The five participants in factor group 2 supported research into gene-based pest control technologies, as evidenced by their introductory interviews. They also strongly value broad and diverse opinions in the debate on genetic technologies and the importance of Te Tiriti in discussion and decision-making. Group 2 included one Māori and four NZ Europeans.

Treaty/Tiriti partners should agree on gene-based pest control before it is used [statement #7]

This statement was strongly agreed upon by all participants. A NZ European self-identifying as Pākehā asserted:

> Treaty/Tiriti partners should agree on gene-based pest control before it is used. That is not negotiable to me. We live in a Treaty based country and Tiriti partners should be in dialogue about any significant government decisions including the environment and our species, specifically, the species that are affected and not the species that are targeted (AC3).

Another noted that this approach is consistent with the social and political times: "In New Zealand we are working very hard to move to partnership governance between Māori and Pākehā. I am a big believer personally in equality" (AC6). Others concur but believe that full consensus will be impossible to achieve:

> I do strongly agree that this is a Treaty matter. It requires both Treaty partners. We pretty much are all stakeholders in our Aotearoa society to have a very wide consensus. It is never going to be united; it would be quite contentious (EN11).

Mātauranga Māori (Māori knowledge) counts in the decision to use gene-based pest control [statement #2]

Similarly, strong agreement with this statement highlights the importance to group 2 of mātauranga in decision-making on gene-based pest control. One who moderately–strongly agreed stated "It is very similar to the Treaty partner [question], I do agree that Māori knowledge does count" (EN11).

Three participants in the other groups explicitly noted they found this and the previous statement #7 difficult to place, reflecting an uneven ability to engage with issues important to Māori.

My opinion counts in the decision whether to use gene-based pest control [statement #32]

Group 2 registered moderate–strong agreement with this statement, with EN11 stating "I think that everyone's opinions count, or I suppose I am being naïve, but I believe it should count." EX1 showed slight disagreement but with the caveat that "all of our opinions count." Group 2 also moderately disagreed with statement 30: "I am not knowledgeable enough to decide if gene-based pest control should be implemented."

Gene-based pest control in Aotearoa would [not] lead to global extinction of the pest species [statement #17]

Group 2 registered moderate–strong *disagreement* with statement #17, with one noting:

> I think it is totally implausible to think that things that happen in Aotearoa would lead to global extinction in another country, let alone all the countries. I just don't think there is any evidence for all that (EN11).

A scientist concurred, noting that from his experience many "… potential hypothetical things that could happen, I actually think [there] are very strong valid logical evidential reasons why they wouldn't hold" (AC6).

Gene-based pest control is [not] part of a hidden agenda [statement #26]

Group 2 were in even stronger disagreement than group 1 that gene-based pest control is part of a hidden agenda, and they interpreted it as "conspiracy thinking." EX1 noted it as a "very extreme reaction to the thought of gene-based pest control":

> That would give government organization far too much credit for what it is worth … That kind of conspiracy is not, at least in New Zealand, [they] just haven't got the organization to do it (AC6).

EX1 adds "I don't believe that. I am not aware of a hidden agenda, which I guess is the point. At least from my understanding, it's pretty open about what they want to achieve."

Overall, participants in group 2 were quite similar to group 1 in their views on gene-based pest control, also disagreeing with any suggestion of hidden agendas or conspiracies behind them. Group-wide agreement with statements #7, #2, and #32 signifies that group 2 is committed to a Tiriti-based approach to decision-making, to mātauranga Māori and other diverse opinions being heard in debates, and on consensus-building.

Group 3: wary, need more information ($n_3 = 3$)

Participants in group 3 had personal experience with traditional pest control techniques. Group 3 was slightly untrusting of governments and/or science and wanted more knowledge to make an informed decision on gene-based pest control technologies.

Gene-based pest control is an example of humans "playing God" [statement #5]

Two group 3 participants very strongly agreed with the statement. Any form of editing a living being's genome was seen as "playing God." VL4 notes that "gene modification has been done for a number of years but it is still 'playing God' in a way". From experience, VL4 acknowledges it is unlikely that pests can be eradicated in traditional ways, noting they catch "over 3,000 rats in each suburb and the number of rats each month stays the same as 5 years ago." VL4 thinks gene technology will be involved in the solution but also expects controls to be put in place.

VL2 placed the statement in the neutral category, but explained that 20 years ago they would have agreed with this statement. VL2 has since gained more knowledge and notes "that we are understanding more and more how genes work and how DNA works and it's becoming more matter of fact and we just have the knowledge."

I am not knowledgeable enough to decide if gene-based pest control should be implemented [statement #30]

Group 3 registered strong agreement with this statement, but no one addressed it directly in the interview. One noted a science communication gap worked against their desire to be informed:

> I want to fully understand it and I've had university training and science training, so I should be able to understand the issues. If I don't there is a problem with the [communication], not a problem with me and there are lots of people in New Zealand who are fully capable of understanding the issues, so we should be informed (VL2).

A group 2 participant also asserted that not knowing enough science is not a reason to be excluded from the debate:

> I don't think this decision is a question of knowledge or information, it is a question of values, belief. I think that anybody can and should have a say on this topic and hearing people's views is also a not negotiable step to determine whether to use gene-based pest control (AC3).

Gene-based pest control is a technical fix for broader social, cultural, and spiritual issues [statement #3]

Group 3 registered moderate–strong agreement with this statement, but only one participant addressed it directly, noting "It is most definitely a technical fix. It gets back to this thing, community participation. I will say this, people actually get a lot of satisfaction from being involved" (VL4).

Pest trapping gives me more personal satisfaction than gene-based pest control would [statement #34]

Group 3 registered moderate–strong agreement with this statement. Their first-hand experience with traditional pest control methods gives them intimate knowledge of the "wins" and community-building aspects of pest control: "People buy in and feel like they're achieving more. It gets the community involved with direct action in trapping" (VL4). This sentiment was also important to wasp volunteers in Wasp Wipeout and was noted by participant V/K8 quoted earlier.

By contrast, a group 1 participant noted in relation to statement #34:

> Unless you want to be perpetually trapping the rest of your life for that little dopamine hit, we need to look at the big picture, and we need to find other ways to get satisfaction, if that's from seeing birds nesting in the garden or knowing that actually, we were right in that the whole project is achievable (VL5).

I [do not] trust the government to only implement gene-based pest control if a majority of people agree [statement #11]

Group 3 registered moderate–strong disagreement with statement #11. "I think we have seen many cases of things being implemented despite what the majority of people think. That gets back to this trust thing and communication" (VL4). This testimony suggests that a lack of trust stems from a lack of communication and also government track records of ignoring citizen feedback. Similar concerns stemmed from suspicions of governments' ulterior motives relative to genetic technologies: "Gene-based pest control is an agenda to make us look good internationally, so I do not trust the government to make the right decision" (VL9).

Scientists [do not] communicate effectively about gene-based pest control [statement #29]

Strong disagreement with statement #29 was registered for group 3: "I am a bit doubtful about that. I think the whole vaccine thing has probably created a lot of distrust of scientists and governments, me included" (VL4). The mistrust alluded to here stems from a perception of poor communication and management of issues related to COVID-19, particularly during 2021–2022 in Aotearoa.

I [do not] trust scientists to develop ethical gene-based pest control [statement #22]

Statement #22 also registered strong disagreement from group 3 although participants only discussed trust in relation to governments. A group 1 participant found this statement difficult to place, noting "Only, I have to trust scientists because you can't be an expert on everything, so you do have to put some trust and responsibility. Is the emphasis on I trust scientists or is it on the ethical?" (VL5). In relation to statement #22, a group 2 participant noted that ethical matters are for other kinds of specialists and all must contribute:

> I trust scientists to develop the technologies that they are trained to develop. I do not think it is their job to engage in debates about ethics. I think they are really good contributors to those debates, but they have a different social function and part of their job is to listen (AC3).

Overall, group 3 values pest control as a community action and is interested in new technologies. However, group 3 lacks trust in government and scientists, who they feel "play God" when it comes to genetic technologies. Group 3 notes their own lack of knowledge in order to decide on gene-based pest control but feels that science communication is lacking.

Discussion

In debates on whether, when, and how Aotearoa might use gene technology for pest control, the public must feel informed and enabled to contribute their perspectives and expectations for gene tech development to the conversation. Through conducting distinct and complementary studies that open up this conversation, we have extracted views and aspirations of the Aotearoa public, environmental specialists, and conservation volunteers—Pākehā and Māori—drawing on their experience of wasp and rat control,

and their positions on broader environmental, cultural, and societal contexts. Data collected and analyzed here reveal significant areas of consensus among participants, especially Māori and Pākehā, providing critical common ground for discussion. The research also reveals diverging perspectives, as well as important insights and suggestions for future action. The flowchart in Figure 7 briefly reiterates the three methods and gives major findings from each and a braiding together of these.

Overall, the public sees pest control as vital to protect native ecosystems, thinks we should do more pest control, and agrees that the Aotearoa New Zealand government should invest in pest control. Careful discussion and consideration of gene tech among environmental specialists and conservation volunteers elicits optimism about their targeted nature compared with poisons, but with healthy sides of reservation and caution. Given a pest eradication goal, the public sees national development of gene-based tools as the only way to achieve this aim. Environmental specialists and conservation volunteers agree and want safe, effective, and affordable pest control. They expect that risks are mitigated and that unknown effects are anticipated. Environmental specialists and conservation volunteers expect to be informed on scientific developments, noting that trust can be eroded if not. They want controls that support their communities as well as their environmental work. The public is split between Māori and Pākehā, on whether treaty obligations should guide pest control. However, a significant minority of environmental specialists and conservation volunteers support decision-making processes that honor Te Tiriti, where all concerns are heard and the Māori Tiriti partner agrees before gene-based technologies are implemented.

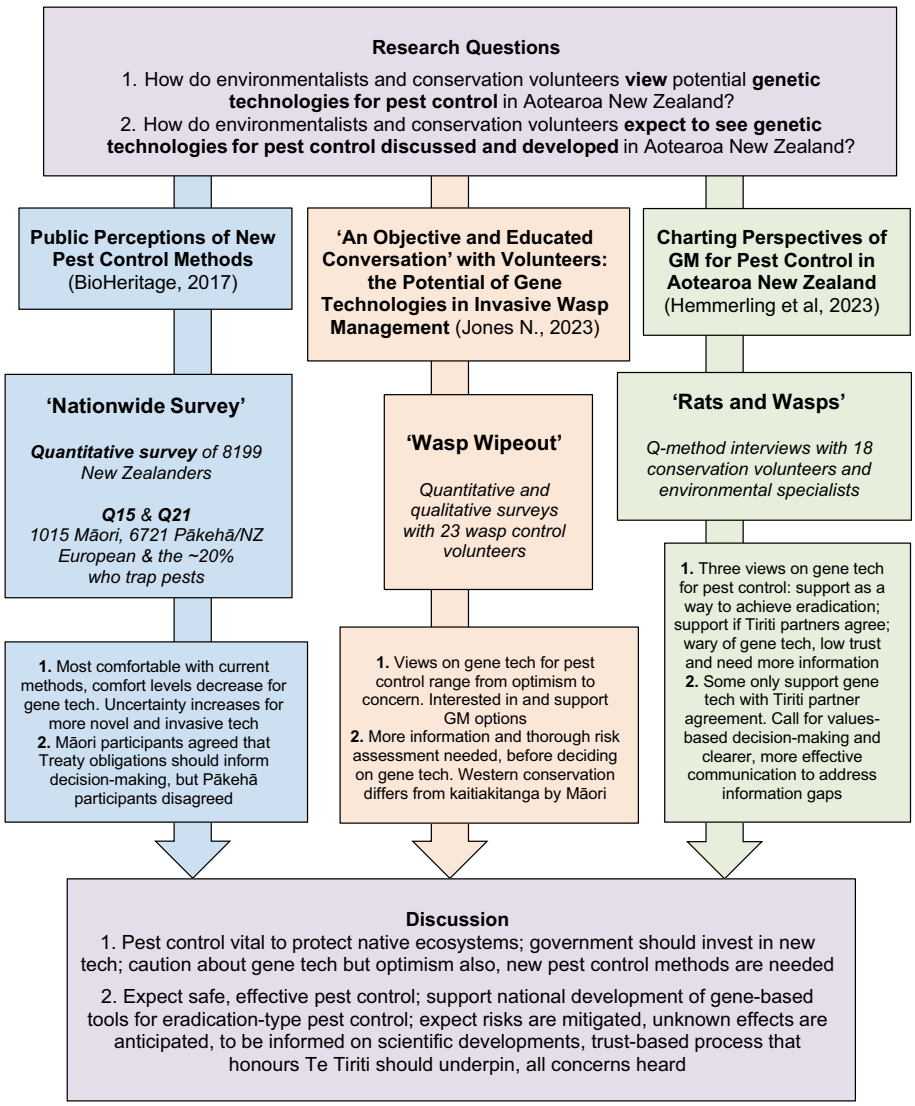

FIGURE 7
Flowchart depicting (in boxes top to bottom) two research questions, three distinct studies, shorthand study names and method summary, key findings of each study against each research question, and combined findings.

"Bring it on if you can"

Māori and Pākehā participants in the nationwide survey as a whole agree that pests are a significant conservation problem; pest control is as important as other conservation issues; not enough pest control is currently being done; pest control is necessary to support Aotearoa's biodiversity; native species have greater rights than non-native species; we should kill rats, possums, and stoats to protect native species; and investment in pest control benefits future generations.

Rats and Wasps participants (largely Pākeha) went a step further, agreeing that "the government should invest more funding into gene-based pest control" as a tool that could prevent the extinction of native taonga species. Most participants in Wasp Wipeout and Rats and Wasps believe that novel gene technology would be crucial to the goal of eradicating pests by 2050, and none explicitly questioned the PF2050 goal. Overall, Wasp Wipeout participants want to see development and use of gene technologies for wasp control as current wasp control efforts take valuable time and resources away from other conservation activities. P23's comment "bring it on if you can!" emerges from their experience that current controls are not effective enough. Likewise, group 1 in Rats and Wasps strongly agreed that PF2050 is not achievable with current methods.

Growing fatigue and desperation among volunteer communities makes some willing to put aside personal concerns regarding gene technologies if it will help to eradicate wasps. There were 86% of Wipeout participants who agree (with no one disagreeing) that GM tools such as gene drive should be considered an option, and the majority group in Rats and Wasps support GM. The nationwide survey results also reveal a higher level of support among conservation volunteer communities, including Māori conservationists, although in general Māori were far more uncertain about rating their levels of support for novel technologies such as gene drive and were more cautious about genetic technologies than NZ Europeans.

"Generally, I am for it if…"

The "nationwide survey" revealed pest controllers (regular trappers) to be more comfortable with all types of pest control than the public. However, it also showed increasing discomfort and increasing levels of uncertainty among Māori and Pākehā pest controllers the more technical and theoretical the pest control under consideration. This uncertainty, also expressed by the Wasp Wipeout and Rats and Wasps participants, led cohorts in those studies to assert conditions under which they would consider novel gene technologies acceptable. Wasp Wipeout participants emphasized the necessity of effectiveness, safety, and risk mitigation. Conditions stipulated by group 2 participants in Rats and Wasps included that they were only in favor of gene-based pest control if Te Tiriti partners agreed. The nationwide survey found that Māori slightly agree on average that "Treaty obligations should guide decisions about eradicating pests," but NZ European/Pākehā slightly disagree—a perspective gap that would need bridging in order to move forward.

Underlying the sense of eagerness is an undertone of concern based on fear that time pressure to eliminate pests may prompt hasty decision-making, without fully understanding the possible implications of novel gene technologies. V/U20 expressed their concerns in terms like "unsettling" and "I hope this is carried out very carefully." While cautious, all Rats and Wasps participants agree that some risks, such as the global extinction of the pest species and the food web collapsing, are not logical arguments against genetic technology. Likewise, V/K8's statement "generally I am for it if it helps and is controlled and generally safe" conveys a guarded acceptance of the idea of new gene controls, shared by many participants.

"An objective and educated conversation"

The more complex and unknown the pest control technique became, the more nationwide survey participants opted for "I don't know" answers. We mitigated against this in Wasp Wipeout and Rats and Wasps through carefully constructed gene tech explainers and explanations. However, a desire for "more knowledge" (VL2), before making an informed decision about the future of wasp control, emerged across both qualitative studies.

A deeper understanding of the technologies and associated risks may cause participant's opinions to shift. Involving volunteers, environmentalists, and experts in "an objective and educated conversation about the risks vs rewards for gene editing" (V19) not only has the potential for decision-makers to benefit from a wealth of conservation knowledge but could also boost morale and support for wider PF2050 goals. "Empowered engagement" (Hartley et al., 2022:39) fosters pride and a sense of ownership and responsibility and could ease concerns regarding new control methods within volunteer communities and the wider community in which they reside. Participants across both studies desire clear communication from the scientific community. Without "this trust thing and communication" (VL4), issues arise, such as belief in conspiracy and ulterior motives for gene technology. None of the Wasp Wipeout participants selected "non-genetic modification" as a desirable feature of novel pest controls. This is a fascinating result, considering the recent "GM-free" sentiment in the general Aotearoa public and the attendant Royal Commission recommendations to "proceed with caution" regarding genetic modification (Royal Society Te Apārangi, 2019). This may be because the technologies were presented and explained by a conservationist of their community.

While "the biggest barrier to [GM] adoption is [likely to be] the social one" (Dearden et al., 2018), if decision-makers leverage off the strong sense of pride and community held by volunteers and their willingness to be involved in "the discussion from early in the development … more buy in to slightly more challenging ideas like GM" (V7) may be achieved. This is also seen in Rats and Wasps, in which participants seek that engagement in discussion be done "properly, thoroughly, respectfully" (AC3). Furthermore, EN12 explains that:

> My community is very proud of the predator trapping we do because it makes us feel good, and we have more bird life in our lives, which makes us happy. I would love to give up trapping a rat because not only is it boring and repetitive, I think it would be more satisfying if I knew my taxes were going toward solving the problem for us.

Most Rats and Wasps participants felt that religion and spirituality should not be included in the discussion regarding novel pest controls. While this is consistent with a tendency to secularize technological debates, it is not clear whether this response is a rejection of Western, Eastern, or Indigenous and Māori spirituality, or all of the above. The call for an "objective and educated" conversation could be seen as preferring the exclusion of social and cultural perspectives also. Some participants explicitly wish to embrace all perspectives and diverse knowledge systems for inclusivity. The recognition of mauri by Wasp Wipeout participants suggests increasing awareness (and acceptance) of Māori spiritual concepts in conservation, with mauri increasingly used in mainstream ecosystem health discourse. Attention should thus also be paid to spiritual and cultural concerns.

"An opportunity to enhance guardianship"

While volunteers "play a critical role in conservation in New Zealand" (Heimann and Medvecky, 2022:1), the concept of volunteering is a Western one and, in some instances, volunteer involvement in pest control on contested lands may contribute to the ongoing marginalization of Māori. Māori underrepresentation in conservation volunteer communities, with over 80% of conservation volunteers identifying as Pākehā (Bell, 2003; Heimann and Medvecky, 2022), could be attributed partly to the current model of conservation volunteering, which does not restore relationships between Māori and te taiao (Walker et al., 2019). Given options to self-identify their work by Māori concepts, such as kaitiaki and mahi aroha (compassion work, volunteering), these statistics would likely shift dramatically (Office for the Community and Voluntary Sector, 2007; King, 2007). Excluding Māori from the conversation not only perpetuates the disconnection of Māori from te taiao but also has implications for driving support (for or against) certain pest management options. Since an exclusively Western approach to conservation volunteering is not necessarily recognized by, or inclusive of, Māori (Bargh, 2014; Volunteering New Zealand, 2020), it is unlikely to achieve the best outcomes for te taiao. If we are to realize EX1's aspiration that gene-based pest control could enhance Māori guardianship over the environment, enhancing Aotearoa's foundational human relationship, Māori, Maori values, and mātauranga Māori would need to be in rangatiratanga and governance positions.

Gene technologies for pest control were a new concept to most participants. The volunteers and environmental specialists here shared their personal experiences and perspectives eagerly, as we also found in our previous studies focused on Māori. Other communities need to be involved in this conversation in order to achieve broader societal support on controversial means to achieve pest eradication, and an important aspect of that is being heard and included. Jones had an existing relationship with most of the Wasp Wipeout participants and facilitated a Māori-led, Māori-lensed environment of manaakitanga and whanaungatanga, where knowledge could be shared and discussed freely, potentially softening any barriers of uncertainty and mistrust. Communicating effectively thus means devising alternative, community-appropriate media, including face-to-face explanation and discussions underpinned by consensus-seeking values.

Conclusion

> This is not about killing our predators; this is about saving our ecosystem (EN12)

Genetic technologies are currently the best hope of achieving Aotearoa's target of a predator-free future, but gaining public support for the contested technology is key, and support from kaitiaki, environmentalists, and volunteers is essential. Most of our participants here have first-hand pest control experience, so their views are crucial to discussion, development, and any implementation. An open dialogue is needed to enhance trust in government and scientists. Māori and Pākehā have similar levels of concern for native biodiversity and agree new solutions are needed. Māori are more cautious about gene tech and more conservative than Pākehā in stating their personal views on gene tech for pest control. Māori are more convinced than Pākehā, on the whole, that Te Tiriti relations must guide discussions about pest eradication. Most participants support genetic pest control tools being researched and support government investment in research, as long as technical risks are mitigated and the development is an open process that takes account of diverse social and cultural concerns.

Prior to this study, most had little to no knowledge or awareness about gene drive, genetic modification, and gene editing research being undertaken in Aotearoa. Careful thought and preparation had to go into introducing, communicating, and explaining gene-based technology options to participants, conducting these face to face so participants could ask questions. As the technologies are still under development, uncertainties around their effectiveness, safety, and cost also made it challenging to communicate firm possibilities. Nonetheless, participants were eager to engage in these early-stage discussions, with early involvement of the public in technological developments widely seen as critical to social engagement. Their rigorous engagement and feedback exposed some limitations in our survey instruments, which could be fine-tuned, for instance by removing distracting Q statements. Conclusions from the in-depth survey and interviews are also not intended to be representative of the general population but indicative of the Aotearoa conservation volunteer community, conducted as they were with relatively small numbers of predominantly Pākehā participants. Māori participants being underrepresented in our qualitative studies underscore that Māori engagement in te taiao and kaitiaki practice largely occurs

outside of Pākehā styles of volunteerism and conservation practice. Therefore, the views and development aspirations noted here need to be read alongside other studies focused on Māori. Notably, however, a significant minority of Pākehā participants support mauri-based approaches to environmental health, mātauranga Māori as a contributor to pest control, and Tiriti-based decision-making. These gestures of solidarity are an important touchstone in consensus-building toward decision-making. Aligning Māori and Pākehā perspectives on Te Tiriti could be a powerful lever in future national decisions.

Future work should involve discussion with other groups, expanding with whom and how we communicate this complex and evolving intersection of technological feasibility and social and cultural concerns. Culturally and politically aware, sensitive, playful, and nuanced approaches are needed for inclusive communication and discussion on genetic technologies for pest control. Sociocultural and political education and discussion may well be needed in some contexts, in addition to explanations of gene tech. Participants in these discussions should feel comfortable airing their views, as well as learning about new technologies and decision-making. Participants should be given sufficient understanding that enables them to share their own perspectives, identify opportunities and risks, and suggest how future developments occur. Through careful choice and design of interview types and engagement methods, we can bring diverse peoples into this complex conversation. By doing so, together we mitigate against technical, natural, social, cultural, and spiritual risks, as well as strengthen society through supporting our Te Tiriti relationship in Aotearoa New Zealand.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Human Ethics Committee, Victoria University of Wellington and the Institutional Review Board, Worcester Polytechnic Institute. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

NJ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. ORM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing, Project administration, Resources, Supervision. AKH: Conceptualization, Methodology, Supervision, Writing – review & editing. LH: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. LM: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. JH: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. RK: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. SP: Methodology, Writing – review & editing. SB: Writing – review & editing. PL: Funding acquisition, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Publisher’s note

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Glossary

Kaitiaki	environmental guardian
Manaakitanga	care
Mahi aroha	compassion work, volunteering
Mātauranga	Māori knowledge
Mauri	lifeforce
Pākehā	New Zealand European
Rangatiratanga	self-determination
Taonga	native treasure, natural resource
Te taiao	the natural environment
Te Tiriti o Waitangi	the Māori text of the Treaty of Waitangi
Whānau	family group
Whanaungatanga	kinship