New Zealand's Biological Heritage National Science Challenge
Scoping Panel Report
SO5 – Tools, technologies & strategies (post border)

Vision and link to the Challenge mission

By 2024 we will have set a platform with tools and technology, from which we can move rapidly towards eradication of pests in New Zealand.

New Zealand's biological heritage is declining primarily because of the impacts of invasive invertebrate and vertebrate predators. Although these pests can be controlled at local scales, current tools, especially toxins, have a range of undesirable side-effects, such as non-target impacts, residues, or animal welfare concerns. They are also difficult and expensive to scale up to regional or national scales. Additionally, current control strategies require an ongoing sustained commitment of funding and effort, which significantly limits their ability to be scaled up.

To address the invertebrate problem, NZ needs a step-change in tools that shift control from a reliance on chemical applications to smart, gene-based or other emerging technologies that enable control to be self-disseminating rather than point-source applications. For vertebrates, there are three knowledge gaps that require filling: (1) how do we cost-effectively remove the last 5% of survivors to achieve eradication; (2) how do we cost-effectively prevent immigration back into areas that have been eradicated; and (3) how do we do these with the necessary social licence to operate? Developing and implementing these step-change technologies will make a significant contribution to enabling NZ to reverse the decline of its biological heritage.

Strategic Outcome 5 Post Border (SO5PB) will research novel tools, technologies and strategies for the control or eradication of biotic threats, and by 2024 have demonstrated the effective use of at least two of these (one invertebrate and one vertebrate solution) for deployment at scale throughout New Zealand.

Success in 2024 will be measured by the demonstration of at least two novel technologies that can achieve landscape-scale pest eradication and the widespread interest in adoption of these technologies by relevant organisations and communities, establishing the platform for ongoing investment and further technology development.

Guiding principles

A. We give effect to Te Tiriti partnership.

B. We give equitable consideration and implementation of Te Ao Māori understanding, values, approaches and opportunities.

C. We value collaborative approaches.

Longer Term Aspiration

New Zealand is enabled technically, legislatively and socio-culturally to efficiently eliminate the impact of vertebrate and invertebrate pests across the country.

2024 Goals

1. Evaluate and select an exemplar **invertebrate** pest to eradicate or control at a large scale and select novel technologies with potential to achieve a step-change.

2. Demonstrate the application of novel technologies to control or eradicate the selected **invertebrate** pest, in order to eliminate its impacts at large scales.
3. Demonstrate the application of novel technologies[1] to eradicate **vertebrate** predators in order to eliminate their impacts at large scales.
4. Demonstrate at least one broadly applicable, non-fence option for defending large-scale, **vertebrate**, multi-pest eradication sites.
5. Ensure legislative and socio-cultural licence to implement the technologies at a national scale.

Beneficiaries

The successful delivery of technologies that eradicate or control pests, both **vertebrate** and **invertebrate**, to the level where their impacts are removed across large-scale areas of New Zealand will create a significant list of beneficiaries. The list of benefits can be categorised into social benefits (improved experiences and removal of nuisance factors), industry benefits (financial and productivity improvements), biosecurity and biodiversity benefits, and cultural benefits. Primary beneficiaries include government agencies tasked with delivering national and regional biodiversity and animal health outcomes, individual farmers and primary producers desiring biodiversity and/or production outcomes, tourism companies, community groups involved in pest control, and iwi/hapū, through improved health of te taiao (the environment) and employment opportunities.

The exemplar **invertebrate** pest we examine will be nationally distributed and likely to be of substantial economic, ecological and/or health cost. While we have advocated an open process to select the target invertebrate pest, we know enough to outline the benefits of targeting wasps as an example for the purpose of this document. New Zealand's people, biodiversity and economy would benefit substantially if we deploy novel approaches to control wasps. Below we list key groups that would exemplify beneficiaries of wasp control:

Social
- Tourists and the public – improved social experiences and recreational activity

Industry
- Tourism
- Bee keeping – reduction in production losses and improved financial returns
- Horticulture – improved pollination, reduced nuisance factor, improved financial returns
- Forestry – improved financial returns
- Farmers – improved financial returns
- Product suppliers

Biodiversity, biosecurity and pest management
- Iwi and hapū
- Regional Councils – improved pest control options
- Central Government
- DOC
- OSPRI
- Primary Industry

[1] Novel technologies in this instance exclude Aerial Papp and 1080 to Zero that are due to be completed within the next few years without requiring BHNSC investment. Technologies is pluralistic – we are seeking a suite of new technologies.

Cultural

- Hapū and iwi – improved survival of native species and food sources

It is possible that a different pest with similar attributes could be successfully nominated during the initial six-month phase of this project.

For **vertebrates**, A technology that enables and defends eradication areas will create a shift from sustained long-term control to eradication. Currently, without defence mechanisms such as costly fences, eradication areas can be re-invaded. The technology developed for this goal would benefit all groups undertaking predator control programs in New Zealand, by enabling a cost-effective solution for eradication rather than just control. This includes PF 2050 Ltd., the PF2050 programme, DOC, regional councils, territorial authorities, OSPRI, Sanctuary NZ and community groups.

Delivery pathways

Delivery pathways for all five goals overlap, but each goal has its own distinct pathway. Because of the diversity of invertebrate pests, specialist knowledge will be required to determine which invertebrate pests to focus on for maximum impact and which step-change technologies to develop to control both invertebrates and vertebrates.

Identified cross-challenge issues

During the development of this report, it became clear that there were some fundamental enabling actions that needed to be undertaken for this SO to be successful. All of these appeared to cross all SO's. These are:

1. Data Commons – the ability to nationally share and fully utilise data for decision making.
2. Data Connectivity – setting up the infrastructure for data transfer across the whole of New Zealand's land mass. Without this capability, the potential of "smart" devices won't be realised.
3. Social-Cultural Licence – although outlined as Goal 5 in this report, we believe that this is an issue for all strategic outcomes.
4. Māori capability and capacity building – all SO's are asking for increased input from Māori, that would require resourcing and co-ordination.

Invertebrates

Goal 1 requires us to select and confirm both the exemplar invertebrate pest and next-generation technology for development. In Tranche 1 of the BioHeritage Challenge we developed social wasps as an exemplar target organism. Technologies such as gene drives and gene silencing were also examined and are candidate approaches for Tranche 2. In our Scoping Group consultation, however, we received feedback requesting other approaches and exemplar pests should be given opportunity for Tranche 2. Having an efficient initial phase of consultation on pest species and technologies will benefit the programme.

Our pathway towards goal 1 will involve providing research organisations with the opportunity to suggest both exemplar pests and potential technologies. We believe that this consultation will involve just a 6-month process, and will provide the opportunity for fresh ideas and to increase transparency and engagement in the Challenge process. For the purposes of this Scoping Panel Report we use wasps and gene drive as examples of a target pest and novel technology for eradication, simply to build a picture around the risks and level of investment that may be required. However, an important first step is a consultation process amongst researchers and specialists that is likely to provide a number of species and technology options for consideration.

The key delivery pathways for **Goal 2** will depend on the pest and novel technology chosen. However, if the exemplar pest with the use of gene drive as the control technology are the ones chosen as an outcome from Goal 1, then delivery pathway will be the successful completion of identification of specific gene sequences that can impact on the survival capability of the wasp. The development of this pathway will carry beneficial cross-linkages to control methodologies for other invertebrate pests and therefore benefits to a much larger audience

Historically, some large-scale control of wasps has been achieved with the development of new insecticide products. However, for the goal of landscape scale control or eradication this pathway is considered inadequate.

Key considerations for the development of gene drive technologies would be the timeframes required both for development and implementation. If the mechanism of control requires a reduction in reproductive capability, then key factors would be the lifecycle of the pest chosen, and the ability to transmit the technology outcome through a sufficiently large proportion of the population to impact population survival. Flexibility in design of the specific gene drive methodology is critical to allow similar outcomes through variable physiological interferences, should inadvertent barriers occur during development of the initial choice. Development of gene technologies are likely to be the most expensive and time consuming solutions, but will also be the most effective if they work.

Currently the understanding of available technology and development of modelling to predict impacts and likely time to success are available through specific university groups and scientists within New Zealand. Public, societal and cultural acceptance of the technologies may be significant barriers.

The successful development of a technology that becomes both socially acceptable and capable of large-scale deployment has the potential to substantively change the whole approach to management of invertebrate pests. Moving it away from the current management methods that have residue and toxicity risks associated with them.

The ultimate delivery pathway is likely to be through regional councils (in collaboration with research developers) delivering the technology across chosen areas. This could be delivered as a demonstration through selected trial areas in the first instance.

Vertebrates

The primary delivery pathway for **Goal 3**, is through key partnerships developed with end-users during the innovation, translation and adoption stages of the research. Co-design will be critical to good delivery along with strategic use of conferences, workshops, and end-user technical groups such as the Council Biomanagers, MPI Bionet, PF2050 and DOC.

Two key areas to pursue for **Goal 3** are gene-based toxins and the application of Artificial Intelligence.

Ultimately, **Goal 4** aims to create defendable mainland areas, free from predators. This would allow the "free-from" areas to be co-joined across New Zealand which, once achieving coverage, would achieve the Predator Free 2050 goal. The exact geographical approach requires a spatial strategy to be developed.

Goal 4 has the capability to provide a solution at efficiently defending re-invasions, thereby retaining the impact from the initial eradication effort. This goal requires a blend of novel thinking, industry knowledge, and technology expertise. SO5PB will utilise strategic partnerships combining specialist knowledge of scientific experts from academia, CRIs and DOC, and engineering/technology experts from industry. A multi-discipline and multi-industry approach will be used for initially identifying areas to be further investigated. The behavioural ecology of the pest species will be vital to understand.

This approach will initially focus on the deployment of existing technology in a novel way. The application of newly developed tools and technologies should further improve efficiency and efficacy. The system that is developed will have a huge ROI as it would be a transformative step in achieving a predator free NZ.

The delivery pathway for **Goal 5**, "Ensure legislative and socio-cultural licence to implement the technologies at national scale", is twofold. The first pathway is in the regulatory space and requires only a small audience of key developers and practitioners to be reached, whereas the second pathway, the social-cultural pathway, will need to be more comprehensive and wide-ranging. The second pathway will influence the first as social-cultural acceptance may be required before a tool can gain regulatory approval.

Developers and researchers will need access to the EPA, ACVM, MPI and other government departments, as well as policy support to change legislation and get approval to develop, trial and implement novel technologies in the field.

Ensuring social-cultural license will only be achieved if engagement and communication around novel tools reaches a wide sector of the community and is flexible enough to respond to a broad range of values and concerns. It will therefore be essential to share social values research and cultural understanding to a wide range of communities and practitioners so that engagement and communication utilises the most up to date social research and understanding around community concerns.

Pathways will therefore rely on delivery by many different practitioners throughout the country and it will be important for them to receive adequate messaging and training. Pathways to reach key practitioners include: the Predator Free 2050 Knowledge, Innovation and Improvement Collaborative Group; the regional council Biomanagers; industry biosecurity groups for Goal 5 and university invertebrate science groups; industry biosecurity managers; specific iwi groups (e.g. TTW); and National Science Challenge iwi partners. Additional investment in regional roadshows and training, conferences, field days, maintaining a high quality website of best practise and knowledge such as Bionet, and having a comprehensive communication strategy for new research that covers all media types could help ensure results reach a wide audience.

An additional pathway is to include co-design with key partners in the tools development right from the initial stages. This will ensure social-cultural concerns can be addressed throughout the development process, tools are produced that are already acceptable and the wider community does not have to be convinced that they are safe.

Risks

Invertebrates

There is a risk for **Goal 1** that agreement cannot be made on which exemplar pest and novel technology should be targeted. The wide scale removal or control of the pest needs to bring significant benefits for a range of sectors if it is to overcome potential social acceptance barriers. While social wasps are an obvious choice because of a wide-scale nuisance factor and concurrent biodiversity and economic impacts, there could be more support from groups such as the horticulture sector for control of a pest that creates economic impact on their industry. Ensuring that a robust inclusive consultation occurs both at the selection phase and also throughout delivery of Goal 5 is important to mitigating this risk. The chosen technology and exemplar pest need to be matched and married. Ensuring good quality facilitation of the selection process and a wide range of involvement of participants will help mitigate these risks. Furthermore, a prioritised short-list of invertebrate pests will be created, enabling the team to pivot quickly should the first target prove too difficult initially. We believe that risks associated with choosing exemplar pests and technologies can be minimised by using a small committee of individuals who would be unlikely to have a financial conflict of interest in the outcome of pest and technology decisions.

Regardless of the species chosen, we believe that the development of the technology platform will enable rapid availability for application to other pests.

The primary risk for **Goal 2** is related to the development of a novel technology for control of the pest. It is currently difficult to quantify the risk without knowing specifically what technology will be chosen. Every new technology is untested and has risk. One technology that has potential for development is, for example, gene drive methodologies. While there are processes and approaches to the use of the CRISPR-Cas9 system for genetic modification in hymenopteran insects, there is risk with this technology in that it hasn't been implemented in social wasps previously. There is risk that gene targets selected may not be effective when altered. The incorporation of international researchers working with the CRISPR-Cas9 modification of hymenopteran insects, and further development of existing genetic work in New Zealand, should mitigate such risks to an extent. Should other technologies be chosen, different risks and solutions would emerge.

The largest identified risk around novel technologies involving genetic manipulation, is public acceptance. Public sentiment is mixed at the moment and it is likely that social licence will not be obtained unless some hard work is done now to engage the public and develop a licence (see Goal 5).

Vertebrates

In regard to **Goal 3**, the major risk with developing step-change technology is that it is not technically fit-for-purpose or too expensive to be operationalised. These risks will be minimised by clarifying technical and price specifications at the start of each project and reviewing these with a technical advisory group at regular intervals. Each of the proposed technologies being recommended in this report address the current concerns of 1080 use, and so it is anticipated that this goal directly addresses this current risk and does not raise additional ones. Nevertheless, new products, especially toxins, will need a range of regulatory requirements, and these might delay the delivery of new products for translation and adoption. Changing political and funding priorities are an ongoing risk.

The main risk associated with **Goal 4** is that the technology is unsuccessful during initial field trials. However, the first stages of the project with consortium collaboration and via a cross-discipline workshop, minimize this risk. Sufficiently experienced and qualified people, both technology experts and ecologists, will be consulted to identify suitable solutions to investigate and develop.

In case the solution does fail during initial trials, there will be a number of solutions which are considered the most likely to succeed. This will enable other solutions to potentially be developed consecutively, thus minimizing risk to overall goal failure, or providing the option to pivot to another technology. However, this will depend on available funding.

Depending on the solution devised, there could be hurdles with end-users, landowners and iwi for the deployment of the solution – both in the trial and any future scale out. Other perceived risks include a lack of collaboration and effective, clear communication between disciplines. An example would be that an engineer would not clearly understand the animal characteristics known by an ecologist or would misinterpret the requirements of the solution. As with all the goals, extensive consultation and early co-design will help mitigate risks.

Goal 5 is to ensure legislative and socio-cultural licence to implement the technologies at a national scale. Similar to previous risks, the risks for this goal are dependent on the technology and choice of pests involved. Despite working up front with the community and legislative bodies there is a risk that social license cannot be gained for novel technologies within the 5 years, or that legislative change does not occur. This could result in preventing the national roll out of a novel technology.

The current social concern and push back around the use of sodium fluoroacetate (1080) and glyphosate are important examples of what can happen when social-cultural licence is not adequately invested in during tool development and use. Investing in Goal 5 and social research, as well as ongoing information sharing, will help prevent these scenarios being repeated with the next novel technologies. It is, however, important to be clear that the social research is around social values, audiences and communication pathways; there is a risk it could be conceived as social engineering, which it is not.

Communication champions will be needed to mitigate risks associated with the social-cultural licence of these novel technologies.

Communications and relationship management

For invertebrate pests, most of the communication and relationship management will be achieved through the completion of **Goals 1 and 5**. Specific, timely communication updates to all identified groups will be the key requirement to ensure ongoing acceptance of outcomes and success for the goal.

Communication with the New Zealand science sector is essential to evaluate and select an exemplar invertebrate pest and select novel technologies with potential to achieve a step-change. We hope to initiate this process in late 2019. We will develop a one or two page form in which groups can submit technology and pest proposals to a small committee, composed of individuals familiar with Tranche 1 and with Māori and National Science Challenge representation. Communication will be essential with groups such as AgResearch Ltd, Plant & Food Research Ltd, Manaaki Whenua - Landcare Research Ltd, and the universities. A key component will also be the use of a survey process for gaining input and ultimately acceptance from a cross section of society.

For Goals **3 and 4**, important relationships are with the project lead and between the project team, particularly across disciplines. There will have to be clear communication channels between scientists and technology developers/providers. A dedicated programme leader will need to have, or develop, linkages with researchers, end-users and key stakeholders.

To ensure novel technology solutions are cost-effective and suitable for scale-out, potential manufacturers will have to be consulted. Impacts on supply, such as manufacturing turnaround, price point and available delivery will need to be analysed, not only for the trials but also for future nationwide use.

Iwi will need to be consulted and included during the project timeline to ensure that the suitable solutions are culturally acceptable forms of control. This is important not just for local field trials, but also any potential risks when attempting to deploy nationwide.

End users will need to be consulted at the project commencement to understand project area requirements and potential solution usage. Throughout the project, end users should be consulted for feedback to provide critique and identify areas for change or improvement. For the field trials, a variety of end-users will be communicated with to establish suitable trial sites.

For **Goal 5**, ensuring legislative and socio-cultural licence to implement the technologies at national scale will require outstanding communications and relationship management. The social research carried out as part of this goal will be used to inform relationship management and communications for all the SO5PB goals. For instance, it will highlight the key audiences that we need to engage with and the social and cultural values we need to understand and connect with.

We anticipate that a comprehensive communication and engagement plan will be developed in 2021 and updated annually based on the results from ongoing social research. However, as a minimum, we would expect this plan to include:

- Public outreach, including annual hui & regional workshops.
- Reaching out to new partners, including those that may not agree with the use of existing tools e.g. anti-1080 lobby, SPCA, hunting groups.
- Workshops with policy experts and legislative bodies (EPA/MPI).
- Employing a dedicated person managing partnership.
- Utilising marketing/brand/advertising experts.

Essential activities

Initial activities will focus on convening national and international experts to identify and prioritise which invertebrate pests we should target and which control technology to develop as a demonstration of what's achievable by 2024. The intention here is to focus investment across researchers and science providers on one pest and one control technology in order to maximise return on investment in the shortest period of time.

Similarly, with vertebrate predators, we will draw on the knowledge and expertise of international researchers and industry to focus on one technology solution for both Goals 3 and 4 and maximise the use of effort and time to product demonstration.

Alongside these initiatives we will engage with legislative bodies and the public to understand current issues and develop and implement a communication and engagement plan. The latter will take the public with us for the use of what some will consider controversial technologies, but will be required if we wish to achieve a step-change in these fields.

1. Evaluate and select an exemplar **invertebrate** pest to eradicate or control at a large scale and select novel technologies with potential to achieve a step-change.
    - National invertebrate pest committee formed to deliver the goal of determining a pest species to target and control methodology to be developed.
    - Develop Terms of Reference for the committee.
    - Public survey competition developed and run to garner engagement and support.
    - Ensure submissions from scientists include potential national and international partners.
    - Have the committee meet to identify exemplar pest and novel technology. A symposium was initially suggested to aid in this decision-making process. We think, however, that organising and running an international symposium within a 6-month period is unrealistic. We believe that a committee decision would be sufficient after a submission process.

2. Demonstrate the application of novel technologies to control or eradicate the selected **invertebrate** pest, in order to eliminate its impacts at large scales.
    - Development of model platform to demonstrate outcomes.
    - Identify relevant teams for delivery, based on selected pest and technology.
    - Understand legislative framework for technology so we know the hurdles which we may need to overcome in achieving product registration.
    - Identify affected parties who may support or oppose and engage with them as appropriate.
    - Develop and test novel technologies. Seek co-investment where research institutions can align core science funding.
    - Share process with all parties.
    - Obtain necessary approvals, regulatory and socio-cultural.
    - Choose demonstration site.

3. Demonstrate the application of novel technologies to eradicate **vertebrate** predators in order to eliminate their impacts at large scales.
    - International workshop to scan technology. Ensure AI/robotics/'smart' technologies are part of the mix. The workshop will ensure trans-disciplinary input is obtained to either identify novel technologies not currently known or to confirm those research priorities already identified. It is important that input is obtained from as many potentially relevant disciplines as possible, including ecology, chemistry, toxicology, pharmacology, electronics, artificial intelligence, robotics, physiology, behaviour, and defence technology.

- Develop research programme infrastructure. Develop data commons.
- Find trial sites in a wide range of environments. Undertake pen testing and field testing.
- Ensure genomic mapping of pests is completed and available. Research gene designed species specific selective toxin and develop.
- Spatial strategy for pest eradication developed.
- Support development and application of AI solutions.
- Data connectivity for back country installed. Automated sensors developed.
- IP management. Engage with EPA/ACVM.

4. Demonstrate at least one broadly applicable, non-fence option for defending large-scale, **vertebrate**, multi-pest eradication sites.
    - International workshop for idea generation. Bring together AI, engineering and toxin sciences from both research institutions and commercial companies to develop device concepts. Seek collaboration and co-investment from companies involved in co-design.
    - Investigate eradication zones as barriers to movement (e.g. farmland). Include engagement with farmers and landowners to get early co-design and buy-in for when we wish to up-scale.
    - Gain an understanding of animal psychology from pest experts. Support development of AI sensors and lethal devices.
    - Data connectivity solutions for remote areas developed and installed. Investigate and develop spatial strategies for managing pest movement.
    - Wānanga/hui re: options for iwi/hapū mātauranga and kaitiaki.
    - Find appropriate trial sites and get landowner approval. Product registration (if required).

5. Ensure legislative and socio-cultural licence to implement the technologies at national scale.
    - Assessment of current state of legislation and public opinion to understand our baseline existing "social licence".
    - International symposium, EPA/ACVM workshop, and series of hui or wānanga to understand international positions on technology options and secure early engagement with regulators and relevant stakeholders.
    - Develop a social research plan/programme.
    - Develop marketing and engagement strategy.
    - Gain legislative approval for trials and field use.

Essential partnerships and relationships

Goal 1 we believe one of the first steps in our programme will be to select a mana whenua and non-Māori champion for this programme, in order to facilitate a strong partnership with iwi, hapū and other community groups. A strong relationship will be needed with national and international scientists, biodiversity managers including DOC, regional councils, EPA, and MPI. These groups will be involved in the evaluation and selection of an exemplar invertebrate pest and will select novel technologies with potential to achieve a step-change

For **Goal 2**, the national and international science partnerships and relationships formed will be dependent on the choice of pest and technology being developed. Our goal is to maintain the partnership with iwi, hapū and other invested groups through the mana whenua and non-Māori champion for this programme.

Key research partnerships for **Goal 3** and **Goal 4** will be identified/confirmed through holding an international workshop (step 1).

For species-selective toxins there will need to be key partnerships between CRIs, universities, drug manufacturing companies, pest control manufacturing companies and key pest control agencies (e.g. DOC, OSPRI). Ongoing relationships with social scientists, ACVM, EPA and iwi/hapū will be required to ensure any toxins developed have the necessary social licence and regulatory approval for adoption and scale up.

For the development of intelligent control devices and barrier systems, partnerships will be developed between CRIs, universities, product developers and manufacturers. Key relationships will need to work through any conflicts that might arise between the need for commercialisation and IP protection, versus working in an open-source environment. Relationships with key end-users will also be critical to ensure any technology developed will be fit-for-purpose and affordable. These relationships could be managed and made operational through developing a technical advisory group (TAG).

Manaaki Whenua – Landcare Research has recently secured MBIE funding to identify survivor behaviours and they will be a key partner for this research. Additionally, because PF2050 Ltd and DOC's PF2050 programme support tool development it is essential these agencies are key partners.

The PF2050 collaborative groups can assist these projects by providing an interface with many stakeholders. PF2050 Ltd, OSPRI, DOC and regional councils are also important partners. Federated Farmers, Beef+Lamb NZ, Dairy NZ and Fonterra will be key relationships to understand the potential impact any solution might have.

For **Goal 5**, our relationship with iwi, hapū and rūnanga, will be essential for gaining social licence and legislative change. This may take the form of a partnership approach to research as well as building mutual trust and understanding of what social licence means for Māori.

With respect to invertebrate pests, Goal 5 will require the development of trust and mutual ownership of the whole process from the outset if it has any chance of success. Given the general position of many New Zealanders to the broad concept of genetic modification and the associated perception and lack of understanding of the complexities of technologies such as gene drive, there will need to be an uncoupling of the perceptions around any form of gene modification and the 'New Zealand Inc' brand. Key trusted partners who can collaboratively assist in the collective education and demystification of the technologies is essential for any success. There will also need to be a relationship formed with the media and key channels of social media to be able to manage ongoing conversations that will result from this work. Fortunately, there has been a growing momentum and media communication within New Zealand to reconsider genetic modification, led by individuals such as the Prime Minister's Chief Science Advisor Prof. Juliet Gerrard. If gene drives are chosen as technologies for investigation we will build on this momentum. Other approaches, such as the use of pheromones, may need a lesser and different approach for social licence and legislative change.

Vertebrate predator work is in a fortunate position in that research in this area has already started and is supported by nationally significant programmes such as Predator Free 2050. The Challenge will be able to utilise existing partnerships and relationships to support this work. Partners that are already engaged include Predator Free 2050 Ltd, Predator Free NZ Trust, Predator Free 2050 Knowledge, Innovation and Improvement Collaborative Group, OSPRI, MPI, DOC, regional councils, Sanctuaries NZ, Manaaki Whenua, CRIs and universities.

Reaching out to other non-traditional partners will also help support this goal. New relationships could be forged with organisations such as Fish and Game, Tourism New Zealand, the New Zealand Māori Forum and key influential iwi groups for invertebrate pests; and the SPCA, Anti-1080 Lobby, the Royal Society, National cat strategy group and Federated Farmers for vertebrate predators. It will also be important to work closely with legislative bodies such as EPA and ACVM.

Essential resources

All goals will require access to mātauranga Māori expertise to provide advice and input through all stages of development.

The requirement to have free flowing and freely available data (a Data Commons) supports all goals, as does requiring affordable data connectivity across all of New Zealand's geographical extent.

Goals 1, 3 and 4 include a committee formation as an early step. A project manager is suggested to pull together and facilitate committee formation.

Goal 2 is to demonstrate the application of novel technologies to control or eradicate the selected invertebrate pest in order to eliminate its impacts at large scales. The essential resources will depend on the technology and exemplar pest examined. However, the major resources are scientific expertise, laboratory availability, insect rearing, release and development costs, and monitoring costs. We will also likely develop some modelling systems to determine likelihood of outcomes for implementation. There are already entomologists working in this area, with MBIE funding, that could offset these costs.

For **Goals 3 and 4** capability will include engineers, ecologists, animal behaviour experts, AI developers, chemical ecologists, and product developers and marketers. These disciplinary experts will provide knowledge related to genome mining, drug development, product development and marketing, animal behaviour, product design and artificial intelligence/machine learning.

Adequate funding will be critical in order to deliver the necessary step-change R&D, and lab and pen trial facilities will be required.

Goal 5. Research funding for social scientists is required, as is funding for policy experts and lawyers. This work links closely with SO2, so resource sharing and joint funding could help increase efficiency and effectiveness.

Section 3: Quantifying Cost Elements

Budget details and cost narrative

We have assumed that a total cost is required, not just the likely investment requirements of BHNSC. All of these goals either have existing work underway, or co-investment options available. Ideally, some investment from BHNSC will leverage and accelerate. Full and detailed resource plans are a next step for SO5PB.

Two key enablers have been identified for this SO – a Data Commons and Affordable Data Connectivity for remote locations. An investment of $500k per annum is recommended to accelerate the creation of a data commons. Data connectivity could be solved by a one-off investment in satellite infrastructure (estimated $10m). The ability to affordably transmit data in remote areas is a high impact investment, enabling AI and Smart Devices, automated monitoring, etc.

Goals 2, 3 and 4 will be the most expensive as they involve the development of novel technology capable of generating a step-change in the control and eradication of both invertebrate and vertebrate pests.

For **Goal 2**, the budget resources will depend on the technology and exemplar pest examined. We note the ambitious nature of the overall aspiration for New Zealand to be enabled technically, legislatively and socio-culturally to efficiently eliminate the impact of invertebrate pests across the country. For a technology such as gene drive, substantial technical work would be needed to develop this technology to be ready by 2024. A fully costed programme to deliver this aspiration would require time from technical staff, post-doctoral fellows and scientists in an equipped laboratory. We would estimate a fully costed programme for this goal would equate to more than $2 million per annum, and would be dependent on the technology and approach chosen.

Any genetic modification programme takes time, with much 'trial and error' involved. In a typical, resource-limited science programme this work would be slow, constrained by the availability of scientists, technicians, lab and insect rearing facilities and capital. In such a scenario, 2024 would be an unrealistic timeframe for gene drive technology.

However, in this scoping panel report we seek to bring together a team of scientists and facilities from multiple CRIs and universities to work together to accelerate the programme, running parallel work – genetic modification, insect rearing, release and monitoring trials – simultaneously. This will enable a fast-fail approach to be taken and allow teams to pivot quickly when one or more teams show promising results, providing support for the most likely line of work worth pursuing. Bringing such a team together and maintaining it for 5 years is likely to cost $3-5m per annum.

There is potential for linking NSC funding with existing MBIE-funded work on novel pest control programmes involving pheromones, gene silencing, or new programmes being proposed to MBIE on gene drives. We will look to leverage the most promising of these with this work programme. Aligning these work streams and bringing scientists on board with this SO5 goal will be challenging but is achievable with a well-funded programme that provides strong support and clear, rewarding goals for the scientists involved.

Similarly, for **Goal 3**, development of any novel vertebrate eradication technology will require design, prototype manufacture and testing to get it to a point where it is sufficiently robust and reliable to be rolled out for large-scale trials. If one of the new technologies of preference is a new toxin then we will bring a multi-disciplined team of ecologists and chemists together from CRIs, universities and private companies such as BioPacific Partners to work on developing a solution. Investigating several solutions simultaneously in several laboratories will be expensive but maximise outputs in the timeframe. It will require lab and pen trials, testing on non-target species and environmental safety testing before going to the field trials required for subsequent product registration. Either of these options is likely to cost in the order of $2 million per annum.

Major cost elements to **Goal 4**, in order of requirement, include workshop organisation and marketing to ensure suitable experts are present at the workshop; solution research by technology experts and ecologists; development of priority solutions to an acceptable proof of concept stage; and large-scale field trial set up, management and monitoring. Expensive components of these work streams include AI software development and field trials. This is likely to cost $2m per annum.

2024 Goal Metrics

Goals	2020	2021	2022	2023	2024
1. Evaluate and select an exemplar invertebrate pest to eradicate or control at a large scale and select novel technologies with potential to achieve a step-change.	July – Invertebrate pest and novel technologies selected.				
2. Demonstrate the application of novel technologies to control or eradicate the selected invertebrate pest in order to eliminate its impacts at large scales.	September 2020 – Teams formed to develop novel technologies. Strong partnership network established. Mana whenua champions & non-Māori champions identified.	Insect rearing facilities developed. Target genes identified (wasp example).	Computer simulations completed.	Novel technology developed. Invertebrate pest population reared. Consultation with EPA, iwi and hapū groups, and the public completed, with legislation.	Novel technology ready for release (hypothetical example – gene drive for wasps).
3. Demonstrate the application of novel technologies to eradicate vertebrate predators, in order to eliminate their impacts at large scales.	International workshop held. Identify priority technologies to develop and form best team. Identify genes that encode receptors and proteins. Develop R&D plan to clarify	Potential agents that inhibit target receptors identified and progressed to validation trials. Pen and field trials completed to identify strengths and	Optimise agents using medicinal chemistry for selectivity and toxicity identified. Technology developed to stage of being ready for field trials. Complete	Optimised agents pen tested against at least one target species. Field trials at operational scale completed to assess	Compile data required for product registration through further pen trials. Complete field testing and finalise operational design

	technology needs for intelligent control devices. AI integrated prototype ready for initial testing.	weaknesses. Trials of mechanical/electronic options commence.	establishment of Data Commons.	efficacy and cost effectiveness.	ready for large-scale adoption.
4. Demonstrate at least one broadly applicable, non-fence option for defending large-scale, vertebrate, multi-pest eradication sites.	International workshop held. Design investigation into farm eradication as a barrier (collaborative approach). Secure additional funding and/or partners. Evaluation and industry/partner review of concepts.	Technology development and testing commences (multi-year effort).	Complete establishment of data commons. Small scale field trials commence on selected sites.	Deploy data networks. Conduct field trials with collaborators such as ZIP and PF2050.	Large-scale field trials undertaken.
5. Ensure legislative and socio-cultural licence to implement the technologies at national scale.	Social research – values assessment. Establish/ understand baseline with respect to social licence for selected tools/technology. Key target audiences are established. Long term social-cultural research needs are defined, and a research programme put in place.	Gap analysis of legislative need and policy gaps - we understand the key legislative barriers that need to be solved to allow our novel technologies to be utilised. Link to larger, national GMO discussion. Utilise year 1 baseline social research to inform communications & engagement approach. Start long-	Completion of a range of national hui on technology and associated issues. Policy development based upon gap analysis. Consultation carried out around policy changes. We have draft policies ready for government adoption. Social research continues and is updated based on	Make legislative changes (EPA, Biosecurity Act) to allow tools to be used. Social research continues and is updated based on feedback loop (see below). Communication and engagement plan, including annual hui & regional workshops, are continued and updated based on research.	Legislation change (if required) enacted to allow new technologies. Feedback loop created with all other goals.

		term research as designed in year 1. We have a comprehensive communications and engagement plan that address key findings from the social – cultural research. As a minimum we have conducted hui & regional workshops.	feedback loop (see below). Communication and engagement plan, including annual hui & regional workshops, is continued and updated based on research. Public surveys show that there is support for the use of our novel technologies and for the required legislative change. End-products have been adapted/co-designed with partners. The number of partners can be used as a measure of effectiveness.	Public surveys show that there is support for the use of our novel technologies	

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