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# Mātauranga Māori framework for surveillance of plant pathogens

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Faced with growing biosecurity risks and threats, countries worldwide seek to protect their biodiversity from ecosystem degradation and loss. Biosecurity surveillance of plant pathogens and the diseases they cause is fundamental for management and eradication of these risks. To date, the surveillance systems in Aotearoa New Zealand have reflected empirical scientific principles and have been largely devoid of mātauranga and te ao Māori, which have seldom been regarded as valid or relevant knowledge systems to inform biosecurity. Because of this, mana whenua themselves have been disconnected from these systems. The inclusion of mana whenua and their mātauranga is important, not only to recognise their role and rights as indigenous peoples of Aotearoa New Zealand, but because it is through place-based approaches that better biodiversity and environmental outcomes can be achieved. Here, we describe a mātauranga Māori framework for surveillance (MMFS) of plant pathogens, which introduces the principles and methodologies that aim to elevate mana whenua and mātauranga research into the biosecurity and science systems. The MMFS facilitates the co-existence of mātauranga and empirical scientific knowledge without the need for inter-dependent validation, on the assumption that this will lead to better research and operational outcomes. It addresses issues around data ownership and sovereignty, informed consent, and cultural licence. We present a case study where the MMFS has been applied to research initiatives aimed at addressing myrtle rust and kauri dieback in Aotearoa New Zealand. The MMFS informed the development of a data storage platform, which anchors data to the place of origin, recognising its provenance and giving effect to Māori data sovereignty. This process ensures mana whenua have timely access and use of existing and emergent data. Following the principles of the MMFS, we developed and used a "proof of pathogen absence" tool to co-design with mātauranga environmental experts a risk-based surveillance plan for the purpose of demonstrating freedom from disease in areas where a pathogen has not been detected. The MMFS provides a way of planning and implementing environmental surveillance that can be applied to the full range of environmental problems internationally where indigenous populations are involved.

KEYWORDS
**biosecurity, myrtle rust, kauri dieback, New Zealand, traditional indigenous knowledge, cultural licence**

# 1 Introduction

The contribution of indigenous traditional knowledge to environmental management, including protection of biological heritage from biosecurity risks and threats, is important globally because it offers long-term knowledge on the state of the biological, physical, and spiritual environments (Berkes and Berkes, 2009; Gagnon and Berteaux, 2009; Berkes, 2017; Wehi and Lord, 2017). This level of knowledge and understanding of the environment, acquired and passed on across generations, gives rise to a distinctive perspective on underlying ecosystem structures which can contribute towards more robust biosecurity outcomes (Kuru et al., 2021). Furthermore, adoption of indigenous values can result in meaningful involvement and a greater chance of long-term success as indigenous groups can see benefits, in the form of economic returns and upholding of cultural values, from involvement in incursion responses or long-term management of forest pests and pathogens (Wehi and Lord, 2017).

In Aotearoa New Zealand, many hapū/iwi generate and continually update information on biodiversity and ecosystems at fine spatial resolutions through engagement at place with their environment, share this knowledge broadly through sophisticated social and extended familial networks, and pass it down through generations. The Māori worldview sees people as having deeply interconnected and interdependent relationships with their natural environment, elevates the wellbeing of future generations above that of current generations, and places the status of nature above that of humans in any environmental decision making. Despite its importance and the protection of rights, interests and property of Māori guaranteed within Te Tiriti o Waitangi, mātauranga Māori is seldomly regarded or adopted as a valid and relevant knowledge system that can inform regional and national biosecurity (Lambert et al., 2018; Black et al., 2019). In this context, the challenge has been to recognise that both te ao Māori and empirical scientific knowledge systems have an equitable responsibility and part to play in the protection of people and places (Lambert et al., 2018).

Plant pathogens are of great concern globally because of the severe detrimental impacts they can have on environmentally, economically, and culturally significant flora and fauna (Koblentz, 2010; Chakraborty and Newton, 2011; Singh et al., 2023). In Aotearoa New Zealand there are two serious diseases of native flora. Kauri dieback – caused by the microscopic soilborne pathogen *Phytophthora agathidicida* – is devastating the remnants of iconic native kauri (*Agathis australis*; Waipara et al., 2013). Kauri are considered a taonga by Māori and a species of special significance to many New Zealanders. Myrtle rust – caused by the airborne rust fungus *Austropuccinia psidii* – threatens several of Aotearoa New Zealand's native myrtle species, such as iconic pōhutukawa (*Metrosideros excelsa*) and rātā (*Metrosideros* spp.), and other native myrtaceous that are fundamental to Māori culture, language, identity, and intergenerational narrative and history (Teulon et al., 2015; Black et al., 2019). Additionally, myrtle rust has the potential to have severe economic impacts on plant nurseries, forestry, and horticulture (Beresford et al., 2019).

Surveillance is fundamental for the management of plant pathogens and the diseases they cause (Parnell et al., 2017; Carvajal-Yepes et al., 2019). Surveillance comprises the system of tools and techniques that enable increased detection, knowledge, awareness, and reporting of plant pathogens that can inform management actions to prevent or minimise their impacts on host plants and ecosystems. In trying to address kauri dieback and myrtle rust, Māori have struggled in their attempts to collaborate with researchers and government officials, both locally and nationally. This is primarily because the New Zealand biosecurity system engages hapū/iwi well after decisions and prioritisation for resources and funding have been set by government agencies. Rangatira are directed by authorities to seek out "community" values and concerns, but hapū/iwi exert very little influence over the decisions and management methods that are used to protect their taonga.

In addition to the above shortfalls around indigenous engagement, data needed for surveillance planning and implementation are collected and managed by multiple agencies (e.g., government departments, government-funded crown research institutes, universities, and regional councils) which are disconnected from the places (and people) where they originated (Campbell and Teulon, 2018; Bradshaw et al., 2020). Surveillance is often intermittent, irregularly reported, and follows different methodologies scaling through local, regional, and national levels. Challenges for regular, reliable, and systematic data sharing have been created by a history of mistrust between partners, tensions in the protection of cultural heritage, concerns about data mining, and the desire to protect confidential commercial information. Surveillance data, though intended to be shared, is more often "banked" and inaccessible, which limits their long-term usefulness. This creates data integrity issues, with data being duplicated or "lost." Many kaitiaki and rangatira are concerned that surveillance is currently being delegated to community groups and report a lack of access to data about their sovereign territories, and poor resourcing and funding to produce and curate data. Disadvantaged by these challenges, hapū/iwi are unable to effectively participate in planning and in conducting surveillance that enables kaitiakitanga of their taonga and whenua.

There are significant challenges in ensuring that the inclusion of indigenous people and knowledge into the development of environmental management strategies or research priorities is done equitably (Harmsworth and Awatere, 2013; Lyver et al., 2019). Not all these issues can be solved quickly, but there are several steps that can be followed to begin working towards a more equitable relationship between indigenous and non-indigenous knowledge. In this paper, we present the principles and methodologies of the mātauranga Māori framework for surveillance (MMFS) of plant pathogens, which aims to elevate mana whenua and mātauranga research into the biosecurity and science systems in Aotearoa New Zealand. We first describe how the MMFS creates opportunities for the co-existence of mātauranga and empirical scientific knowledge, and addresses issues around data ownership and sovereignty, informed consent, and cultural licence. We then present a case study where the MMFS has been applied to research initiatives aimed at addressing myrtle rust and kauri dieback in Aotearoa New Zealand. Finally, we describe how the MMFS informed the development of two online tools: the integrated intelligence platform (IIP) and the proof of pathogen absence (POA). The IIP is a data storage platform which anchors data to its place of origin, recognising its provenance and giving effect to Māori data sovereignty. The POA is a tool to co-design with mātauranga and scientific environmental experts a risk-based surveillance plan for the purpose of demonstrating freedom from disease in areas where a pathogen has not been detected. Te Tiriti o Waitangi and WAI262 guided the development of the MMFS, which builds upon both existing and emergent understandings, values, approaches, and opportunities to improve surveillance in Aotearoa New Zealand.

## 2 The mātauranga Māori framework for surveillance of plant pathogens

The three principles of the MMFS centre around enabling equitable representation of indigenous and scientific knowledge systems in the development of research initiatives for the surveillance and management of plant pathogens. The principles are: (1) equitable status of knowledge systems; (2) equitable access to data and information; and (3) equitable investment and/or resourcing. We describe these principles below, including methodologies that have been developed to aid the application of these principles.

### 2.1 Mātauranga Māori and empirical scientific knowledge

In the MMFS, indigenous and empirical scientific knowledge are viewed to generate different manifestations of valid knowledge, promoting connections across knowledge systems in a respectful and culturally sensitive manner. The MMFS emphasises the complementarity of knowledge systems and the value in letting each system speak for itself without assigning one dominant knowledge system as an external validator; this is in contrast with the more common practice of requiring scientific validation of indigenous knowledge before its inclusion in decision making processes (Tengö et al., 2014). In the MMFS, research initiatives for the surveillance and management of plant pathogens are classified as falling within one of four quadrants (**Figure 1**): mātauranga Māori-driven, empirical science-driven, or a combination of both knowledge systems. Recognising and sharing this information serves as a legitimate starting point for further analysis and knowledge generation, and for the emergence of strategic trust relationships between players from both knowledge systems. It also helps to catalogue and describe examples and strategies for weaving indigenous knowledge and empirical science to identify key research gaps that may benefit from additional research and funding.

There are two overarching reasons why mātauranga Māori is important to the surveillance and management of plant pathogens in Aotearoa New Zealand. First, many mana whenua engage with their environment through place-based institutions that gather detailed knowledge of local biodiversity and ecosystems that is continually updated at fine spatial and temporal resolutions (Gagnon and Berteaux, 2009). This unique body of knowledge gathered through local, self-authorised observations reflects the specific characteristics of a location and can contribute to indicate wellness/illness of an environment and taonga, and/or presence/absence of disease and pathogens (**Figure 2**). Second, although this knowledge is place dependent, it can feed into a larger repository of information that can serve as a national network of plant and forest health status. For example, it can help examine the transferability and adaptability of cultural indicators and observations to different areas across Aotearoa New Zealand facing similar issues.

### 2.2 Equitable access to data and information

#### 2.2.1 Data custody and sovereignty

Key to the MMFS is the clear distinction between "data sovereignty" and "data custody." Data sovereignty states that data are subject to the laws of the nation from which data are collected and refers to the inherent rights and interests that Māori have in relation to the collection, ownership, and application of Māori data (Kukutai and Taylor, 2016). Data custodian refers to any person who acquires, curates, and shares data. Agreed protocols must regulate the flow of data among custodians who collect data and hapū/iwi who have sovereign authority over all data about their taonga. One of the main goals of the MMFS is to centralise all existing and new data and recognise and give effect to Māori data sovereignty by connecting data to its place of origin. This empowers indigenous people through timely access and access in perpetuity to existing and new surveillance data, which includes data collected and managed by diverse custodians (e.g., government departments, government-funded crown research institutes, universities, regional councils, commercial companies, and nurseries). Within the MMFS, any data about taonga is recognised through its provenance to a naturescape/waterscape/oceanscape, i.e., it is place-based and anchored to its place of origin. More specifically, data are linked to a designated "Biodiversity Management Area" (BMA).

The BMAs are spatially delimited areas based on contiguous Tribal Committee Areas (TCAs) that were gazetted under the Māori Social and Economic Advancement Act, 1945 and the Māori Community Development Act 1962 s8.[1] The gazetted TCAs represent geographical areas that designate sovereign tribal territories, where hapū held rangatira over the management and protection of taonga and their people. The process of documenting the BMAs required the digitisation of the original 434 gazetted narratives that described the TCAs (**Figure 3**). These narratives described the boundaries of each geographical area, through referencing natural features such as rivers, streams and mountains, but also named cartographical blocks. In some instances, copies of original historical maps depicting TCAs were sourced from the cartographic collection at the National Library of Aotearoa New Zealand. In the MMFS, the BMAs and associated digital standards (unique name, ID, and spatial attributes) provide a practical mechanism for including provenance of data, reshaping relationships between data, place and people within digital archives, collections, and libraries.

1 http://www.nzlii.org/nz/other/nz_gazette/

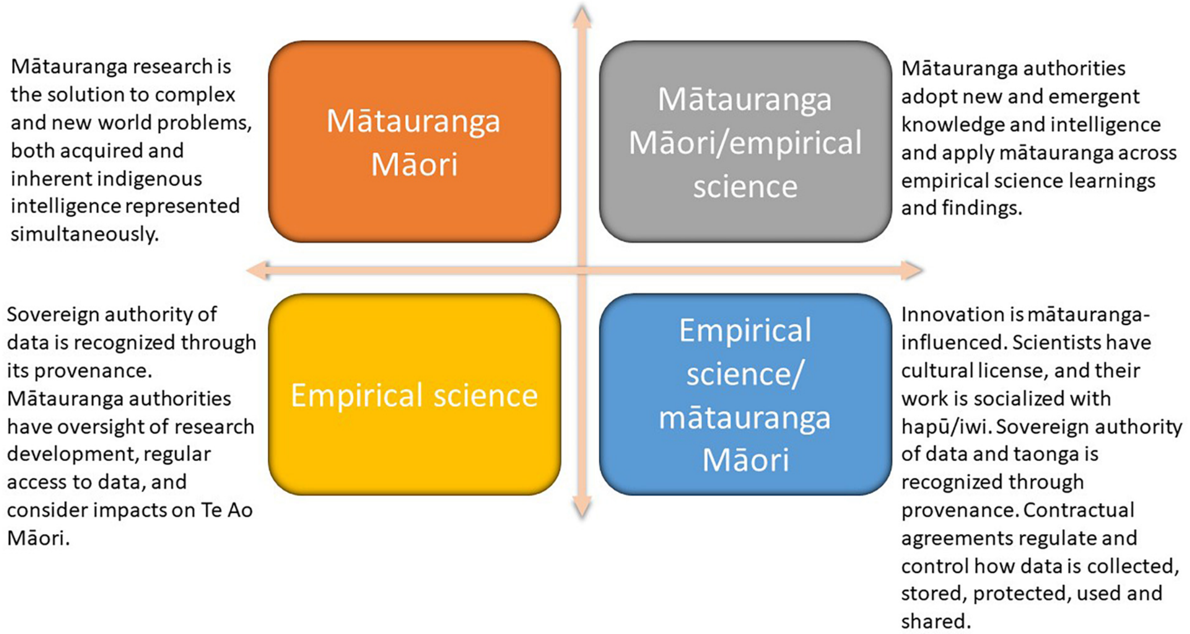


FIGURE 1
An illustration of a multiple evidence-based approach, where mātauranga Māori and empirical science knowledge systems are both recognised as generating useful knowledge to support the surveillance and management of plant pathogens. Recognising this value serves as a legitimate starting point for further analysis and knowledge generation, and for the emergence of strategic trust relationships between players from both knowledge systems.

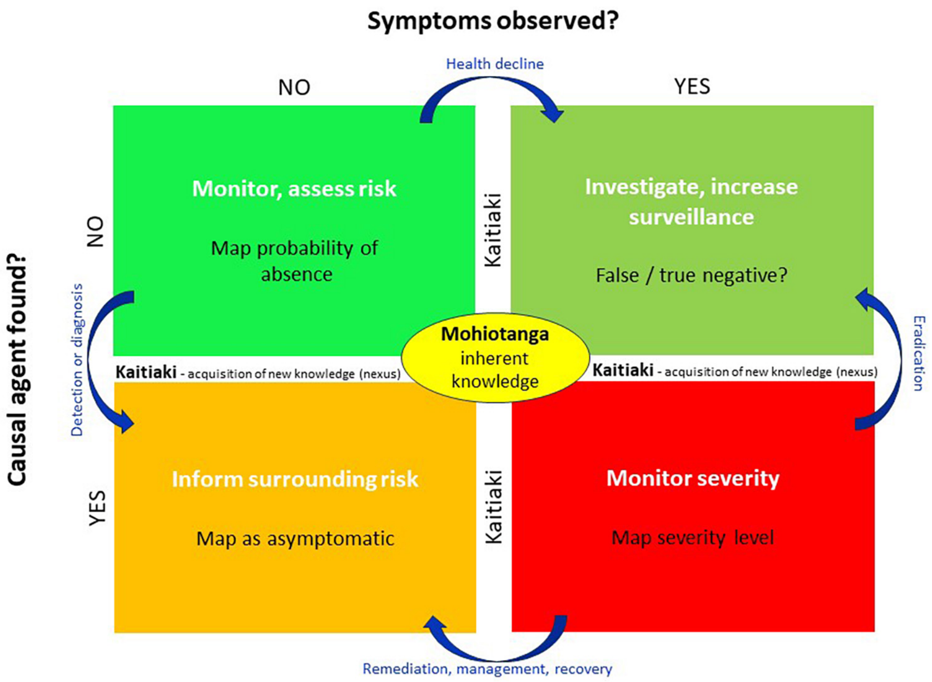


FIGURE 2
When the mātauranga Māori framework for surveillance is applied, the focus of surveillance is widened to give equitable status to the environment, pathogen, and host, as opposed to mainly focusing on the pathogen or disease. Kaitiaki involvement in research ensures that they acquire a better understanding about exotic species they do not have intimacy with, while supporting the cultural capability and sensitivity of scientists. In this way, kaitiaki continue to build upon their detailed, inherent, and unique knowledge of local biodiversity and ecosystems that reflect the specific characteristics of a location. This knowledge allows them to recognise changes in the wellness/illness of an environment and taonga, which can indicate presence/absence of disease and/or pathogens.

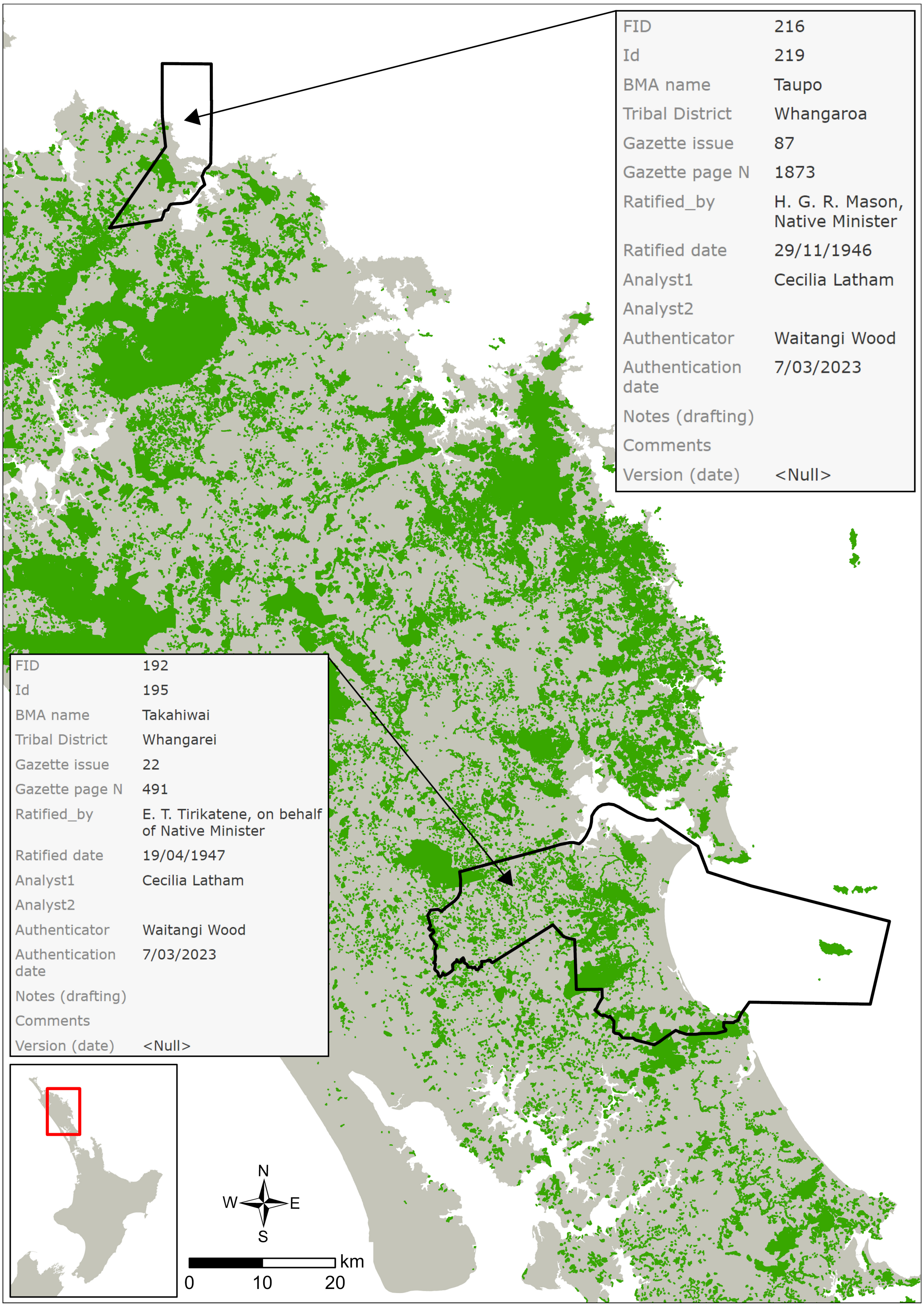


FIGURE 3
The boundaries of Biodiversity Management Areas (BMAs) were delimited using the Tribal Committee Areas (TCA) gazetted under the Māori Social and Economic Advancement Act, 1945. In the mātauranga Māori framework for surveillance, the BMAs represent the sovereign authority to which all data about taonga is anchored. Tribal Committee Areas were digitised from scanned historical maps or through interpretation of the gazetted narratives describing the boundaries of each TCA based on natural and cartographical features. The attributes that describe each BMA include the name, the tribal district, the gazette issue and page number, the minister that ratified the TCA and the ratification date (shown in the grey boxes). The map shows two examples of BMAs, one in the Whangaroa tribal district and one in the Whangarei tribal district.

Data custodians are distinct from the BMA sovereign indigenous authority, who are the direct "voice" for the naturescape (Marsden, 1988).

### 2.2.2 Informed consent

The challenge remains to establish culturally appropriate approaches, procedures, and participatory mechanisms that facilitate and guide surveillance efforts that respect, include, and promote indigenous aspirations and issues (Lambert et al., 2018). In the MMFS, linking data that are collected to a BMA enables a foundation for the development of cultural authority arrangements and opens discussions to inform processes that recognise sovereign authority of data and consider custodian control and consent of data use and dissemination. This process connects custodians with "tangata kōkiri," who have been identified for each BMA or BMA cluster. Tangata kōkiri can ensure that hapū/iwi values, societal and cultural norms, and mātauranga Māori are explicitly considered in designing and implementing surveillance in targeted areas. This is supported by the development of a "Disclosure Document," which provides a detailed description of the purpose and methodologies of the research and is intended as a first step in the engagement process. The approach recognises the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), where it is stated that free, prior and informed consent should be sought from the indigenous communities whose data are collected and used (Taiuru, 2020).

### 2.2.3 Cultural licence

Across BMAs, tangata kōkiri identify the hapū/iwi who are most affected by a given research project and establish a relationship that supports their engagement in the design, development, and/or implementation of that project. This approach establishes effective engagement channels, through which mana whenua can directly contribute to research projects and potentially develop their own mātauranga Māori investigations and applications. To this effect, cultural authority agreements (CAAs) have been developed to provide a practical tool for establishing best practices and review processes agreed upon by all parties involved. The implementation of CAAs demonstrates cultural licence to operate for a given research project (Hanna and Vanclay, 2013). Ultimately, the CAAs and other developments within the MMFS aim to provide a nexus between data custodians and the mana whenua with recognised sovereignty, established by the provenance and/or whakapapa of the data.

## 2.3 Equitable investment and resourcing

Third, mana whenua can provide the crucial workforce needed for surveillance and management across their naturescapes and for establishing long-term monitoring of taonga and plant pathogens (Hester and Cacho, 2017). Historically, government agencies have relied on external contractors who often work within a designated site determined by the agencies, rather than by the hapū/iwi most affected. Kaitiaki with intimate knowledge of their respective rohe have been called upon to support these external contractors to ensure that cultural sites of significance were being protected, instead of being trained and contracted to do the work. Consequently, mana whenua have grown increasingly frustrated at the prioritisation and funding of "preferred contractors" above that of hapū/iwi kaitiaki. Furthermore, once the surveillance contract is completed, unless there is additional funding, surveillance ends with little to no consideration for continued monitoring of the site. Investment in building capability and capacity of indigenous resource management units and their kaitiaki would ensure sufficient surveillance across geographical areas and enable long term monitoring, future-proofing biosecurity management and giving effect to hapū/iwi rightful role as rangatira, kaitiaki and Te Tiriti partners.

## 2.4 Case study: kauri dieback and myrtle rust

We tested the MMFS by applying its principles and methodologies to the development of a mainstream research programme (Ngā Rākau Taketake) focusing on kauri dieback and myrtle rust. The MMFS provided the foundations for linking empirical scientific research with mātauranga Māori research across 12 nominated BMAs whose taonga are affected by either of these diseases. By being directly involved in the research, mana whenua have acquired a better understanding about exotic species they do not have intimacy with, while supporting the cultural competency and sensitivity of scientists. Culturally intelligent and connected scientists are better able to engage with mana whenua, providing the foundation for high integrity trust relationships and ensuring that mana whenua and mātauranga Māori authorities are better positioned to support the application of mātauranga Māori in and alongside Aotearoa New Zealand's science system.

The focus of traditional disease surveillance programmes is often on the pathogen and its host, with surveillance programmes set up to locate the source and extent of infection, the symptoms and severity of diseases, the source of inoculum, the pathways for pathogen spread and the conditions that favour its development (Beresford et al., 2019; Bradshaw et al., 2020). However, as Lyver et al. (2017) suggest, the alignment of scientific-based measures with community-based ones can enrich and deepen knowledge about the state of biodiversity and broaden the relevance of monitoring and reporting within indigenous communities. As an example, discussions between mana whenua and scientists engaged to Ngā Rākau Taketake have led to the design of a set of tohu observations that complement "standard" kauri dieback and myrtle rust surveillance forms. These tohu reflect local mātauranga, which considers that the presence or absence of the pathogen cannot be ascertained by looking at the pathogen and its host alone, but rather by taking a more holistic approach that considers the general health and resilience of the environment (Chetham and Shortland, 2013). Practically, the complementary observations include sensory information (sounds and smells) and the presence/absence of other plant and animal species in addition to kauri and myrtaceae trees, and are collected monthly by mana whenua to assess changes across lunar cycles and seasons.

Another example of the application of the MMFS within the Ngā Rākau Taketake programme has been the co-development with hapū/iwi of surveillance research zones. These zones are locations of special value to mana whenua within their forests where they want to ascertain presence or absence of pathogen or disease on their taonga, yet of small-enough size to be surveyed using their current taiao capacity. Follow-up surveillance and biodiversity observations in these zones enhances the capability of kaitiaki to collect robust data and increases their understanding of kauri dieback and myrtle rust epidemiology. The approach puts the MMFS into practice with the following benefits. First, it supports mana whenua to build their surveillance and monitoring capability, which will enable them, working alongside scientists, to get a better understanding of the pathogens and the impact on their taonga. Second, it provides sophisticated solutions to curate, protect, share, and use existing and new surveillance data, recognising and giving effect to data sovereignty. Third, it widens the surveillance practice by supporting the collection of biodiversity observations alongside information about the pathogen and the disease (Jetz et al., 2019) and enables hapū/iwi to develop their own research enquiry and apply their mātauranga. Lastly, it provides avenues to determine where to invest and prioritise surveillance effort and resourcing within a BMA. Additional examples of the application of the MMFS to a variety of research projects under the Ngā Rākau Taketake programme can be found on the website https://bioheritage.nz/about-us/nga-rakau-taketake/.

The concept of biosecurity is not new to Māori. Traditionally, Māori practised many of the approaches that can be recognised within western biosecurity management and surveillance. These include eco-sourcing taonga; tracking and tracing taonga through whakapapa and narrative where plant species were introduced or gifted out of region; managing the impact of plant species on the balance of the natural environment to ensure resilience of taonga against natural or human introduced pathogens and diseases; stopping pathogen spread through practices such as rāhui; and establishing inter-tribal pathways that ensured that people did not venture into unauthorised areas or outside of designated travel routes. By recognising the complementarity of mātauranga and empirical scientific knowledge, and the importance of involving Māori and community into biosecurity management and research, the Ngā Rākau Taketake programme aims to achieve integrated management of kauri and myrtle ecosystems which will result in better research and biosecurity outcomes.

## 3 Integrated intelligence platform – an approach to support indigenous data sovereignty priorities

The IIP[2] is a user-registered web-based spatial data infrastructure for storing, viewing, mapping, and sharing of spatial data. The key challenge addressed by the IIP is how to practically encode indigenous provenance information and cultural responsibilities into existing and new surveillance data. Within the platform, the sovereignty of data is determined by the place of origin of the taonga, i.e., it is place-based and anchored to a BMA. In practice, any data uploaded onto the IIP is "tagged" as belonging to a given sovereign authority, which is represented by the BMA where the data were collected. During this "tagging," the tangata kōkiri from that BMA gains access to the data. Accordingly, any user of the IIP can request access to a specific dataset by requesting it from the custodian (who uploaded the data) or from the sovereign authority (who shares ownership of the data and is represented by the tangata kōkiri). The platform establishes common descriptors for the attributes of each BMA (**Figure 3**), including a field to identify the tangata kōkiri. The BMAs are designed to directly support and benefit hapū/iwi, and to signal that place-based information carries accompanying cultural rights and responsibilities, meaning that appropriate permissions must be sought for future use of that knowledge. By querying which tangata kōkiri is associated with a given BMA, researchers can begin to engage with the chosen hapū by following the appropriate communication channels. The use of the IIP by custodians encourages collaboration with indigenous tribal communities and creates a digital space for indigenous provenance. Data can be easily accessed and contributed by anybody holding surveillance and monitoring data. On the flip side, the platform ensures mana whenua have timely access to up-to-date data collected within their BMA, which is of utmost importance for decision-making (Hudson et al., 2016).

An essential goal of this data repository is to facilitate the discovery of and access to available resources. Such a process relies heavily on the quality of the metadata. The platform adheres to the ANZLIC Metadata Profile[3] and defines a minimum set of metadata that must be supplied for spatial datasets and other resources (**Figure 4**). See **Supplementary material** for a full description of each metadata attribute. It also defines a minimum set of attributes constructed from the Darwin Core[4] open standard to link biologically and ecologically important metadata with downstream data products. Furthermore, the platform allows custodians to input information about the contribution of Māori to the design and implementation of the project. For example, one metadata field allows custodians to indicate whether there is consent in place from the indigenous community for collection of the data (in the form of a signed CAA) and signal their level of engagement with hapū/iwi.

Digital field surveillance forms[5] enable trained kaitiaki to undertake monitoring of myrtle rust and kauri dieback to track their impact on plants and ecosystems over time, ensuring that the same data are consistently being collected by different observers. Both myrtle rust and kauri dieback field collection forms have been co-developed with kaitiaki and linked to online apps, collecting data via web or mobile devices, and defining a minimum number of attributes that need to be collected, many of which have predefined options. Collecting the same data from both infected and uninfected plants and the surrounding environment, and across data contributors will mean that in the future, data from different custodians will be comparable. This will provide a better understanding of the impact and severity of plant pathogens across BMAs and nationally. The key principles behind storing surveillance data on the IIP are transparency and confidence in the data-sharing obligations, and the opportunity for mana whenua authorities to review and approve research involving Māori-centric

2 http://iip.co.nz/

3 https://www.anzlic.gov.au/

4 https://dwc.tdwg.org/

5 https://arcg.is/1rWme51

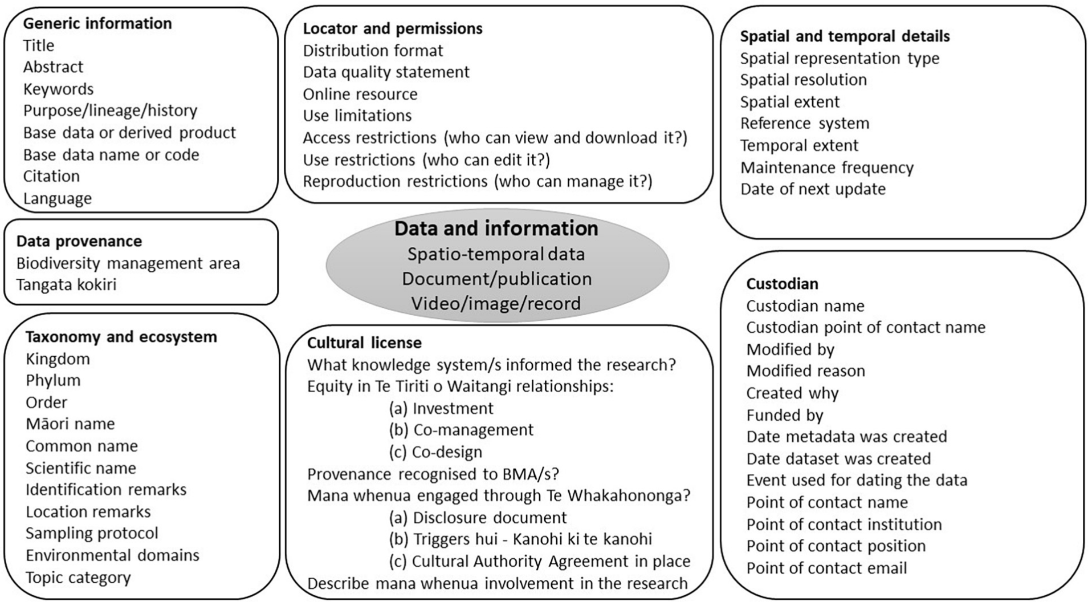


FIGURE 4
A full account of the metadata attributes that have been incorporated into the integrated intelligence platform. The platform's metadata adheres to the ANZLIC Metadata Profile, as well as defines a minimum set of attributes constructed from the Darwin Core open standard. The attributes in the "Data provenance" and "Cultural licence" categories help encode indigenous provenance information and cultural responsibilities into existing and new surveillance data. See **Supplementary material** for a full description of each attribute.

data. As such, the platform is a mechanism to capture both bodies of knowledge in one place and enables a reconciliation of information to support surveillance and monitoring efforts.

## 4 Proof of pathogen absence modelling – creating space for mātauranga Māori

The MMFS widens the focus of the surveillance practice to include the environment, pathogen, and host, as opposed to mainly focusing on the pathogen or disease (**Figure 2**). By tapping into the detailed, inherent, and unique knowledge of local biodiversity and ecosystems held by kaitiaki, changes in the wellness/illness of the environment and taonga can be recognised and investigated further to confirm whether they indicate presence/absence of disease and/or pathogens. If pathogen presence is suspected, a surveillance plan is needed to confirm or deny this. However, the lack of pathogen detection during surveillance efforts in an area of interest is not equivalent to pathogen absence, but it does provide some confidence in its absence. This confidence will vary with the intensity of surveillance that is conducted, the risk of spread from known infestations, and the presence of environmental factors influencing the vulnerability to the pathogen (Bradshaw et al., 2020; Sutherland et al., 2020). The more we search for a pathogen and do not find it, the more confident we can be that it is not present. The proof of pathogen absence modelling quantifies this confidence into a probability of absence (PoA; Anderson et al., 2013).

The proof of pathogen absence modelling approach superimposes a grid-cell system over the area of interest. The grid cell is the fundamental surveillance unit, i.e., the aim is to detect whether the pathogen is present in a grid cell. Given no detection of the pathogen in the area of interest, our level of confidence in pathogen absence depends on: (1) our confidence that the targeted area is free from the pathogen before doing any surveillance (for example, as evidenced from the health of the ecosystem); (2) the level of effort that is spent in finding the pathogen; and (3) the probability of detecting the pathogen if it is present in the targeted area (system sensitivity). The first quantity is called the "*prior*" and is specified as a probability distribution (Anderson et al., 2013). This prior is then updated with the no-detection surveillance data to produce the posterior PoA. If the calculated PoA is not high enough, then more surveillance needs to be conducted (thus increasing system sensitivity) until an acceptable value of PoA is reached. It is statistically impossible to achieve PoA = 1, so the level of confidence needed to declare that the targeted area is free from the pathogen (i.e., the target PoA) becomes a management decision. The target PoA value must be chosen so that the risk of incorrectly declaring an area free from the pathogen is balanced against the expense of additional surveillance activities incurred to achieve a higher PoA (Gormley et al., 2018). Establishing a target PoA and a quantitative mechanism for estimating effort required to achieve it helps guide decisions and resource allocations and creates consistent goals and expectations among local surveillance experts, managers, and policy makers.

Specifying the *prior* requires on-going discussions among local mana whenua and kaitiaki, plant pathologists, modelling and surveillance experts. The prior can be obtained using the following: (1) information from previous surveillance programmes set up to locate infection and the extent of the infection; (2) statistical forecasts of pathogen distribution; (3) mātauranga Māori and expert opinion/judgement/observations; or (4) a combined approach of the previous options – essentially using mātauranga

Māori and expert opinion/judgement/observations, but informed by knowledge from previous surveillance programmes, forecast of pathogen distribution and other factors. In this way, this Bayesian framework provides a mechanism by which both mātauranga Māori and empirical scientific knowledge can be equitably adopted into the proof of pathogen absence model and used to map areas free of the pathogen.

The proof of pathogen absence model is intended to assist in the design of risk-based surveillance for the purpose of demonstrating freedom from disease in areas where the pathogen has not been detected or delimiting the disease front in areas known to be infected. Risk-based surveillance is an approach to disease surveillance that involves looking for disease where it is more likely to be present. At the heart of risk-based surveillance and proof of absence modelling is therefore an understanding of risk factors and their impact on disease and pathogen distribution. However, the paucity of data presents a major constraint in the design of risk-based surveillance in the plant disease context. In particular, the areas where more information is required for kauri dieback and myrtle rust include: (1) quantitative evidence of the risk factors influencing pathogen occurrence; (2) estimates of the sensitivity of diagnostic tests used to detect pathogen presence; and (3) data on prevalence of infection for different plant species and locations. At present, the only feasible approach to design kauri dieback and myrtle rust risk-based surveillance programmes that are specific to each BMA appears to be consultation with mana whenua and kaitiaki, surveillance experts and plant pathologists. The approach is currently being trialled and co-designed with mana whenua from three BMAs with kauri forests. The data obtained will allow us to refine the proof of pathogen absence model assumptions and parameters and fill some of the existing data gaps. This will have benefits not only for efficient surveillance but for disease control more generally.

## 5 Conclusion

The increasing threat of invading pathogens that affect taonga species in Aotearoa New Zealand creates new challenges in designing surveillance approaches that can provide sustainable, and socially and culturally just outcomes. Strategies are needed that empower the role of hapū/iwi as kaitiaki of their taonga. In this article, we describe the MMFS, an approach in which indigenous and empirical science systems generate different manifestations of valid and useful knowledge that contribute to innovate and support the discovery, surveillance, and management of plant pathogens; and to achieve positive biodiversity and ecological outcomes (Black et al., 2019).

Using kauri dieback and myrtle rust as case studies, we have presented how the MMFS ensures that hapū/iwi are elevated into the biosecurity system, and mātauranga Māori into the science system. More generally, the MMFS articulates a way of looking at environmental surveillance that can be applied to the full range of environmental problems and to indigenous populations within Aotearoa New Zealand and internationally. The approach consists of three principles. First, it acknowledges that both indigenous and empirical scientific approaches and perspectives have their strengths and can complement each other, and therefore should be considered and attributed equitable value in environmental surveillance systems. Second, it recognises and gives effect to the sovereignty of the data required for the surveillance of plant pathogens and environmental monitoring. Key to the MMFS is the use of BMAs, which allow indigenous tribes to be directly connected with data generated by various custodians and provide a practical mechanism to digitally integrate data provenance and cultural licence into research practice and data collection, use and storage. Third, it recognises that hapū/iwi require equitable resourcing and/or funding to engage in surveillance, monitoring, and management of plant pathogens.

The MMFS seeks to provide benefits for Aotearoa New Zealand biosecurity and science systems through several tangible outcomes. First, a stronger cooperative and collaborative local and national approach to surveillance driven by partnerships between mana whenua and central, regional, and local organisations. Second, a better understanding of the current and emerging capability gaps for mana whenua involved in surveillance. Third, the development of a data storage platform which anchors data to the place of origin and ensures improved information standards, resulting in more robust and credible information on Aotearoa New Zealand's plant health and pathogen distribution. Finally, a "proof of pathogen absence" tool, which assists in the design of risk-based surveillance for the purpose of demonstrating freedom from disease in areas where the pathogen has not been detected. We have argued that the adoption of indigenous knowledge and practices such as kaitiakitanga, whanaungatanga, and rangatiratanga, and the empowered engagement of indigenous environmental resource managers and their hapū/iwi are vital for the sustainable management and long-term protection of kauri ecosystems and *Myrtaceae* species across Aotearoa New Zealand. Such a collaborative approach provides efficiencies in national, regional, and local biosecurity strategies and tactics and, importantly, enables the fulfilment of indigenous aspirations of spiritual, economic, environmental, and cultural wellbeing as well as engagement of rangatira and kaitiaki into Aotearoa New Zealand's biosecurity and science systems.

## Data availability statement

The original contributions presented in this study are included in this article/**Supplementary material**, further inquiries can be directed to the corresponding author.

## Author contributions

WW: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. AL: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. ML: Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing. DA: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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## Conflict of interest

WW was employed by Wai Communications Ltd.

The remaining 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.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2024.1392083/full#supplementary-material

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## Glossary

| | |
|---|---|
| Data | Any observations, narratives, information or knowledge in a digital or digitisable form. |
| Iwi | Tribe |
| Kaitiaki | Deity and/or tangata Māori tasked with maintaining natural balance between the environment and/or people |
| Kaitiakitanga | Guardianship, protection, preservation or sheltering. Māori people's way of managing the environment, based on the traditional Māori world view. |
| Hapū/ | Sub-tribe |
| Mana whenua | Person/people who have genealogical intergenerational links to tribal or sub-tribal lands (sovereign territory) |
| Māori | Indigenous people of Aotearoa New Zealand |
| Māori data | Information or knowledge in a digital or digitisable form that contains any Māori content or association to Māori, including data about their lands and waters, regardless of who collects and controls it (Taiuru, 2020) |
| Mātauranga Māori | Māori knowledge system, acquired knowledge |
| Mauri | Living energy |
| Ngahere | Forest |
| Rāhui | To put in place a temporary restriction, closed season, ban, or reserved access. Traditionally a *rāhui* was placed on an area, resource or stretch of water as a conservation measure or as a means of social and political control. |
| Rangatira | Māori leader who has recognised authority across a tribal territory or within a whānau, hapū and/or iwi to ensure the cultural, social, economic, and environmental aspirations of their people are fulfilled |
| Rangatiratanga | Māori leadership |
| Rohe | Territory or boundaries of tribes (iwi) |
| Taiao | The environment that contains and surrounds us, including all natural resources and living communities. |
| Tangata kōkiri | Key mana whenua technical experts who facilitate strategic trust relationships across Biodiversity Management Areas and between Māori society and Western societies and communities |
| Tangata whenua | People of the land |
| Taonga | i) Those things and values which Māori treasure, both intangible and tangible<br>ii) As articulated in Te Tiriti o Waitangi Article II |
| Te ao Māori | The Māori world, including society, traditions, histories and values |
| Te Tiriti o Waitangi | Constitutional document, written in Māori and signed in 1840, that establishes the obligation between Māori hapū/iwi and British Crown representatives in Aotearoa New Zealand |
| Tohu | i) Intergenerational observations of cycles and patterns in nature<br>ii) Signs, marks, symbols |
| The Treaty of Waitangi | Constitutional document, written in English and signed in 1840, that establishes the obligation between Māori hapū/iwi and British Crown representatives in Aotearoa New Zealand |
| WAI262 | A Te Tiriti o Waitangi claim that seeks to restore "tino rangatiratanga" (Māori authority and self-determination) of the whānau, hapū and iwi over their taonga, as stipulated in Article II of Te Tiriti o Waitangi |
| Whānau | A collective of people connected through a common ancestry (whakapapa) |
| Whanaungatanga | Relationship, kinship, sense of family connection – a relationship through shared experiences and working together, which provides people with a sense of belonging |
| Whakapapa | Genealogical table, lineage, descent |