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Embedding indigenous principles in genomic research of culturally significant species: a conservation genomics case study

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Abstract

Indigenous peoples around the world are leading discussion regarding genomic research of humans, and more recently, species of cultural significance, to ensure the ethical and equitable use of DNA. Within a Māori (indigenous people of Aotearoa New Zealand) worldview, genomic data obtained from taonga (culturally significant) species has whakapapa – generally defined as genealogy, whakapapa layers the contemporary, historical and mythological aspects of bioheritage – thus genomic data obtained from taonga species are taonga in their own right and are best studied using Māori principles. We contend it is the responsibility of researchers working with genomic data from taonga species to move beyond one-off Māori consultation toward building meaningful relationships with relevant Māori communities. Here, we reflect on our experience embedding Māori principles in genomics research as leaders of a BioHeritage National Science Challenge project entitled "Characterising adaptive variation in Aotearoa New Zealand's terrestrial and freshwater biota". We are co-developing a culturally-responsive evidence-based position statement regarding the benefits and risks of prioritising adaptive potential to build resilience in threatened taonga species, including species destined for customary or commercial harvest. To achieve this, we co-developed a research programme with the local subtribe, Ngāi Tūāhuriri, that integrates Māori knowledge with emerging genomic technologies and extensive ecological data for two taonga species, kōwaro (Canterbury mudfish; *Neochanna burrowsius*) and kēkēwai (freshwater crayfish; *Paranephrops zealandicus*). The foundation of our research programme is an iterative decision-making framework that includes tissue sampling as well as data generation, storage and access. Beyond upholding the promises made in The Treaty of Waitangi, we contend the integration of Māori principles in genomics research will enhance the recovery of taonga species and enable the realisation of Māori values.

Tuhinga whakarāpopoto

He taonga ngā raraunga huinga ira mai i ngā koiora o Aotearoa na te mea he whakaahuatanga ēnei raraunga o te whakapapa o Aotearoa. Nā konā, he tapu ēnei raraunga huinga ira, ā, he tika kia Māori te rangahau o te mātai iranga. Ko te haepapa o ngā kairangahau e mahi ana ki ngā raraunga huinga ira ki te whakawhanaunga atu ki ngā mana whenua o te takiwā kia kaha ake ngā mahi rangahau. Nā konei, ka whaiwhakaaro mātou e pā ana ki tō mātou whakakotahitanga o ngā āhuatanga o te kaupapa Māori me ngā mahi rangahau mātai iranga ki roto i tētahi kaupapa matua mai i Ngā Wero Pūtaiao o Ngā Koiora Tuku Iho o Aotearoa, ā, ko te ingoa o tō mātou take ko “Characterising adaptive variation in Aotearoa New Zealand’s terrestrial and freshwater biota”. Kei te whakawhanake a tahi mātou ko ngā kaitiaki o Ngāi Tūāhuriri i tētahi kōrero e pā ana ki ngā piki me ngā heke o te whakaarotautanga o ngā urutaunga ira ki te awhi i ngā momo tata korehāhā, ngā momo mahinga kai hoki. Kia tutuki i ēnei wawata, i hangaia tētahi kaupapa e mātou. Ko te take o tēnei kaupapa ko te whakakotahitanga o te mātauranga Māori, ngā hangarau hou o te mātai iranga, me ngā āhuatanga o ngā pūnaha hauropi hoki, o te kōwaro (*Neochanna burrowsius*) rāua ko te kēkēwai (*Paranephrops zealandicus*). Ko te paparahi o tēnei kaupapa ko tētahi pou tarāwaho mō ngā tikanga o te kohinga pūtautau, te waihanga raraunga huinga ira, me te rāhuitanga o ngā raraunga. Ko te tumanako ka tūtaki i ngā wawata o Te Tiriti o Waitangi, atu i tērā, mai i te whakakotahitanga o te kaupapa Māori me te mātai iranga, ka pai ake te atawhai ki ngā koiora o Aotearoa, ā, ka whakamana hoki i ngā whanonga o ngā iwi Māori.

Keywords: Mātauranga Māori, rangatiratanga, kaitiakitanga, mahinga kai, taonga species, kaupapa Māori

Lay summary: To provide an example of an effective approach for building meaningful relationships with relevant indigenous communities for mutual benefit, we reflect on our experience and show that using a bicultural approach enriches genomic research on culturally significant species. Embedding indigenous principles leads to more contextualised research thereby maintaining both cultural and biological integrity.

Indigenous peoples around the world are leading discussions regarding genomic research to ensure the ethical and equitable use of DNA (e.g. Hudson et al. 2016a, 2016b; Hudson et al. 2019; Jacobs et al. 2010; Reardon and Tallbear 2012). While these discussions have primarily focused on humans (e.g. Hudson et al. 2016a, 2016b), there is a growing dialogue regarding genomic research of species that have cultural significance to local indigenous people. In Aotearoa New Zealand, there are many native and endemic species that are **taonga** to **Māori** (herein see Glossary for words in bold). Taonga species can be generally defined as culturally significant species that shape **Mātauranga Māori** and **whakapapa**, but ultimately, local **iwi** and **hapū** have the authority to define their own taonga (http://www.waitangitribunal.govt.nz/; Ngāi Tahu Claims Settlement Act 1998). Many of these taonga species are also of significant interest to both national and international researchers. Here, we discuss the cultural significance of taonga species and show how Māori approaches can be better integrated in the genomic research of taonga species in Aotearoa New Zealand.

Te Tiriti o Waitangi / The Treaty of Waitangi (1840) is a crucial founding document that frames the relationship between Māori and the British Crown in Aotearoa New Zealand. Thus, Te Tiriti o Waitangi should be at the forefront of all interactions between Māori and **Pākehā**. Article Two of Te Tiriti o Waitangi guarantees to Māori the **rangatiratanga** over their taonga and ensures that the rights of both Māori as **tangata whenua** and Pākehā are preserved. Historically there have been numerous actions from the Crown that breached these promises of Te Tiriti o Waitangi (Walker 1990). Iwi Māori fought for generations to settle these historical grievances which led to the Treaty of Waitangi Act 1975 and the establishment of the Waitangi Tribunal (Walker 1990). Now, many iwi are moving beyond settling their historical grievances into an era of growth and partnership. For example, in his address at the Ngāi Tahu Treaty Commemoration Hui at Ōnuku Marae (2019), Tā Tipene O'Regan stated:

"…we have now reached a point where we must see ourselves no longer as the damaged and dispossessed victims of the New Zealand Project but as part of, and contributors to, the development of what this nation might yet become."

As a living document in Aotearoa New Zealand, Te Tiriti o Waitangi has led to government policies and Waitangi Tribunal Reports that provide a clear mandate for research partnership. Of particular relevance, Vision Mātauranga (Ministry of Research, Science and Technology 2007) seeks to ‘unlock the science and innovation potential of Māori knowledge, people and resources’ and Ko Aotearoa Tēnei/This is New Zealand, a report into the WAI 262 claim conventionally known as WAI 262 (http://www.waitangitribunal.govt.nz/), extends the scope of Te Tiriti o Waitangi to claim the rights of Māori to ngā taonga katoa (reviewed in Ataria et al. 2018). In Te Ao Māori, ngā taonga katoa refers to all things that are treasured by Māori, including indigenous culture, knowledge, flora and fauna. Thus, Te Tiriti o Waitangi is an important consideration for all research conducted in Aotearoa New Zealand, especially research involving taonga species.

As researchers based at The University of Canterbury, we fall within the territory of Ngāi Tahu who are **mana whenua** for most of Te Waipounamu / the South Island. Ngāi Tūāhuriri is the hapū that are mana whenua from Hurunui to Hakatere and inland to the Main Divide. Te Rūnanga o Ngāi Tahu negotiated Treaty settlements with the Crown earlier than most iwi and since then, have experienced significant growth and development. However, not all tribal groups have had the same experiences, and each iwi and hapū are at a unique stage of development. These factors can affect the capacity for mana whenua to be involved in taonga species research, but it does not influence the relevance of the research to them. Furthermore, for researchers, developing a deeper understanding of the needs, aspirations and circumstances of relevant iwi or hapū enables them to better apply their skills to research questions that are of interest to mana whenua.

The following quote from Kemps Deed, the largest Ngāi Tahu land purchase by the Crown (Evison 2006) details the importance of **mahinga kai** to Ngāi Tahu:

“Ko ō mātou kāinga nohoanga, ko ā mātou mahinga kai, me waiho mārie mō ā mātou tamariki, mō muri iho i a mātou.”

“Our places of residence, cultivations and food gathering places must still be left to us, for ourselves and our children after us”.

As a reminder of past breaches of Te Tiriti o Waitangi and a forecast of the future direction for the iwi, it led to the following quote which now acts as the guiding **whakataukī** for Ngāi Tahu:

"Mō tatou, ā, mō kā uri ā muri ake nei"
"For us, and our descendants after us"

Kaupapa Māori research is based on several key principles and philosophies that are applicable to all research conducted in Aotearoa New Zealand. It is an approach that has arisen from Te Tiriti o Waitangi that enables researchers to consider ethical, methodological and cultural issues from another perspective throughout the research process (Pihama et al. 2002; Smith 1997; Smith 2013; Walker et al. 2006). Kaupapa Māori research originated within an education context (Smith 1997) and has since been expanded by several Māori theorists to encompass research in a more general sense (Pihama 2012; Pihama et al. 2002; Smith 2013). Although there are many interconnected kaupapa Māori research principles, some may be more relevant than others within any given context.

Ngāi Tahu and Ngāi Tūāhuriri place a strong emphasis on embodying the following core values: whakapapa, **whanaungatanga**, **manaakitanga**, **tikanga**, **tohungatanga**, rangatiratanga and **kaitiakitanga**. All of these are either kaupapa Māori principles themselves or encompassed by them. Below, we frame these core values and highlight four key aspects of kaupapa Māori research applicable to genomic research involving taonga species with a particular focus on Ngāi Tahu interests.

Ngā taonga katoa

This context provided by Article Two of Te Tiriti o Waitangi is about acknowledging the validity and relevance of Māori ways of knowing and understanding the world (Pihama et al. 2002). Below we discuss several interconnected concepts in Te Ao Māori that we advocate researchers use when working with taonga species that may lead to opportunities to integrate Mātauranga Māori and western science.

Te Reo Māori is an excellent starting point. Te Ao Māori is entrenched in the language, including Māori place names, whakataukī, and associated stories (Wehi et al. 2009; Whaanga et al. 2018). In contrast to the analytical nature of the English language, Te Reo Māori is filled with symbolism and emotional embellishment that allows Māori to intuitively grasp complex concepts. Embracing the strengths of both languages can lead to co-development of research frameworks relevant to both Māori and non-Māori (Mercier 2018; Walker et al. 2006). For example, **mauri** is the life force found in all things: it is the essential quality and vitality of an entity, whether that is a physical object, an individual or an ecosystem (Hikuroa et al. 2011). The integration of Mātauranga Māori and western science can enable frameworks that seek to maintain and enhance mauri and other Māori values (Harmsworth and Tipa 2006; Hikuroa et al. 2011; Hudson et al. 2016c; Rainforth and Harmsworth 2019).

Tikanga Māori is about the appropriate way to operate within a Māori context; including customary practices, protocols and ethics (Mead 2003). While the details of tikanga vary across iwi, tikanga still apply to all facets of Māori life. It dictates how Māori interact with each other, and with their environment and taonga. Tapu and noa are multifaceted Māori concepts that fundamentally shape tikanga Māori. Tapu refers to that which is sacred, special, forbidden or restricted; whereas noa is the inverse of tapu and refers to the common and unrestricted (Mead 2003). All taonga are inherently tapu, and tikanga therefore determine how people interact with our taonga.

Mātauranga Māori is traditionally passed down orally through **pūrākau**, **waiata**, **pepeha** and whakataukī, or visually through **mahi toi** (Hikuroa 2017). These ancestral stories are then contextualised using whakapapa (Tau 2001). Although many pūrākau are myths and heavily symbolic in nature, they still serve the practical function of passing on Māori culture and the knowledge of the natural world through a Māori world view (Hikuroa 2017). They also explain the relationship that **tangata whenua** share with the world around them by associating their ancestors with specific aspects of the environment. For researchers with a genuine interest in embedding Mātauranga Māori in their research, developing a general understanding of Te Ao Māori is invaluable. Moreover, we argue it is imperative for researchers to be mindful of local context, particularly when working with the whakapapa of taonga species.

Whakapapa is generally defined as genealogy, but in Te Ao Māori, it encompasses much more than that (Te Rito 2007). It layers the contemporary, historical, spiritual and mythological aspects of heritage (Tau 2001). Whakapapa is critical in shaping how Māori view the world, and from a traditional Māori perspective, all life on Earth can be traced back through whakapapa (Tau 2001; Te Rito 2007). Although the most common application of whakapapa in a modern context is to describe family pedigrees, whakapapa is not limited to people. The whakapapa of people, animals and plants; mountains, rivers and winds are all interconnected and explain these complex relationships through a Māori lens (Tau 2001). There are a multitude of similarities between whakapapa and a range of western science disciplines, the most literal being DNA-based research.

DNA is a physical expression of whakapapa. Like DNA, whakapapa is unique to any one hierarchical group. This uniqueness inherently renders whakapapa - and by extension, DNA - as a taonga and something that is tapu (Beaton et al. 2017; Hudson et al. 2016a, 2016b, 2016c). Therefore, tikanga should influence the way that genetic and genomic data are generated and used. However, not all traditional tikanga practices apply to something so novel. Indeed, as modern western science continues to develop new methods, the tikanga surrounding it will also change. Thus, there is a need for Māori communities to be involved with emerging DNA technologies so actions appropriate for Aotearoa New Zealand can be co-developed by researchers and tangata whenua.

The whakapapa of Māori deities can be viewed as a hierarchical classification of the origin of both the abiotic and biotic aspects of the environment. There are similarities in these ancient creation stories across iwi, but subtle differences between them reflect the need for Māori to describe novel landscapes in new ways. Whakapapa in these settings is used as a tool to enrich Mātauranga Māori within local contexts. For example, the story of Ranginui, Papatūānuku and their children is a very common Māori creation narrative (Reed 2004). However, Pokoharuatepō, the first wife of Ranginui and the mother of Aoraki has special significance to Ngāi Tahu. In this narrative, the creation of what is now known as Te Waipounamu is attributed to the wreckage of Te Waka o Aoraki when Aoraki and his brothers journeyed to meet their new step-mother Papatūānuku. Aoraki and his brothers eventually turned to stone on top of their overturned canoe where they now form the principal peaks of the Southern Alps. This perspective of the landscape in Te Waipounamu is unique to Ngāi Tahu and this whakapapa illustrates the importance of Aoraki / Mt Cook to the people of Ngāi Tahu. By extension, researchers working in the Ngāi Tahu takiwā need to be mindful of the local narrative, for example, by developing an understanding of the significance of place names and the stories behind them (e.g., publicly available resources such as the cultural mapping project, Kā Huru Manu, http://www.kahurumanu.co.nz/).

Key kaupapa Māori principles for genomic research on taonga species

A major focus of kaupapa Māori research is enabling rangatiratanga by providing tangata whenua with the autonomy and authority to practice and share their own culture, knowledge and other taonga in their own way (Pihama et al. 2002; Smith 1997). Within a research context, it enables Māori to shape how their taonga are researched.

"He aha te mea nui o te Ao? He tāngata, he tāngata, he tāngata."
"What is the most important thing in the world? It is the people, it is the people, it is the people."

Whanaungatanga represents our relationships with one another and enables kaupapa Māori research through the process of building and maintaining meaningful partnerships with tangata whenua that are necessary for collaborative projects and an expression of rangatiratanga (Smith 2013; Walker et al. 2006). It lies at the core of Māori culture and society, therefore, **whakawhanaungatanga** is the most important step for researchers looking to engage with Māori in a meaningful way. Although there are frameworks available to assist researchers (e.g. Wilcox et al. 2008; Hudson and Russell 2009; Smith 2013), building significant relationships with Māori cannot be reduced to simple step-by-step procedures. However, these frameworks can help researchers to recognise and acknowledge the unique culture and tikanga of each iwi, hapū and **whānau** that are involved in the research.

Kaitiakitanga is often translated as guardianship or stewardship. It is a term that has become widely used in mainstream New Zealand regarding species conservation and ecosystem restoration. However, it encompasses more than just conserving species or restoring ecosystems: kaitiakitanga includes everything that is taonga to tangata whenua, including knowledge, culture and language (Lyver and Tylianakis 2017, Wehi and Lord 2017, Wehi et al. 2018, Lyver et al. 2019). Research focused on recovering taonga species, particularly mahinga kai species, has the potential to enhance these interconnected elements. Kaitiakitanga of mahinga kai includes the environment, language, culture and knowledge associated with harvesting practices. Thus, research that aims to enhance species recovery can facilitate more interactions with these species, allowing for the revitalisation of the associated language and practices (Wehi and Lord 2017, Wehi et al. 2018).

Tohunga were traditionally expert practitioners in a given field that gave direction to others and helped to develop others. Therefore, **tohungatanga** encourages whānau to develop capability and capacity while supporting the development of others. The very nature of science collaboration with mana whenua achieves tohungatanga, as it builds expertise within iwi and hapū to pursue knowledge and ideas that will enable them to strengthen and grow. Furthermore, whanaungatanga is realised through genuine co-development of research ideas and active engagement throughout research process. In doing so, rangatiratanga and kaitiakitanga are also realised because the authority and sovereignty that mana whenua have over their own taonga are recognised.

As researchers with pre-existing relationships with Ngāi Tahu and Ngāi Tūāhuriri, we were given the opportunity to incorporate these key kaupapa Māori principles in a new scope of work involving genomic research of threatened taonga species, and together with mana whenua frame a narrative that speaks to the subtleties of Te Ao Māori often overlooked by typical western science practice. Here, we share this narrative, not as a template to be followed or as a series of boxes to be ticked, but as an example of one way to better enhance the recovery of taonga species.

Genomic research

Genetics and genomics approaches for studying DNA have become invaluable tools for many biological disciplines, including the conservation of threatened species (reviewed in Galla et al. 2016). New technologies are rapidly expanding our ability to extract, generate and understand DNA. As these technologies become more efficient, they become more affordable and accessible too. Here, we provide a brief description of conservation genetics and genomics, and outline several necessary considerations when generating these data from taonga species.

Traditionally, conservation genetic studies use a small set of genetic markers scattered throughout the genome to estimate genetic diversity within and between populations in an effort to inform conservation management (Frankham et al. 2010). These strategies are generally implemented in a way that seeks to reduce adverse effects associated with small, isolated populations by minimising inbreeding and the loss of genetic diversity (Frankham et al. 2017). However, there are limitations to using only a small number of genetic markers within a genome that has millions, if not billions, of DNA base pairs, including variation at a small number of selectively neutral markers unlikely being representative of genome-wide variation and, at best, only being able to be used as a proxy for the ability of a species to adapt to changing environments (Allendorf et al. 2010; Ouborg et al. 2010; Funk et al. 2012; Defaveri et al. 2013).

High-throughput DNA sequencing is rapidly changing the way that we address conservation genetic questions. These new technologies are enabling the generation of reference genomes, as well as the characterisation of many thousands of single nucleotide polymorphisms (SNPs), for non-model species (e.g., Galla et al. 2019). The ability to generate a large number of genome-wide markers within and among natural populations is enabling researchers to address old questions at higher resolution (e.g., estimating relatedness; Lemopoulos et al. 2019) and to tackle entirely new ones (e.g., characterising adaptive potential; Chen 2019; de Villemereuil et al. 2019).

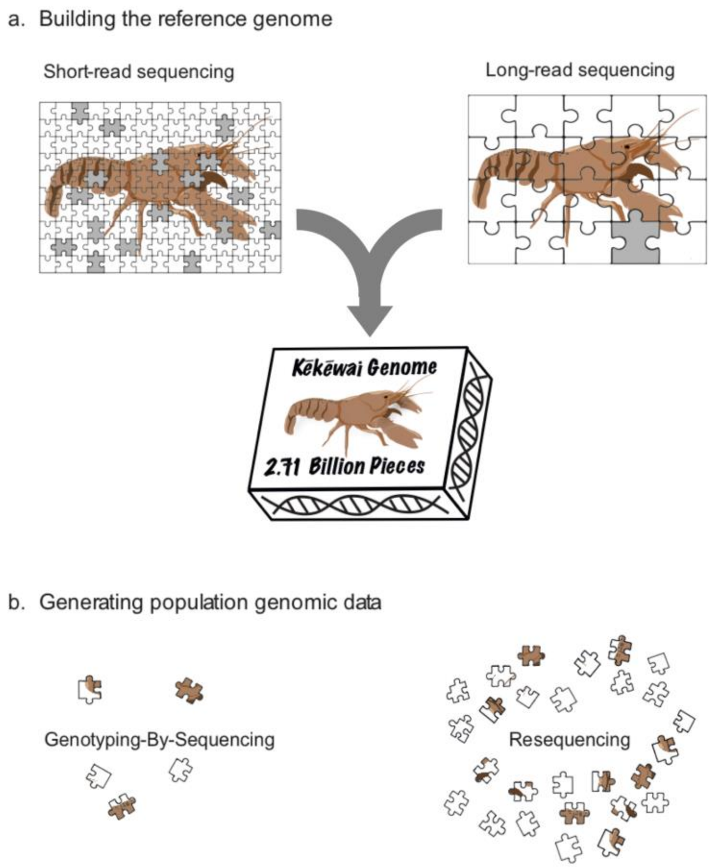

Figure 1. A reference genome, similar to a completed puzzle, provides a guide to locate genomic markers (represented here by puzzle pieces) and determine whether those markers are neutral or adaptive. **(a)** Reference genomes can be generated through short-read sequencing, long-read sequencing or a combination of both. Short-read sequencing is cheaper and yields lower coverage of the genome, but generally at higher depth than long-read sequencing – providing more confidence in genomic markers. Long-read sequencing, although more expensive, can bridge gaps between shorter reads to enable a more comprehensive genome assembly. **(b)** Reference genomes can enhance assembly and analysis of population genomic data, typically generated through resequencing or reduced-representation approaches such as Genotyping-By-Sequencing (GBS). GBS sequences only a fraction of the genome (i.e., a few pieces of the puzzle), while resequencing offers higher coverage but at a higher cost per sample. Regardless of the approach used to generate a reference genome or population genomic data, all genomic data belonging to taonga species in Aotearoa New Zealand have whakapapa and are taonga in their own right.

Regardless of whether researchers generate handfuls of microsatellites versus thousands of SNPs, or single reference genomes versus numerous re-sequenced genomes, the status of these data as taonga remains the same (Figure 1). However, researchers working with genetic and genomic data from taonga species have often failed to acknowledge this in a meaningful way. As a result, data security and management of genetic and genomic data from taonga species has become paramount and considered discussions from a Māori perspective are underway across Aotearoa New Zealand (e.g., SING Aotearoa – Summer internship for INdigenous peoples in Genomics, https://www.singaotearoa.nz/). These include discussions that will lead to the development of guidelines for genomic research of taonga species led by Genomics Aotearoa (Te Nohonga Kaitiaki, https://www.genomics-aotearoa.org.nz/projects/te-nohonga-kaitiaki). In the meantime, there are growing initiatives in Aotearoa New Zealand that seek to manage access and storage of genomic data from taonga species with appropriate kaitiakitanga (Catanach et al. 2019, Galla et al. 2019, Wellenreuther et al. 2019; for example, password protected genomic data at: https://www.genomics-aotearoa.org.nz/data and http://www.ucconsert.org/data).

Case study

As leaders of a Biological Heritage National Science Challenge project entitled "Characterising adaptive variation in Aotearoa New Zealand's terrestrial and freshwater biota", we co-developed a research programme with mana whenua that is integrating Mātauranga Māori with emerging genomic technologies and extensive ecological data to characterise adaptive potential - or the ability to adapt to environmental change - in two taonga species, kōwaro (*Neochanna burrowsius*) and kēkēwai (*Paranephrops zealandicus*). We are combining these data with three additional focal species to co-develop a culturally-responsive, evidence-based position statement regarding the benefits and risks of prioritising adaptive potential to build resilience in threatened taonga species, including mahinga kai species destined for customary or commercial harvest. The foundation of our research programme is an iterative decision-making framework that embeds kaupapa Māori relevant principles. It begins by framing the research narrative in partnership with mana whenua followed by active engagement to make decisions regarding tissue sampling as well as data generation, storage and access, and ends by sharing the research narrative in partnership with mana whenua (Figure 2). Below, we show how we applied the iterative decision-making framework to our conservation genomic research on kōwaro and kēkēwai. We also demonstrate how this framework is broadly applicable to all genomic research on taonga species.

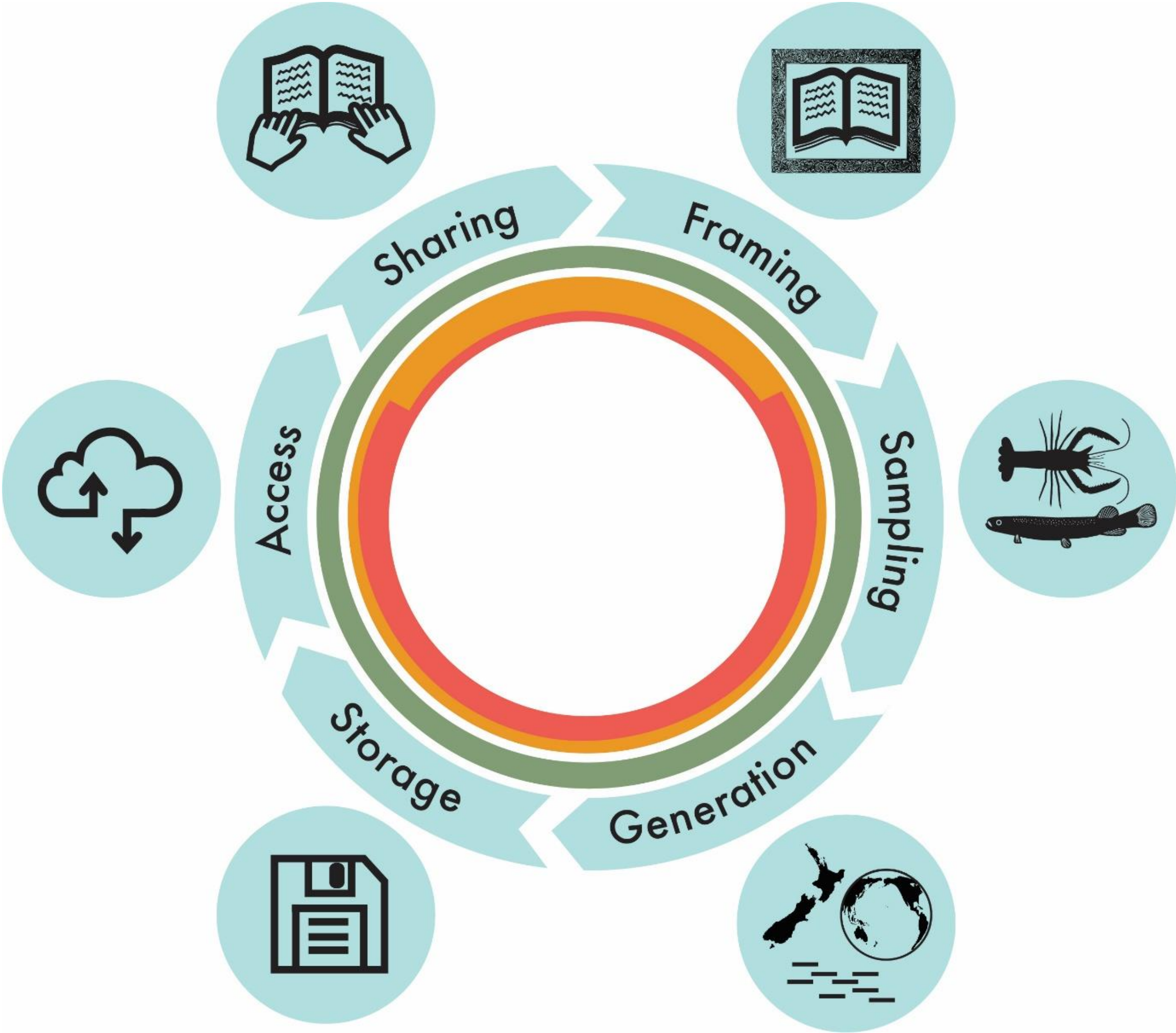

Figure 2. An iterative decision-making framework co-developed with Ngāi Tūāhuriri indicating relevant kaupapa Māori principles and focal areas for active engagement with mana whenua regarding genomic research on two threatened taonga species, kōwaro (*Neochanna burrowsius*) and kēkēwai (*Paranephrops zealandicus*). Colours denote the following: Rangatiratanga (blue) – realising the authority that tangata whenua have to practice and share their culture in their own way. Tohungatanga (green) – enabling the development of capability, capacity and expertise of tangata whenua. Whanaungatanga (light orange) – building and maintaining meaningful relationships with tangata whenua. Kaitiakitanga (dark orange) – enabling the guardianship of all taonga by tangata whenua – including environment, knowledge and culture. While all four of these kaupapa Māori principles feature in the entirety of our genomic research on kōwaro and kēkēwai, whanaungatanga is particularly relevant when co-developing and co-sharing research, whereas enabling kaitiakitanga is particularly critical when making decisions about tissue sampling, data generation, data storage and data access. See text for details.

The first taonga species that we co-identified with Ngāi Tūāhuriri is kōwaro (Canterbury mudfish; *Neochanna burrowsius*), one of the most endangered endemic freshwater fish species in Aotearoa New Zealand, currently classified as “Nationally Critical” by the Department of Conservation (Dunn et al. 2018). Kōwaro are restricted to the Canterbury plains, and they have a fragmented distribution between the Rakahuri (Ashley) and Waitaki river catchments (Cadwallader 1975; O’Brien and Dunn 2007). Range restriction and severe loss of habitat due to land use intensification in Canterbury are key factors contributing to its current conservation status (Barrier 2003; Dunn et al. 2018; O'Brien and Dunn 2007). The continued threat of local extirpation across its range has led to a call for urgent conservation action (Dunn et al. 2018).

One such conservation action is a translocation project based at Tūhaitara Coastal Park. The park was established by Te Kōhaka o Tūhaitara Trust following the Ngāi Tahu settlement with the crown and it encompasses Te Tiriti o Waitangi; a collaborative effort between the people of the treaty. The area is rich in Ngāi Tūāhuriri history and mahinga kai, and kōwaro are an integral part of this ecosystem. Kōwaro was co-selected for our project because a conservation genomics approach is likely to enhance conservation outcomes to help preserve kōwaro as part of the unique biodiversity of Tūhaitara Coastal Park.

Endemic to Aotearoa New Zealand, kēkēwai (freshwater crayfish / kōura; *Paranephrops zealandicus*) are a declining taonga species found in lakes, streams and ponds in the east and south side of Te Waipounamu / South Island as well as Rakiura / Stewart Island (Grainger et al. 2018). The *Paranephrops* genus has been a traditional food source for Māori across Aotearoa New Zealand for centuries and has more recently been the focus of aquaculture initiatives for customary and commercial harvest (Parkyn and Kusabs 2007; Monk 2017).

Although kēkēwai as a species is not at immediate risk of extinction, land use intensification in Canterbury is fragmenting kēkēwai populations and driving local decline (Thoms 2016). Most remaining populations within the Ngāi Tūāhuriri takiwā now face extirpation. In addition to informing the recovery of declining wild populations, kēkēwai was co-selected for our project because a conservation genomics approach can enhance customary and commercial harvest, making these practices more sustainable so that they can continue for generations to come (Kristensen et al. 2015; Galla et al. 2016).

After framing the research narrative for each species, we discussed sampling design with Ngāi Tūāhuriri, including tissue sampling at sites of cultural significance traditionally used for mahinga kai. Doing so is especially important when generating reference genomes because these invaluable resources are a physical representation of Ngāi Tūāhuriri whakapapa. For the kōwaro reference genome, the obvious choice of location was within Tūhaitara Coastal Park. However, due to the uncertain status of this small, fragmented and isolated population, we collectively decided to lethally sample a single individual from a larger, healthier population elsewhere in the Ngāi Tūāhuriri takiwā. For kēkēwai, we lethally sampled two individuals approximately one year apart from a small stream near Tuahiwi at the heart of the Ngāi Tūāhuriri takiwā.

Sampling animals has its own tikanga and practices within western science, typically regulated by animal ethics committees. Māori have their own tikanga and Mātauranga for taonga species and have harvesting practices that are excellent for sampling (Kusabs and Quinn 2009). As a mahinga kai species, kēkēwai allowed us to integrate Mātauranga Māori into a modern context to sample effectively and ethically. We used bundled bracken ferns to create tau kōura as a traditional method of harvest to efficiently capture kēkēwai (Parkyn and Kusabs 2007; Kusabs and Quinn 2009; Thoms 2016) and the maramataka (Māori lunar calendar) to determine favourable days for collection.

In addition to the lethal sampling conducted for the reference genomes, we also used non-lethal methods for sampling populations across both species' range (i.e. fin-clips for kōwaro, pleopod-clips for kēkēwai). This was also an opportunity to include Ngāi Tūāhuriri children from Te Kura o Tuahiwi (Tuahiwi School) in the population sampling of kōwaro at the nearby Tūhaitara Coastal Park, which helped whakawhanungatanga with the wider hapū by following their tikanga. All tissue sampled from kōwaro and kēkēwai has value in the information it contains, therefore the tissue itself is taonga

(Hudson et al. 2016c). Ngāi Tūāhuriri have the rangatiratanga to determine the tikanga for generating the reference genomes for these species. As researchers with the relevant expertise, it was our responsibility to clearly communicate the benefits and risks of any given approach (Figure 1). Thus far, we have focused on whether to generate the reference genomes here in Aotearoa New Zealand or overseas. After considering data quantity, data quality, data security, turnaround time and cost, we made the collective decision to send DNA for both kōwaro and kēkēwai to a trusted provider overseas with extensive experience handling culturally sensitive material. By including mana whenua in this way, we promote rangatiratanga while building tohungatanga around the research. In addition to generating genomic data, we are characterising the ecological characteristics of kōwaro and kēkēwai habitats. It is important to note that like tissue and DNA, ecological data from taonga species each have their own mauri, all of which add another layer to the whakapapa and should therefore be treated with the same manaakitanga (e.g., Bond et al. 2019).

During our research we have encountered existing or new transcriptome data that can be used to supplement the reference genomes for both kōwaro and kēkēwai (Wallis and Wallis 2014, P. Dearden unpublished data). Despite the fact that they are readily available, we are actively engaging with relevant mana whenua prior to the inclusion of these data in our own research. Related to this, we are also expanding our research to elsewhere across the wider Ngāi Tahu takiwā. As anticipated, whakawhanaungatanga is a unique experience with each hapū and papatipu rūnanga but the intent to be responsive to the needs and aspirations of each different group remains..

Te Tiriti o Waitangi promises that tangata whenua retain the rangatiratanga over their own taonga which includes the whakapapa of taonga species. Genetic data have traditionally been shared openly on globally accessible databases. Rapid advancements in the field of genomics has led to data that are more complex and valuable. Therefore, rangatiratanga has become increasingly important in how knowledge and data from taonga species are shared. The challenge of upholding Te Tiriti o Waitangi is a national one, but it is tangata whenua who ultimately have the right to determine how their own whakapapa is shared. As people of Te Tiriti o Waitangi, researchers and tangata whenua can collectively make decisions regarding how whakapapa as genomic data is stored and accessed in a mutually beneficial way (e.g. password protection of genomic data). For example, as one of few available decapod genomes, the kēkēwai reference genome is likely to be of interest to domestic and international researchers to address both fundamental and applied questions. Thus, we will continue to engage with relevant mana whenua regarding the ongoing security and management of these data.

Concluding Remarks - We have shown that using a bicultural approach enriches research: In addition to upholding the promises of Te Tiriti o Waitangi, embedding kaupapa Māori principles leads to more contextualised genomic research on taonga species thereby maintaining both the cultural and biological integrity of Aotearoa New Zealand.

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Glossary:

Hapū – subtribe

Iwi – tribe

Kaitiakitanga – guardianship, stewardship (see main text for extended definition)

Kaupapa – topic, agenda

Mahinga kai – refers to all aspects of traditional food gathering and the places where those resources are obtained

Mahi toi – art

Manaakitanga – respect

Mana whenua – authority over the land

Māori – Indigenous people of New Zealand

Mātauranga Māori – Māori knowledge

Mauri – life-force

Pākehā – New Zealander of European descent

Papatipu rūnanga – regional tribal council

Pepeha – tribal saying

Pūrākau – myth, legend, story

Rangatiratanga – Chieftainship, sovereignty, autonomy, authority (see main text for extended definition)

Rūnanga – tribal council

Takiwā – territory, area, district

Tangata whenua – people of the land

Taonga – treasure, culturally significant

Te Ao Māori – The Māori world

Te Reo Māori – The Māori language

Te Tiriti o Waitangi – The Māori version of The Treaty of Waitangi

Tikanga Māori – Māori customs, etiquette, protocol

Tohungatanga – expertise

Waiata – song(s)

Whakapapa – genealogy (see main text for extended definition)

Whakataukī – proverbs

Whānau – family, extended family

Whakawhanaungatanga – building relationships

Whanaungatanga – relationship, sense of family connection (see main text for extended definition)

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