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Sovereign genes: wildlife conservation, genetic preservation, and Indigenous data sovereignty

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The application of conservation genetics to wildlife preservation efforts are ongoing and promising. These involve the mobilization of a toolkit that ranges from monitoring the genetic diversity of rare species to more ambitious experiments in repopulating species experiencing genetic bottlenecks. All such efforts are predicated upon the deliberate and thoughtful preservation of existing genetic diversity. The history of genetic collection and conservation, however, for medical and health applications, is one that has repeatedly fallen into colonial habits, violated Indigenous sovereignty, and sown distrust with Indigenous communities. Given the importance of Indigenous communities in the future of wildlife conservation, the future of conservation genetics is best assured through the honoring of Indigenous Data Sovereignty. This paper reviews the stakes of this question, reflects on the status of recent conservation genetics efforts relative to the question of Indigenous sovereignty, and lays out a preliminary set of principles for collaborative work on wildlife conservation employing genetic tools.

KEYWORDS

genetics, conservation, indigenous sovereignty, biobank, biobanking, biopreservation

Introduction

Animal species worldwide are undergoing severe reductions in population sizes and species richness, due to anthropogenic causes: habitat loss and fragmentation, over-harvesting of wild populations, direct conflict, introduction of invasive species and pathogens, and climate change. These stressors have led to highly increased rates of species extinction and a likely human-induced global mass extinction, as defined by a loss of 75% of species, within the next several hundred years (Barnosky et al., 2011; Ceballos et al., 2020; Trisos et al., 2020).

Accompanying traditional habitat protection and restoration, conservation genetics has been identified as a critical set of tools to help address this crisis. This toolkit includes measures that range from modest efforts to monitor the genetic diversity of rare species, as well as more ambitious experiments in repopulating species experiencing genetic bottlenecks, to more radical proposals for de-extinction. Undergirding most of these approaches is biopreservation, elsewhere also referred to as biobanking. Biopreservation involves the collection and storage of samples representing genetic diversity from endemic wildlife and plant life for long-term storage and potential future use in advanced reproductive technologies (e.g. cloning, generation of gametes and embryos *in vitro* or in host organisms). Biopreservation requires the collection and storage of genetic samples, optimally through non-invasive or minimally invasive means. Harnessing the full potential of this approach, however, requires the collection, moreover, of sufficient existing genetic diversity in the form of stored physical biological samples.

Recent experiences with human biobank efforts in the United States healthcare and research settings, however, have revealed a critical problem confronting *any* efforts at genetic preservation: colonial history, settlement, and science. Within the United States context, as well as in other countries, the historical legacy of colonialism, settlement, and ongoing imbalances of power between Indigenous and non-Indigenous communities has repeatedly led to the collection and use of genetic materials without the consent and control of Indigenous peoples. The emerging consensus insists that no work in genetic preservation can proceed without consideration of, consultation with, and respect for the sovereignty of Indigenous peoples. Principles of Indigenous Data Sovereignty (IDS), specifically, have been developed to guide ethical practices. These have gone some way toward institutionalizing approaches to research that honor the rights of Indigenous people. Numerous studies have explored how IDS can and should be implemented in human research and health practice (Carroll et al., 2020).

To date, the application of such an approach to samples of genetic material from non-human organisms - especially wildlife - is less well-developed, although there are examples worldwide of related work. Although the examples provided here represent a wide array of conservation genetics approaches, this manuscript focuses specifically on applying the principles of IDS to biopreservation, for two reasons: 1) physical samples will likely be required for any reintroduction of genetic diversity needed for biodiversity management in the foreseeable future, thus (given current technology) genomic analysis alone is of limited value with regards to our ability to maintain biodiversity; 2) further applications of conservation genetics, including genetic engineering and synthetic biology, carry additional ethical complexities that will have to be explored independently. Starting from preservation is first essential. Our hope with this work is to provide IDS-based principles for future ethical biodiversity management. In this paper, drawing on such examples and their underlying principles, we therefore ask: how can IDS be applied to genetic preservation of non-human species? What efforts to date provide the most promising examples of approaches and institutions to govern such an effort? What central principles should be applied to biopreservation, when the violent, expropriative histories and present-day realities of settler colonialism are acknowledged as a threat to Indigenous communities worldwide?

By synthesizing closely related case examples, we answer these questions in reference to a set of recommended principles that can begin to guide researchers and non-Indigenous scientists to engage in collaborations that better navigate the complexities of this landscape. Given the diversity of specific contexts, moreover, this paper directs us to "rules of engagement," rather than universal or global protocols, and stresses shared starting places rather than common outcomes. Resolutions of past injustices, theft, and forced removals are necessarily beyond the scope of this analysis, and these recommendations can only prescribe the grounds for future engagement without claims to more universal resolutions of historical violence.

Section I: The genetic biopreservation opportunity

Ecosystem conservation and adaptation (especially important in the era of global climate change) initiatives are paramount in efforts to preserve animal and plant species. Under constant threat by anthropogenic stressors, endemic biodiversity is threatened in countless contexts, with the threats of climate change compounding these negative effects, even for humans themselves (Xu et al., 2020). Under such extreme stressors, the health of safeguarded ecosystems will become increasingly uncertain, even where efforts are made to preserve them (Trisos et al., 2018). Ecosystems derive their robustness from the population health of individual species within the ecosystem network. Thus, population-level health of wildlife populations, itself dependent on genetic diversity, is essential for maintaining healthy ecosystems. Such population diversity is also essential as species adapt to changing conditions, an inevitable part of Anthropocene conditions. So, though safeguarding of physical ecosystems and habitats must be the first priority in conservation, an orthogonal approach involving the preservation of genetic diversity will provide a key, if not crucial, advantage. Such an approach requires broad scale biopreservation (sometimes described as "bio storage" or "biobanking"): the collection and storage of endemic wildlife and plant life samples in sufficient quantity for the represented diversity to be later used in restoration efforts.

While biopreservation has been recognized by several centers and institutions across the globe, its ability to contribute to population scale conservation has been constrained until recently. This is because such efforts have been limited to storage of gametes or fertilized embryos, which can only be obtained through generally invasive methods. However, recent advances in the field of reprogramming, which allows the transformation of somatic cell types into pluripotent cells, has transformed the technology's potential. Through this technology, any somatic sample now has the potential to be used to generate pluripotent cells and, in principle, gametes, leading to entire individuals. Thus, rather than relying on highly invasive and resource-intensive gathering of gametes or embryos from endangered individuals, conservation researchers can now rely on non-invasively collected somatic samples towards future uses in monitoring or reproduction.

In the case of reproductive applications, a variety of advanced reproductive technologies are emerging including: the growth of *in vitro* fertilized embryos using a foster mother, the harboring of germ cells in a host individual to produce gametes, or the cloning of an animal, all from biopreserved samples. For some species, generation of gametes from somatic samples *in vitro*, with nearly the entire process occurring outside of an organism, is already a reality (Hayashi et al., 2011; Hayashi and Saitou, 2013). By way of example, a limitless supply of induced pluripotent cells can be derived from hair follicles or minute blood samples, and animals have even been cloned directly from the same cell types.

The power of such cellular reprogramming to generate differentiated cell types into a germ cell, and technologies to allow those germ cells to generate individuals, will only continue to increase as we gain a greater molecular, cellular and organismal understanding of the processes involved. Thus, the future presents itself as providing a vast toolkit for conservation genetics, with the only bottleneck in the process being the availability of biopreserved cellular samples representing the genetic diversity of currently extant populations. Experience from previous efforts has further taught us that we need to carry out biopreservation proactively, when genetic diversity has high levels corresponding to the undisturbed populations, and that the number of collected samples needs to be large, at least 500 individuals representing this initial diversity, following the 50/500 rule for long-term species health (Harmon and Braude, 2010).

Thus, proactive, large-scale biopreservation of species genetic diversity now, coupled with novel advanced reproduction methods being developed, should allow the maintenance of long-term genetic diversity in animal populations and greater ecosystem resilience in the future. Indeed, a glimpse into this future is provided by the recent cloning of a healthy black footed ferret from a cryopreserved 40-year-old sample, an approach that should allow the reincorporation into the currently endangered population of three times more genetic diversity than currently exists (Fritts, 2022). Other studies have also shown the potential for inter-species approaches towards conservation, such as the planned creation of functionally extinct northern rhino calves through *in vitro* fertilization and southern rhino surrogate mothers (Tunstall et al., 2018), or the somatic cell nuclear transfer (SCNT)-mediated cloning of endangered mouflons using sheep eggs (Loi et al., 2001), African wild cats using domestic cat eggs (Gómez et al., 2003) and Przewalski horses using domestic horse eggs (San Diego Zoo, 2020).

Biopreservation thus represents an urgent opportunity in molecular conservation genetics, which will necessitate the practice of widespread sampling of existing biodiversity to generate biostorage "refugia" of existing genetic variation. Such proactive, large-scale biopreservation of existing species genetic diversity will be crucial to maintain long-term species genetic diversity and ecosystem resilience.

Section II. Indigenous data sovereignty

The rise of Indigenous data sovereignty

Indigenous Peoples' territories are the richest, most biodiverse places on the planet: indeed, approximately 80% of Earth's biodiversity is protected by Indigenous lands, despite the fact that these lands cover only 22% of Earth's land surface (Sobrevila, 2008). Areas with high representation of Indigenous languages, and indeed highest overall linguistic diversity, coincide with the most biodiverse areas on Earth (Gorenflo et al., 2012). With the shared goal of protecting wildlife genetic diversity, Indigenous Peoples and those engaged in biopreservation projects ostensibly share common goals around the protection of biodiversity. The question for those engaged in wildlife biopreservation projects is how to honor and uphold Indigenous sovereignty over land, knowledge, and the genetic diversity of endemic wildlife on Indigenous territories.

Non-Indigenous biopreservation practitioners may enter the field with the assumption that their technical expertise is sufficient for decision-making on where and how to gather samples, which species' data should be collected, how these should be stored and shared, or indeed whether to embark on biopreservation at all. In this essay, we contend that technical expertise, including the tools and practices described in Section I, is insufficient. When working on Indigenous lands, or even on lands ceded forcibly from them, IDS is the most important ethical guide for biopreservation practitioners.

Historically, Indigenous sovereignty has not been respected regarding the gathering of data from or about Indigenous Peoples, who have had little control over research design, data collection methods, access to data, application of findings, and professional or financial dividends of the results (Department of the Parliamentary Library, 2005; Kukutai and Taylor, 2016; Walter et al., 2020). Too often, Indigenous People are incorporated into research studies after settler states, institutions, or researchers have already set the agenda, methods, and outcomes. In these instances, Indigenous data are regarded by settler institutions as a free good or gift, which results in researchers failing to engage properly and respectfully (Tsosie et al., 2021a). For many communities, Nations, and tribes, this means that the project of data collection in their sovereign territory has been no more than an ongoing expression of colonialism, human rights abuses, and resource extraction.

Aside from the substantial and ongoing harms done by settler researchers as detailed above, further harm comes when Indigenous Peoples must rely on settler states or institutions for data about their own resources or populations. Dependence on a settler state for information or data about their own people or lands undermines sovereignty and creates data dependency (Kukutai and Taylor, 2016). Further, data gathered and held by settler states invariably serves settler purposes and priorities, rather than Indigenous purposes and priorities (Kukutai and Taylor, 2016). Finally, Indigenous educational institutions and natural resource management agencies are often too underdeveloped and underfunded to allow adequate training and infrastructure to independently develop, manage and utilize certain kinds of technical data sets (e.g. genetic samples), and to train the next generation of citizens in these areas.

In today's data-saturated society, in which the trade of data has become a 21st century natural resource economy, these questions are more critical than ever; there is great risk of non-Indigenous actors mining Indigenous data and perpetuating extractive legacies (Oguamanam, 2019). Indigenous people are uniquely at risk of appropriation and theft in this era of big data because existing intellectual property rights (IPR) and patenting systems do not provide adequate support or recognition for Indigenous knowledges and priorities, which encompasses subject matter beyond what is traditionally included in such systems (Department of the Parliamentary Library, 2005).

The current battle lines in the struggle for data ownership are clearly drawn within the realm of human biotechnology and genetic resources. If anything, the explosion of biotechnological inventions in the last decades has led to greater pressure on and need for the development of data protections and protocols. Tragically, recent examples of contemporary biomedical research harms done to Indigenous peoples underscore this need (Dodson and Williamson, 1999; Sterling, 2011). In answer to this, recent scholarship has focused on alternative biotechnology research models that emphasize Indigenous ownership of human genetic data and control over subsequent data use (Beaton et al., 2017; Rainie et al., 2017; Claw et al., 2018; Blanchard and Hiratsuka, 2021; Tsosie et al., 2021a).

Data sovereignty breaches also occur through researcher use of nonhuman genetic data. Biopiracy, a prominent example of this kind of abuse, involves scientists plumbing Indigenous knowledge about biological materials for commercial or scholarly purposes, without acknowledging or remunerating Indigenous people for their contribution or respecting Indigenous control over the resource (Oguamanam, 2019). Officially, Indigenous Peoples' control over traditional knowledge related to land and biodiversity is protected through the Convention on Biological Diversity's Article 8j, which requires countries to conserve and protect Indigenous knowledge and information that relates to biodiversity (Convention on Biological Diversity, n.d.). Breaches of IDS through unsanctioned use of non-human genetic information continue to occur, however. These breaches do not necessarily occur through the illicit collection of new data. Crucially, IDS also applies to previously collected samples, such as those held in museums or other collections, as well as to subsequent sharing and distribution of data from those samples. This puts IDS values around data ownership at odds with data sharing norms in the field of genetics.

Within the field of biotechnology, current norms around data sharing revolve around open access and blanket open data policies. On this subject, Oguamanam writes: "Access and benefit sharing (ABS) is now the traction point for underscoring how biotechnology and Indigenous ecological or so-called biocultural knowledge constitute an invaluable intersection and frontier of data sovereignty. To effectively participate in ABS, it is imperative that Indigenous peoples have control of their genetic resources and associated [traditional knowledge] data" (2019, p.13). These current blanket open data policy norms trespass on Indigenous Peoples' rights by sharing their data without permission (Mc Cartney et al., 2022).

Data practices within biopreservation must therefore be adapted to operate within and with respect for Indigenous data sovereignty if they are to serve Indigenous Peoples. Ultimately, in these contexts, moreover, it must be Indigenous people who lead in the development of such rules and practices. In recognition of this need, several scholars have proposed alternative data storage and sharing frameworks, prominent among which is the local contexts notice system (Liggins et al., 2021; Mc Cartney et al., 2022). The local contexts framework aims to address the unique sovereign rights Indigenous people hold to data collected from their populations or on their land, by holding researchers using Indigenous data to standards that protect IDS.

In this way, Indigenous data sovereignty (IDS) has grown out of ongoing movements for Indigenous sovereignty and self-determination (Carroll et al., 2019; Carroll et al., 2020). IDS affirm the right of Indigenous Peoples to gather, control, store, and interpret their own data about themselves and their lands, or to choose to refrain from these activities, recognizing that data collection is not just information gathering, but a crucial aspect of governance. Indigenous technical capacity, moreover, must not be prevented from being comprehensive enough to either embrace or reject specific methods, techniques and tools. Today, IDS is conceptualized as both a right and a responsibility that mutually reinforces inherent sovereignty and self-determination and governance (Kukutai and Taylor, 2016; Carroll et al., 2019). As a result, settler states have been reluctant to recognize IDS (Oguamanam, 2019).

To further the development of IDS, Indigenous communities and allied researchers across the world have established internationally recognized principles of IDS, e.g. the CARE principles for Indigenous data governance (Carroll et al., 2020), the First Nations Principles of OCAP® (The First Nations Information Governance Center, n.d.), and Principles of Māori Data Sovereignty from the Te Mana Raraunga (Te Mana Raraunga, 2018). These sets of principles advocate for and promote the inherent rights of Indigenous people to their own data, as well as provide guidance and best practices for research and data processes moving forward. Although there is significant overlap between the above listed principles, their components vary in important ways.

Indigenous data sovereignty principles

The CARE principles emerged from the work of the International Indigenous Data Sovereignty Interest Group and include the following components: collective benefit, authority to control, responsibility and ethics (Carroll et al., 2020). These components articulate the rights of Indigenous Peoples in relation to their data: Indigenous data must enable collective benefit for Indigenous Peoples, data must be controlled and governed by Indigenous Peoples, relationship responsibilities such as advancing self-determination and governance must be respected, and representation and participation of Indigenous Peoples must be central to the data collection. "Ongoing processes of colonization of

Indigenous Peoples and globalization of Western ideas, values, and lifestyles have resulted in epistemicide, the suppression and co-optation of Indigenous knowledges and data systems. These processes have limited the ability of Indigenous Peoples to recover, develop and sustain their knowledges, an ability that is central to Indigenous Peoples' capacity to realize their human rights and fulfill their responsibilities" (Carroll et al., 2020). The intent is that the CARE principles work in tandem with the FAIR principles (Findable, Accessible, Interoperable, Reusable) (Wilkinson et al., 2016). Integrating CARE and FAIR practices will allow data to remain under Indigenous control, serve Indigenous purposes, and reflect Indigenous ontologies and epistemologies.

The First Nations Principles of OCAP® assert that Indigenous communities have sole ownership and control over data collection in their communities, and that they alone can determine whether, how, when, and where data is collected, for what purposes, where it is stored, and how it is used (The First Nations Information Governance Center, n.d.). The letters of OCAP® stand for Ownership, Control, Access and Possession. Ownership means that the community owns their data in the same way that an individual owns or controls their own information. Control means that First Nations have the right to control all aspects of research, including the choice to not participate in research. Access means that regardless of where data are stored, Indigenous People must be able to access it. Possession is the physical control and location of the data: in other words, the mechanism for controlling the other three attributes of OCAP®. The goal of OCAP® is to enact data sovereignty, which is both an inherent right as well as a prerequisite to sovereignty and Nation re-building, which allows First Nations to achieve equitable self-governance and closure of socio-economic gaps (The First Nations Information Governance Center, n.d.).

As put forth by the Te Mana Raraunga Māori Data Sovereignty Network, there are six principles of Māori data sovereignty: 1) Rangatiratanga (Authority): Māori right to control data, jurisdiction over storage, data that supports self-determination; 2) Whakapapa (Relationships): context for data is provided, disaggregate data according to Māori needs/aspirations; 3) Whanaungatanga (Obligations): balance the risks and benefits between groups and individuals (collective rights will prevail), and any people producing data are accountable to the communities from whom the data come; 4) Kotahitanga (Collective benefit): data ecosystems should function for Māori benefit, build Māori capacity, and support connections with other Indigenous peoples; 5) Manaakitanga (Reciprocity): collection and use of data shall respect Māori, and consent shall undergird all data use and collection; 6) Kaitiakitanga (Guardianship): Māori data will be stored so that Māori have the capacity to be guardians of their own data, ethics will be respected, and Māori decide which data are or are not accessible (Te Mana Raraunga, 2018).

These frameworks and principles define IDS as covering and governing all types of data that have to do with Indigenous Peoples: their lands, and their lifeways, including: information, knowledge, technologies, natural resources, demographic data, commercial data, traditional and cultural information, arts, oral histories, and genetic data (Carroll et al., 2020). Crucially, ownership and control over genetic data applies not only to human genetic data, but also to the genetic data of more-than-human species, including all forms of life with whom Indigenous Peoples have co-existed and co-evolved for millennia (Department of the Parliamentary Library, 2005; Oguamanam, 2019).

Thus, biopreservation researchers' use of genetic information gathered from endemic animal and plant life on Indigenous lands without consent and attribution is a violation of Indigenous data sovereignty, and could be characterized as biopiracy, regardless of the intent of the researcher. When harvesting genes on non-Indigenous-held lands ceded by force from Indigenous peoples, where those resources are frequently co-governed with Indigenous people, oversight typically entails an even more complex obligation for co-management. But even here, the way data are collected and stored are matters subject to IDS considerations. Acknowledging this, it is perhaps a short distance between biopiracy and biopreservation, in that biopreservation without Indigenous ownership and management could be reasonably interpreted as theft and ongoing colonialism. Therefore, one important distinction between biopiracy and biopreservation is whether the researcher ensures that Indigenous data sovereignty is respected in every aspect of the research, from project conception and design, to funding, methods, analysis, and finally the dissemination of the results and storage of the data.

Section III: Indigenous data sovereignty and biopreservation

The internationally recognized principles of IDS detailed above are a guide for researchers engaged in biopreservation work, but detailed case studies can also serve as instructive roadmaps. To that end, this section outlines examples of projects involving conservation genetics, where IDS principles are instructive, illustrated both by examples of their employment and, sometimes, by their absence. The number of conservation projects that use genomic approaches and partner with Indigenous collaborators is a small but growing subset of the conservation landscape, though overall such projects remain under-documented (Touchette et al., 2021). Biopreservation at scale, though largely unprecedented, therefore, can and should be informed by these closely-related cases.

As noted above, contemporary genomic and biopreservation efforts are increasingly characterized by non-invasive sampling, which aligns better with Indigenous Peoples' values (Touchette et al., 2021). As a result, the worldwide trend in conservation projects utilizing genomics projects has trended toward "closer collaboration between communities and researchers, integrating values, principles and culture specific to the communities involved, [favoring] an ethical approach and giving greater recognition to the quest for self-determination of Indigenous Peoples" (Touchette et al., 2021, p. 309); the ultimate goal is biopreservation research and management decisions co-designed with Indigenous groups.

Researchers who commit to decolonizing their research methods and goals, however, must cede significant control to Indigenous collaborators, and remain open, humble and sensitive for these partnerships to work. Critically, the following three researcher behaviors are essential for successful genomics partnerships with Indigenous communities: 1) "[never permitting the] use of data for purposes other than those planned or the sampling of data without the consent of the involved Indigenous communities", 2) "[centering the] importance of involving communities in all steps of the project, sharing control of the research and obtaining free, prior and informed consent are the foundations for an ethical Indigenous research approach", and 3) clearly communicating the "risks and benefits of potential approaches" (Touchette et al., 2021, p. 305-306). Finally, at the conclusion of analysis, researchers must prioritize returning to share findings and make those findings useful to any involved communities (Touchette et al., 2021). In addition, projects rejecting the old exploitative model can and should include research commitments to biopreservation infrastructure, governance, capacity-building, and training of Indigenous researchers for further, independent research and management goals alongside community benefit (Tsosie et al., 2021b). To that end, all genomics researchers and biopreservation practitioners must continually center and emphasize IDS' sine qua non, archetypically captured in the phrase: "nothing about us, without us".

Ngāi Tahu mudfish and crayfish

The first example emerges from Aotearoa New Zealand, in which researchers from the University of Canterbury (Ngāi Tahu territory) gathered genomic data from two taonga (treasured) species: kōwaro (Canterbury mudfish; *Neochanna burrowsius*) and kēkēwai (freshwater crayfish; *Paranephrops zealandicus*). A partnership between researchers and the Māori subtribe Ngāi Tūāhuriri (upon whose territory the research occurred) enabled the co-development of "an iterative decision-making framework" as part of a research program with the twin goals of improving the species' recovery and upholding Māori principles (Collier-Robinson et al., 2019). In the Māori worldview, genomic data obtained from taonga species are sacred or taonga in their own right due to their whakapapa (genealogy, context, or belonging on a spiritual level) (Collier-Robinson et al., 2019). Participants stress the following elements as critical to their successful research on taonga species: a) Rangatiratanga and Kaitiakitanga – respect for Māori stewardship and control over their taonga; b) use of Māori language for research terms due to the language's strengths in conveying symbolism and complexity; c) grounding research operations in tikanga Māori (practices, protocols, and ethics), d) Whanaungatanga - prioritization of relationship-building; e) Tohungatanga - revitalization of cultural, knowledge, and linguistic practices related to the taonga species; f) sincere co-development of research agendas, questions, methods, issues of storage and access, and ends (Collier-Robinson et al., 2019).

Another significant aspect of this project was its IDS-driven focus on sampling protocol. Ngāi Tūāhuriri and researchers decided jointly how and where to sample. The outcome was a traditional harvest method using bundled bracken ferns for specimen collection (Collier-Robinson et al., 2019). As of the publication date, the collective decision was made to generate reference genomes by sending samples to "a trusted provider overseas with extensive experience handling culturally sensitive material", thereby respecting rangatiratanga (Collier-Robinson et al., 2019). Although this decision means that taonga data will be stored outside of Māori land, the partners' joint decision to send samples abroad nevertheless meets the conditions of IDS by centering Ngāi Tūāhuriri decision-making in that choice.

As discussed above, Indigenous biodata (and other forms of data) should not automatically become open source, but should be protected according to the community's wishes, as communicated through community-determined official cultural and political leadership. In the context of this case study, the authors are sensitive to this issue and underscore the importance of collectively-made decisions regarding the storage of genomic data: "rangatiratanga has become increasingly important in how knowledge and data from taonga species are shared" (Collier-Robinson et al., 2019).

Inwood et al. (2020) provide a further review of current DNA sequencing and gene editing technologies and their potential application in conservation and biopreservation contexts in Aotearoa New Zealand. Like others cited in this survey, the authors urge that all genetic research on taonga species must be done using the principles of IDS (Inwood et al., 2020). One important dimension of advances in this context is that previously captured and preserved specimens (e.g., museum specimens) are now potentially usable for genome sequencing projects. Almost invariably, these specimens were taken without Māori consent, and may even be held overseas. The result is potential for disregard of IDS if sequencing occurs on taonga species that are not controlled by Māori. As discussed above, if such research occurs without permission and partnership, both the conducting of the research and the storage and distribution of its results are in direct violation of IDS. To avoid breaches of IDS, the authors recommend that any researchers engaged in biopreservation work of Aotearoa New Zealand endemic species "engage early and often with relevant Māori iwi and hapū" (Inwood et al., 2020, p. 3).

Another consideration for researchers in such settings could and should include the fate of samples taken in the past without regard for IDS and which are now widely available in open genetic databases. As with current and future data collection processes, these samples should be integrated into an approach that respects the breached sovereignty.

Genetically engineered American chestnut

While genomics research as described above in the Māori case involves the analysis of a species genome (Collier-Robinson et al., 2019; Inwood et al., 2020), other applications of genetic approaches to biodiversity conservation are also growing. While many biopreservation aims are merely to collect genomic samples for storage and phylogenetic mapping and recording, other applications embrace wholesale genetic engineering (GE): altering DNA makeup with the goal of changing a species' traits for preservation and conservation of the species.

As a notable example, a century after catastrophic loss of populations across their native range due to the chestnut blight fungal disease (accidentally imported from abroad), such an effort is underway for American chestnuts (*Castanea dentata*), which once dominated North American forests. Current research seeks to restore the species through the use of genetic engineering, in which the genome is modified to resist the deadly fungal infection (Newhouse and Powell, 2021). These innovations come principally from labs at the State University of New York College of Environmental Science and Forestry (SUNY-ESF). The SUNY-ESF restoration plan to revitalize the nearly extinct American chestnut tree includes the eventual wild release of a genetically engineered chestnut tree (GEAC) in and around the traditional territory of sovereign Haudenosaunee communities of central and upstate New York (Barnhill-Dilling et al., 2020).

Although this project is not an example of biopreservation, the creation and planned release of the GEAC is a crucial case-study for Indigenous data sovereignty, because the American chestnut's near extinction occurred during the time of U.S. government assimilation policies, when Indigenous data and knowledge was being actively destroyed by the settler government. Thus, many Haudenosaunee people, whose territory overlaps with planned GEAC release sites, do not have present-day relationships with chestnut trees (Barnhill-Dilling and Delborne, 2019). This lack of relationship is in direct contrast to the Māori case described above, where the Ngāi Tūāhuriri are in active relationship with the two species studied. Also, unlike the Māori case, data collection for the GEAC project did not occur on present-day Indigenous land.

Despite these differences, IDS is still vitally relevant, as its principles embrace the inherent sovereignty, governance, and self-determination rights of Indigenous people. Appropriately honoring sovereignty, deep collaboration and co-equal partnership must therefore occur before research begins that could have impacts on sovereign territory. Clearly, the eventual wild release of GEAC, which is designed to spread in the natural world, will have substantial impacts on sovereign Haudenosaunee land. Thus, dispersal of GEAC without Haudenosaunee consent and partnership bears on Indigenous sovereignty.

In interviews, respondents from Indigenous communities reported that collaboration and partnership with researchers should have occurred even before the planting of GEAC field sites, which already exist, and were planted before consultation (Barnhill-Dilling et al., 2020). Although SUNY-ESF has since conducted extensive consultation efforts after planting, some respondents found that these consultation efforts were inadequate, because previous planting of field sites without Haudenosaunee permission created mistrust and unease. One respondent offered the following: "nobody came to the Nation and said look, we have this gene-splicing idea, what would you like to be gene spliced? Would we have said the chestnut tree? Save the chestnut tree?" (Barnhill-Dilling et al., 2020, p. 94).

Respondents further felt that the unpermitted movement of transgenic material originating from SUNY-ESF across the borders of Haudenosaunee land is a breach of sovereignty. Specifically, they invoked the Two Row Wampum Treaty of 1613, which states that the European settlers and Haudenosaunee Confederacy are not to interfere with each other's land, and not to disrupt each other's distinct lifeways, governance, and customs (Barnhill-Dilling et al., 2020). In interviews with Haudenosaunee community members, Barnhill-Dilling et al. found that any plan for chestnut tree restoration using the GEAC needs to respect internal tribal governance structures, allow adequate time for Haudenosaunee to conduct their own research and linguistic analysis around the GEAC, and respect the time needed to develop Iroquois words for relevant concepts and investigate whether GEAC could operate as traditional medicine (2020).

Notably, while some respondents believed that genetic engineering is too far outside of humans' roles within the ecological community according to the Original Instructions from Creator, others were interested in building a relationship with GEAC through traditional activities involving the original species, such as cooking and woodworking (Barnhill-Dilling and Delborne, 2019). Still other respondents wondered whether rescuing the American chestnut from human-induced extinction is perhaps a way of redressing the devastation wrought by the introduction of the pathogen (Barnhill-Dilling and Delborne, 2019). Clearly, consultation reveals a diversity of opinions, cultural responses, and ethical formulations. These are best derived before the fact of introduction, whatever the final outcome regarding genetic modification of the wild species. Ignoring these ontological and epistemological differences and proceeding without partnership, and operating with a lack of dialogue, is ultimately the core problem. To avoid these harms, researchers must attend to "dimensions of reciprocal restoration at critical junctures [that] may create space for affected Indigenous communities to preserve important spiritual responsibilities and kin centric relationships, thus preserving important elements of sovereignty" (Barnhill-Dilling and Delborne, 2019, p. 6). Finally, and most significantly, prior consultation with Haudenosaunee leadership would have allowed them to determine, amongst themselves, which competing priorities should determine participation, or not, in such an intervention.

Manoomin research

Manoomin (*Zizania palustrus*), which literally translates to "good berry" in Ojibwe, is known as wild rice in English. It is a deeply important cultural food for Anishinaabe (Ojibwe) communities throughout the Great Lakes region of the United States and Canada, and a critical part of IDS for those communities. In the 1960s, a group of University of Minnesota scientists launched a wild rice breeding program that included genetic research and modification of the species to the way it ripens, to "improve" it for larger scale commercial harvest (Matson et al., 2021). Tribes launched vocal protests, arguing that genetic alteration of Manoomin would likely lead to profits for non-Indigenous people, while harming and degrading the sacred plant (Matson et al., 2021). Despite these protests, the research continued, making this Manoomin research a key case of IDS violation (Department of the Parliamentary Library, 2005; Kukutai and Taylor, 2016; Walter et al., 2020).

Today, a new partnership of researchers has emerged, called Kawe Gidaa-Naanaagadawendaamin ("First we must consider Manoomin"), consisting of students, tribal natural resource managers, and inter-tribal representatives. Together, they seek to address and repair the harms done during decades of nonconsensual research on Manoomin. This partnership studies the decline of manoomin and works "to understand the multiple facets of Manoomin through research predicated upon respect for tribal communities and for Manoomin itself" (Matson et al., 2021).

Although Kawe Gidaa-Naanaagadawendaamin does not consist of "biopreservation" efforts per se, it honors IDS for a culturally significant species, and numerous considerations have been embedded in the emerging research regime, many of which echo those of the taonga species research from the Māori experience. Following Matson et al. (2021), these include: "1) Honor Indigenous sovereignty and rights; 2) Address past and present harms; 3) Be on the path together with researchers and Indigenous partners; 4) Recognize, respect, and value Indigenous participation and intellectual labor; 5) Encourage the robust exchange of ideas; 6) Recognize that documents formalizing a relationship are not the whole relationship; 7) Make a plan for identifying and protecting sensitive Indigenous data; 8) Be prepared to navigate institutional obstacles; 9) Seek, support, and collaborate with diverse students; and 10) Actively listen and be open to different ways of engaging with the world".

The case history of Manoomin research lacks sufficient documented intellectual and institutional history to fully provide a concrete model for appropriate engagement. More thorough investigation will likely reveal more specific details to inform how researchers should better consult relevant communities in genetic research. For the specific challenge of biopreservation, however, the case is illuminating. Evolution of more principled approaches in this case required active, ongoing, and constant political pressure to achieve (LaDuke, 2010). Future engagements in this area can only hope to proceed with less conflict if the rules of engagement are observed from the outset.

Here, in this case of genetic research gone wrong, in which IDS principles were violated, evolved in a co-governed genetic research effort. Notably, researcher investment in relationships and consensus-building with Indigenous collaborators proved key to successful outcomes and to the protection of Indigenous data sovereignty. Early and frequent communication across multiple forms (written, spoken, etc.) is central to shared understandings, while a consultative, sovereign manner of data management is critical to success.

Ojibwe treaty rights and co-management institutions

As discussed above, access to land and natural resources is vital to Indigenous sovereignty and knowledge systems, as well as to IDS. The struggle for these inherent rights resurfaced in the U.S. state of Wisconsin during the 1980s and 1990s, when the Ojibwe people fought successfully to defend land use rights, which had been denied to them by the state for most of the 20th century (Satz, 1991). The results of these events, the institutionalization of IDS-aligned practices through the creation and management of a new governing body, the Great Lakes Indian Fish and Wildlife Commission, provide management examples that chart a way forward for biopreservation and IDS.

In March 1974, two brothers of the Lac Courte Oreilles Band of Lake Superior Chippewa Indians (LCO) were arrested for spearfishing on Chief Lake, Wisconsin in ceded territory (Nesper, 2002). Ceded territory refers to the lands in Northern Wisconsin ceded by the Ojibwe Tribes to the United States through a series of treaties in the mid-1800s where the Ojibwe reserved fishing, hunting, and gathering (usufructuary) rights. The brothers were defended by the LCO Band, which filed suit in 1974 against the State of Wisconsin and Department of Natural Resources Secretary Lester Voigt "for interfering with Chippewa off-reservation hunting and fishing rights" (Satz, 1991, p. 94). Ultimately, in 1983, the U.S. Court of Appeals for the Seventh Circuit ruled in favor of LCO in a ruling now referred to as the Voigt Decision. This ruling affirms the existence of these rights and in subsequent rulings sets the terms and conditions of these usufructuary rights of the Ojibwe throughout territory ceded to the United States through treaties, which guaranteed the Ojibwe their continued use of the ceded territories. The Voigt ruling was further supported when the U.S. Supreme Court refused to hear an appeal.

Following a series of subsequent rulings, issued to specify the extent of these rights, the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) was formed as a key intertribal co-management institution to advise the tribes on effective tribal self-regulation that enjoined regulation by the State of Wisconsin. Confirmed by these rulings, Ojibwe rights extend to walleye and muskellunge harvesting, using a plan proposed by Ojibwe conservation officials from GLIFWC and modified by "safe harvest" calculation given by the state of Wisconsin (Satz, 1991). Similarly, the legal findings assured that the Indigenous and non-Indigenous residents of Wisconsin are each entitled to one half of the state's deer harvest within ceded territories (later also applied to walleye and muskellunge harvest). These, along with several other rulings, clarified the scope of the Ojibwe's rights guaranteed by treaty. Due to these rulings, and to the forward-thinking actions of their ancestors in the treaty-making process, six Ojibwe bands in Wisconsin exercise treaty rights throughout the Wisconsin Ceded Territories (largely the northern third of the state) (Great Lakes Indian Fish and Wildlife Commission, 2018). Natural resource management in the ceded territories in the era after the Voigt decision is now a mandatorily collaborative effort between the Ojibwe tribes (with assistance from GLIFWC) and the state's Department of Natural Resources.

Although the Voigt decision does not explicitly reference genetic materials, its co-management principles hold fast to the tenets of IDS by respecting sovereignty and regarding Indigenous peoples as experts and decision-makers within territories co-governed with settlers. The rulings also show a model of co-management decision-making that could and should direct the review and control for the harvesting of genetic material within the areas of concern, which specifically include lands outside of reserved tribal land. Such contexts are likely to be among the most common and urgent for adjudication. Resolution of complex contexts such as these are essential for biopreservation, since wildlife are mobile, inter-jurisdictional and governed by multiple, competing authorities, communities, and regulations. This process and practice of institutionalizing such principles, should serve as a model for other efforts to advance genetic biopreservation using an IDS management approach.

Section IV: Actionable recommendations: sovereignty, autonomy, institutionalization

If wide-scale collection and biopreservation of somatic cells is an essential part of future conservation efforts, this effort can and must be harmonized with efforts of Indigenous Data Sovereignty. The lessons of IDS in both theory and practice from the experience of American Chestnut genetic engineering, coupled with the useful examples from the Manoomin and Māori case studies and post-Voigt Ojibwe institutional management agreements, point towards an approach to biopreservation that both honors Indigenous sovereignty and allows paths forward for possible collaboration and mutual benefit in biopreservation. The following principles do not reflect specific protocols (though they do call for them), but instead suggest "rules of engagement", or overarching values from which to begin dialogues and programs in biopreservation in and around Indigenous communities. We recommend a generative, consultative, and sovereign approach to biopreservation characterized by early and frequent engagement.

Sovereignty

The first of these principles is sovereignty, which describes total authority. The IDS experience shows a model for how Access and Benefit Sharing (ABS) can become the central principle of wild genetic data collection and storage, but only where Indigenous peoples have complete control of genetic resources and traditional knowledge associated with their territories. Where collection of wild genetic samples from sovereign territory occurs, whether stored *in situ* or ex situ, blanket open data policies for samples must be abandoned, insofar as they trespass on the sharing of Indigenous data without permission.

As the experience at GLIFWC further suggests, this sovereignty can and should extend to consultative agreements even for territories, recognized by treaty or agreement, beyond reserved land. This also points to the utility of prior agreements that can develop institutions to oversee collaboration and assure the culturally appropriate methods for collection and storage in such extra-territorial contexts.

Finally, the case of the American Chestnut points to the urgency of respecting such authority in any "downstream" application of genetic tools. There can be no such application (e.g. species release) on Indigenous territory or territory near or adjoining Indigenous land unless directed or consulted by their sovereign authority.

Autonomy

Autonomy refers to the principle that Indigenous communities may or may not choose to collect and preserve their own genetic samples. In pursuit of this, training and infrastructure development for the technical capacity to do so - if requested and in dialogue with experts in Indigenous communities - should be an obligation associated with efforts by any authorities and researchers working regionally. The purposes or intent of Indigenous data collection must be free from any obligation or expectation that they harmonize with those of other biopreservation efforts that may be ongoing in university or management collections.

This principle further encourages the opportunity for researchers and managers to develop data and metadata in a decentralized network, to share information about local *in situ* collections, at the discretion of autonomous Indigenous "nodes". Such an approach, where differing, autonomous genetic sample collections are linked in a network of information without expectation of central control or shared ownership, has been referred to as "Planned Hindsight". This approach allows collective development of protocols, methods, and findings, by accepting "widely divergent speculative visions" (Radin, 2015, p. 13) and diversities of purposes. As such, it is highly appropriate for collaboration with Indigenous genetic data collection, where the autonomy of Indigenous partners is paramount, but information sharing is prioritized.

Institutionalization

These prior principles must be grounded in the development of explicit rules and expectations. Contrary to the American Chestnut experience, such agreements and consultations benefit from initiation before, and not long after, biopreservation begins.

Where possible and appropriate, existing agreements can be further leveraged for application to wild genetic sampling. One can envision, for example, that existing protocols between the State of Wisconsin and Great Lakes Indian Fish and Wildlife Commission for handling culturally sensitive materials (e.g. wolf carcasses) can be extended to the handling of any wild animal sample. Such previous agreements were developed through a long and careful process (as in the wake of the Voigt case), which served to develop relationships and trust; it would be unwise to "start from scratch."

Moreover, formal institutions will need to be designed, adopted, and evolved to hold researchers better accountable to the principles outlined here. In future, funding agencies, university review boards, and similar entities could play a more active role in encouraging or enforcing such modes of improved engagement. Such interventions might be comparable to the way institutional review boards have evolved from the Belmont Report or where third party accreditors (like the Association for Assessment and Accreditation of Laboratory Animal Care) have played a more active role in reviewing research practice. Prior to this, however, the prior principles of engagement in biopreservation must be better established and developed.

A way forward

In sum, the serious, historic mistakes made in human genetic biobanking and the way in which those efforts harm(ed) Indigenous communities provide lessons that can be used to plan for wildlife biopreservation in approaches that are responsible, respectful, and potentially collaborative. As detailed in this paper, the models that make this possible already exist and show promising precedent. Above all, nascent biopreservation practitioners must respect Indigenous Peoples' right to refuse any biopreservation proposed on their sovereign territory. Institutions and researchers engaging in biopreservation must not trespass on Indigenous land. In our case, none of the four authors of this paper belong to, or represent Indigenous communities. Nevertheless, we are concerned about the potential for biopreservation to violate Indigenous sovereignty, and hope that this article will guide our own institutions and others as the practice of biopreservation grows.

Similarly, as demonstrated in the case of Wisconsin's ceded territories, biopreservation efforts must be co-authorized and co-managed by Indigenous and non-Indigenous partners, as the management of and, relationships with, wildlife in the formerly Indigenous territories are the responsibility of both groups. Complications, of course, remain: animals capable of locomotion regularly move across boundaries, and even animals and plants not capable of propelling themselves independently may be moved by other forces. Thus, biopreservation efforts conducted outside of formally designated territories' and boundaries can and will impinge on organisms that live within them. Although biopreservation is by nature a minimally invasive process, there is inevitably an ambiguity that emerges at these fluid boundaries, especially in co-managed areas.

Stepping further back, enormous swaths of land worldwide are historically Indigenous territory, seized through colonial violence. Thus, there are larger implications inherent to biopreservation wherever it takes place, suggesting that Indigenous peoples native to those places should be involved in biopreservation projects on their historic homelands. As the fields of biopreservation and Indigenous data sovereignty grow over time, we hope to see further inquiry into these questions. By honoring Indigenous sovereignty and community autonomy, and by working to create or leverage existing formalized agreements, powerful genetic toolkits can be brought to bear in the protection and preservation of species of cultural and conservation significance. Their potential will only be realized through real collaboration.

Finally, experience suggests that a host of ethical, historical, colonial, and socio-political questions potentially attend all facets of conservation genetics. Starting from the collection and preservation of wildlife genes, however, the first and most elementary of procedures, is prerequisite to the rest and the most appropriate place to begin. By exploring common interests in conservation with diverse and Indigenous communities and drawing on their own experiences with protecting and preserving wild nature (e.g. extensive seed banks held by North American Tribes and Indigenous Nations), this starting place can become one of consensus and dialogue rather than conflict and domination.

Author contributions

All authors contributed to the article and approved the submitted version.

Conflict of interest

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

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