Exploring the legal, policy, ethical and practical implications of digitisation of botanical and fungal collections

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Societal Impact Statement

Dried plant and fungal specimens held in collections provide a unique asset to understand the natural world and inform conservation approaches. By creating freely available, digital images of these collections, these specimens can be used by more scientists from around the globe to ask research questions and apply new technologies. We consider the relevant laws, policies and agreements which are required to ensure this process is equitable, sustainable and respects the rights of the countries and communities where material was collected. We offer

reflections on these challenges, share learnings from two case studies and explore the roles of institutions and governments in addressing them.

Summary

Collections-based institutions around the world hold an extraordinary wealth of information and knowledge through the specimens and associated information that they house. In recent years, institutions holding botanical and fungal collections have invested significant energy and resources into the digitisation of these collections to make them more accessible and better connected. Digitisation poses a wide range of legal, policy and ethical questions, relating to Open Access, Access and Benefit Sharing, data sovereignty and more. Overlapping policy and legal frameworks at global and, increasingly, national levels create a complex landscape, particularly as new technologies such as AI are applied to digitised collections. This paper reviews the roles and responsibilities of institutions, funders and governments in navigating these challenges in mitigating the risk of reproducing historical biases associated with these collections and to ensure that data can be accessed equitably. We explore three case studies - from University of Trans-Disciplinary Health Sciences and Technology (TDU) University in Bengaluru, India, from Royal Botanic Gardens, Kew and from Manaaki Whenua, New Zealand, to offer insight into equitable approaches to digitising specimens and linking to Traditional Knowledge and Indigenous communities and use these to outline three options that institutions should consider to help navigate this complex landscape.

Key words

Digitisation, Policy, Access and Benefit Sharing, Equity, Data Sovereignty, Infrastructure.

Introduction

This paper discusses emerging, unresolved and urgent legal, policy and ethical issues in the context of digitisation of botanical and fungal collections. We use ‘digitisation’ to mean ‘the creation and publication of digital images of an object’ (Bailey et al., 2024). In the context of botanical and fungal collections, this generally consists of images of specimens and usually includes transcription of the associated data (such as annotations, geo-locations and field collecting notes). Though we focus on digitisation, we acknowledge the important connection to the related term ‘digitalisation’, which refers to the more applied ‘use and implementation of digitised content in a richer and broader context than its original sphere’(Bailey et al., 2024). Digitalisation may, for instance, include artificial intelligence (AI) adoption, and the creation of genetic Digital Sequence Information (DSI) from specimens, raising additional legal and policy questions (Ruiz Muller, 2021 accessed 15.01.26).

Digitisation brings enormous benefits. These include increasing and widening access to the collections and promoting global knowledge sharing; enhancing connectivity between historic collections and making them available to new technological approaches, including AI; creating a "digital twin" to reduce the need for handling and transporting fragile physical specimens and to preserve materials in case of damage or loss; and increasing public engagement and accessibility (Winters et al., 2022; Popov D, 2021; Boon et al., 2025).

Taken together, these benefits will be instrumental in facilitating research that supports conservation actions and delivering benefits to wider society (Hardy et al., 2023; Popov D et al, 2021). Through widening access to information relevant to the conservation and sustainable use of biodiversity, digitisation can also support delivery of global policy targets such as the Kunming-Montreal Global Biodiversity Framework (KMGBF) and the associated Global Strategy for Plant Conservation (GSPC) (Deloitte Access Economics, 2023; Global Partnership for Plant Conservation, 2025; Secretariat of the Convention on Biological Diversity, 2022).

Given these benefits, it is no surprise, that many institutions have progressed with efforts to digitise their collections and have shared best practice and policy recommendations for with other institutions looking to do the same (Bailey et al., 2024; De Smedt et al., 2024; DiSSCo UK 10-Year Digitisation Programme Announced, accessed 08.01.26; Reflora, accessed 27.08.25).

Despite the benefits, digitisation reveals legal, policy and ethical challenges, which are still under-studied from a bio-heritage perspective, and in need of urgent articulation. These are amplified by rapidly developing technologies such as AI, with increased scraping of digitised heritage collections for commercial AI training(Michael Weinberg, accessed 30.04.26). Many of these collections, often located in the global north and with complex colonial histories and legacies, hold important historic and representative samples of the world's known biodiversity, as well as data and information related to it (Johnson et al., 2023; Park, 2023). Digitisation of these collections therefore poses important questions around data sovereignty, respect for Indigenous rights, and the equitable sharing of benefits. In some cases, existing global agreements such as the Convention on Biological Diversity and its Nagoya Protocol (Secretariat of the Convention on Biological Diversity, 1992, 2011) help to address these questions, but these frameworks largely focus on regulating *physical* genetic resources – leaving a legal and policy vacuum around how related *digital* material, and information derived from this, should be treated. Some countries now cover these issues in their national legislations, and institutions and communities around the world are collaborating to navigate and find fair and workable solutions to these challenges together (Ljungqvist et al., 2025). Innovative, collaborative approaches, such as Biocultural Labels (Grounding Indigenous Rights, accessed 08.01.26.) are also being employed to connect specimens to the associated Traditional Knowledge and are explored in the case studies in the present article.

There are also practical challenges for delivering accessible, connected and representative digitised collections. Realising the long-term value of these collections requires a far-sighted view on the equity of access, sustainability and maintenance of the digital collections.

To address this gap, this paper maps out these interrelated challenges informed by case studies, identifies the current gaps in policy and governance, and suggests strategies for how these issues should be more integrally, holistically and directly addressed.

Policy and legal issues associated with digitisation of botanical and fungal collections

Legal frameworks

Consideration of the policy and legal issues associated with digitisation begins with the UN's 1992 Convention on Biological Diversity (CBD), which sets out a pathway of ethical expectations and legal norms for rebalancing equity around access to and use of genetic resources – particularly with regard to the sharing of benefits derived from their use (Secretariat of the Convention on Biological Diversity, 1992).

The CBD's Article 15 recognises the sovereign rights of States/Parties over their natural/genetic resources and sets out the framework of an 'access and benefit sharing' (or 'ABS') regime. This regime, which is subject to and implemented through national legislation, asks Parties to create conditions to *facilitate* access to genetic resources for 'environmentally sound uses' (Article 15.2) on mutually agreed terms (Article 15.4) and subject to prior informed consent (Article 15. 5), unless otherwise determined. Furthermore, it requires the sharing, in a fair and equitable way, of results of research and development, and the benefits arising from commercial and other utilisation of genetic resources with the country providing those resources (Article 15.7).

The CBD's Nagoya Protocol (NP), adopted in 2010 to give more clarity to these 'ABS' obligations, sets out that the utilisation of traditional knowledge associated with genetic resources be included within this scope (NP Articles 7 and 12) (Secretariat of the Convention on Biological Diversity, 2011). It also highlighted the rights of Indigenous Peoples and Local Communities (IPLCs) to benefit from the utilisation of genetic resources within the State based mechanism of the CBD.

While the CBD's articles and provisions appear primarily focused on conservation and sustainable use of *physical* genetic resources, access to (and utilisation of) biodiversity information has increasingly been recognised as a device through which the Convention's objectives can be met. The CBD's Article 17 on exchange of information sets out the need for Parties to 'facilitate the exchange of information from all publicly available sources [...] taking into account the special needs of developing countries', which can be interpreted as broadly in support of open data.

More recently, the CBD's Kunming-Montreal Global Biodiversity Framework (Secretariat of the Convention on Biological Diversity, 2022), and its cross-cutting Target 21, reiterates that biodiversity action requires 'the best available data, information and knowledge' to be accessible to decision makers, practitioners and the public. The related GSPC voluntary complementary action 21b specifically highlights digitisation of collections as a mechanism to achieve this target (Global Partnership for Plant Conservation, 2025).

Concurrently, new national and global frameworks for use of information associated with genetic resources are being developed. International examples include the newly agreed World Intellectual Property Organisation (WIPO) Treaty on Intellectual Property, Genetic Resources and Associated Traditional Knowledge (GRATK Treaty) 2024 and UN CBD decision 15/9 on digital sequence information on genetic resources. Although these examples indicate increased global focus on issues around the use of genetic resources, they are critiqued for having weak enforcement mechanisms and for being diluted versions of the proposals originally made (Henderson, 2025).

The WIPO GRATK Treaty 2024 (not yet in force) aims to prevent patents regarding genetic resources and associated traditional knowledge from being erroneously granted for inventions that are not novel or inventive. This treaty establishes requirements for source disclosure (Article 3), such that patent applicants will be required to disclose the country of origin of the genetic resources or the IPLCs of the associated traditional knowledge. If these are unknown, the applicant must disclose the source of the information, and if this is also unknown, the applicant must make a declaration to that effect. The treaty also establishes requirements for information systems, including databases, to be made accessible to patent offices, noting that this should be done in consultation with IPLCs and subject to appropriate safeguards (Article 6). There is ambiguity as to whether DSI is included within the scope of the disclosure requirement, potentially leading to inconsistent national interpretations and applications of this requirement as regards genetic data (Syam & Correa, 2024).

Given that publicly available information systems and databases could be scraped for commercial AI training, it is crucial that discussions on the implementation of the WIPO GRATK Treaty are given greater profile in AI policy and governance debates, for instance UN Global Dialogue on AI Governance (UN, accessed 30.04.26).

Meanwhile, some countries, anxious to retain control of the use of digitised information relating to their genetic resources, are placing national restrictions on the publication of digital sequence information without specific prior informed consent or attribution (Bagley et al., 2020).

This complex patchwork of rights established across national and international levels is further complicated by a range of other bodies and instruments. At UNESCO level, the 2003 Convention for the Safeguarding of the Intangible Cultural Heritage (ICH), includes as a manifestation of ICH, inter alia, 'knowledge and practices concerning nature'. The 2007 United Nations Declaration on the Rights of Indigenous Peoples (UNIDRIP), state the right of Indigenous peoples 'to maintain, control, protect and develop their cultural heritage, Traditional Knowledge and traditional cultural expressions, as well as the manifestations of their sciences, technologies and cultures, including human and genetic resources, seeds, medicines, knowledge of the properties of fauna and flora (...)'. Despite relevant legal advances, such as UNIDRIP 2007, 'the implementation gap between the adoption of international standards by States and their compliance still remains' (De Mattos Vieira & Viaene, 2024).

These frameworks - the CBD, NP and others - demonstrate an intrinsic tension: while digitisation and open access data has the potential to support broader conservation objectives these goals must be balanced against the recognition of sovereign rights, the need to respect the rights of governments and stakeholders and to obtain prior informed consent for the use of material from relevant stakeholders or IPLCs. This tension is amplified in light of commercial AI, which aggravates the risk of loss of control, misappropriation and misuse of such data. It is therefore crucial that WIPO GRATK Treaty, CBD, NP and related human rights and heritage perspectives are more specifically addressed in AI governance fora, to ensure risks are sufficiently addressed and mitigated. Integrating the environmental expertise of scientists and Indigenous communities, for example, in the UN Global Dialogue on AI Governance, would also help address the critical, but currently overlooked, impact of digital technologies in AI policy and governance discussions(UN, accessed 30.04.26).

Permissions, consent and institutional decisions

Alongside global frameworks and national legislation, institutions must be aware of the terms and conditions of access and use relating to their physical collections to ensure that digitisation is allowed. In some cases, this may involve restricting access to sensitive data (covered in more detail below).

Projects actively collecting plant and fungal specimens must consider possible future use of data and images when negotiating bilateral agreements, so that the utility of these digitised collections and associated information can be 'future-proofed'. Digitisation of historic collections is often more problematic as there is generally no, or less specific, detail relating to consultation and/or consent for digitisation and open, unrestricted use of this data. Historic specimens collected prior to national ABS legislation (or indeed any regulations around plant collecting, export and use) raise complex and often unclear legal obligations regarding their use.

Institutions must carefully consider how their own policies on "use" and digitisation balance their objectives to maximise the use of the data they hold (e.g. to increase access to their collections to support conservation and research) against their obligations to minimise harms which might arise through either inappropriate publication of certain data (e.g. geo-location of threatened species) or commercial use without consent where required, and appropriate benefit sharing. Stewards of natural history collections must also develop responsible approaches to the use of AI in relation to their digitised collections, which fulfil ethical and legal obligations, (Global AI Summit on Africa, 2025; Lawson et al., 2025; Westenberger, 2024 Responsible AI for Heritage: Copyright and Human Rights Perspectives, accessed 08.01.26.).

Given the diversity of collections and the tangled national and international regulatory landscape, there is no one size fits all approach. To make these judgements, collections-based institutions should proactively engage with communities of practice around responsible and ethical digitisation/digitalisation and furnish themselves with policy and legal expertise to navigate this rapidly evolving governance landscape, rather than only seeking guidance from legislative, judiciary and governmental bodies, which may be slower in responding to urgent concerns, for example on AI impacts. Through these groups and communities, we consider that practical tools for designing internal governance processes could be developed to address specific needs and concerns.

Access, bias and Indigenous data sovereignty issues associated with digitisation

As noted above, botanical and fungal collections can incorporate complex historical and colonial legacies. Institutions located in several western and central European countries, as well as in the United States, house over twice the number of species in their *ex-situ* collections compared to the number which occur in the countries of origin of these species (Park, 2023). Digitisation of these collections is not a neutral process, it is shaped by institutional priorities past and present, logistical constraints, historical legacies, resource availability and subjective choices (Heumann & Petersen, 2023).

The inverse relationship between where plant biodiversity exists in nature and where it is housed in herbaria underpins the imperative for collections-based institutions to engage with issues of access, equity and Indigenous data sovereignty(Park, 2023; Sathnam Sanghera, 2024).

Digitisation itself offers one opportunity to address historical inequities by ensuring that digitised data are made findable and accessible through open access platforms such as the Global Biodiversity Information Facility (GBIF.org) and information related to Indigenous knowledge is linked through emerging platforms such as Local Contexts (see case study below).

However, estimates suggest that just one third of herbaria specimens are currently digitised, primarily in the global north (Paton et al, 2025). Gaps in digitisation of the world's herbaria will introduce new bias if conservation policy decisions are taken on the basis of incomplete datasets. These risks are further amplified if AI is trained on these incomplete datasets (Westenberger & Farmaki, 2025). It is, therefore, imperative to resource the responsible digitisation of collections around the world and to integrate these into global infrastructure such as GBIF. This must include exploration of the role that both institutions and users of this data should play in providing this resource.

Bilateral agreements tend to be limited in scope and have thus far failed to deliver the necessary resources to achieve globally representative digitised collections, and thus multilateral funding is likely to be required. Funds generated through the multilateral "Cali Fund" (Secretariat of the Convention on Biological Diversity, 2024) established at the CBD's CoP16 to enable users of DSI to contribute financially to global conservation efforts - have been identified as one potential source of funding, should recipients choose to use it for this purpose. However, the slow adoption of this funding mechanism (Oldham, 2025), and the many competing demands on the funds it may generate, indicate that it is unlikely to be a significant solution, and other multilateral funding sources will be required.

Traditional Knowledge and Indigenous Data Sovereignty

With the shift towards open science, the concept of data sovereignty – that data generated within a state or nation is governed by that nation's laws (rather than the laws of the nation in which it is stored) - has gained significance, particularly in the context of the rights of Indigenous people and source communities (Jennings et al., 2025).

This is important in the context of digitisation as historically (and currently), botanists relied heavily on the knowledge of local and Indigenous people to locate, identify and accumulate the specimens that make up today's celebrated collections (Ashby, 2024). However Traditional Knowledge associated with specimens, which may have been recorded in notebooks at the time, was added inconsistently to specimen records or linked with specimen collection information. Digitisation presents an opportunity to address this gap by considering not only the physical act of digitising specimens, but also how to integrate any associated knowledge into the digitised record. This must be balanced against the rights of those knowledge holders such that it can be made accessible in a way which respects Indigenous data sovereignty. This balance can be met through investing in collaborations between institutions and knowledge holders as explored in case studies below.

More recently, the CARE (Collective benefit; Authority to control; Responsibility; Ethics) principles set out data governance approaches to provide guidance on the creation, collection, storage and use of Indigenous data(Carroll et al., 2020). Efforts to implement the CARE principles are underway and guidance has been published for their application to ecology, biodiversity and earth sciences research/data (Jennings et al., 2023; O'Brien et al., 2024). The importance of these principles has been further emphasised by the UN Special Rapporteur in the field of cultural rights' recent report on digitisation of cultural heritage, which emphasises the need for individuals and institutions to adhere to the CARE principles when digitising collections comprising cultural heritage(UN Human Rights Council, 2025).

The true implementation of these principles can pose challenges to institutions digitising their collections. Digitisation efforts to date have supported efforts to make physical collections findable and accessible, through adoption of the FAIR principles (findable, accessible, interoperable and reusability of data) (Wilkinson, 2016). Implementation of the CARE principles creates a requirement for institutions to collaborate with indigenous communities with regard to their data. This can, inherently, generate requests for collaboration which institutions may be unable to meet.

We suggest three routes through which these collaborations can be achieved and provide case studies below which demonstrate their feasibility:

i. Collections-based institutions create open access platforms for communities to directly contact those institutions to commence discussions on what data they hold and recognition and rights/sovereignty over that data. At its broadest, this would entail opening up of entire global collections for dialogue with communities on recognition of the associated Indigenous data and publishing of sensitive or confidential data on material represented in those collections. This would be the fullest implementation of the CARE principles. However, for many institutions, this approach presents a risk of being unable to allocate the necessary resource required to engage in truly collaborative relationships with communities interested across the breadth of their global collections.

ii. Alternatively, institutions may proactively engage with specific communities or institutions on a project-by-project approach. This can be done prospectively where new collections are established, or associated with specific projects, as explored in case studies below on Kew's Digital Amazon project and Kew's partnership with the University of Trans-Disciplinary Health Sciences and Technology (TDU). This approach allows investment in building trust with communities and truly equitable collaboration such that the value of the collections can be enhanced by greater inclusion of associated Traditional Knowledge. However, it is inevitably limited and covers only subsections of the collections, where funding and resource allow.

iii. A third option involves the creation and adoption of shared infrastructure through which communities are able to record and assert sovereignty of data and knowledge, alongside expectations on its use, which institutions can then reflect in the labelling of their (digitised) collections. The Manaaki Whenua case study and the use of Local Context / Biocultural Notices provides further details on how this approach can work in practice(Anderson et al., 2024; Liggins et al., 2021). The success of this approach is dependent on the ability of institutions to commit to use and adhere to these labelling requests.

*Case Study: C*o-creation of knowledge of digitised specimens, The University of Trans-Disciplinary Health Sciences and Technology

The University of Trans-Disciplinary Health Sciences and Technology (TDU), a leading research university in Bengaluru, focuses on transdisciplinary research into health. Its Herbarium of the Foundation for Revitalisation of Local Health Traditions (FRLH) and Raw Drug Repository focus on medicinal plants used in Indian Medical System – Ayurveda, Unani, Siddha, Sowa-rigpa and

Folk system. FLRH has 75,000 voucher specimens collected from various bio-geographic zones and the Raw Drug Repository has 3,000 botanicals (medicinal and aromatic plants) traded in the country(FRLH Herbarium, n.d.).

Through its digital Herbarium, TDU has thus far digitised voucher specimens of 1,500 plant species, and 300 botanicals samples envis.frlht.org. There is a goal to digitise all the collections at FRLH and as part of this, TDU and RBG Kew are collaborating to increase the precision and interoperability of botanical names and pharmaceutical names by comparing data from TDU's databases to RBG Kew's Medicinal Plant Names Services (https://mpns.science.kew.org/).

A TDU and RBG Kew project, funded by the British Academy, has used newly digitised images of crude drugs to research changing knowledge of herbal medicines in India over the last 200 years, bringing fresh evidence to bear on contemporary plant-based healing practices, both in India and in Ayurvedic medicine in the UK. The project compares textual and specimen data, including the unique collection of 4,000 nineteenth century Indian drug specimens at the RBG Kew and database textual sources held at the TDU, Bengaluru.

This pilot study had three key elements. The first was identification of relevant specimens in RBG Kew's Economic Botany Collection, their photography, and standardisation of metadata concerning botanical names, geography and collector. This element drew on the curation expertise of Kew staff. The second element comprised comparison of RBG Kew's digitised crude drugs with TDU physical specimens to validate and authenticate the identification of the botanical images, drawing on knowledge of the botanical identity and medicinal preparation of crude drugs held by TDU staff.

In the third element, a workshop was held bringing together contemporary knowledge holders in history, medicine, herbal production, pharmacology and regulation to undertake a nuanced comparison of historic and current day practices. In this project there is no single local community or Indigenous group that could be linked to most of the historic specimens, many of which were collected from trade sources or government institutions. In identifying the stakeholder community, the project thus sought to be representative at national level, including in relation to the different medical traditions of India. Many issues that the workshop identified in relation to historic crude drugs, such as botanical identity, quality, and the adoption of new plant species into traditional medical systems, remain current.

The success of this project was underpinned by open communication and mutual respect between all partners. This trust and understanding of local contexts required investment of time to create truly collaborative and inclusive partnerships. In addition, sharing of resources and credit has proved vital to long-term sustainability and shared ownership of digital initiatives. All the digital images and project data have been deposited with TDU, which has unrestricted rights to use these, for example as an addition to its online database. The images are also available through RBG Kew's databases Medicinal Plant Names Services (https://mpns.science.kew.org/) and the Kew Data Portal (https://data.kew.org/), ensuring reach to the broadest possible audience. These experiences will inform future equitable digital partnerships, including as TDU engages with other historical collections to generate an understanding of the documented data of these collections and to ensure their continued use in research, education, and conservation efforts.

Case Study: Digital Amazon and the collections of Richard Spruce

Beginning in 2015, the Digital Amazon project of Royal Botanic Gardens, Kew (RBG Kew) has brought together researchers from the UK and Brazil and Indigenous peoples to reevaluate the collections (herbarium specimens, artefacts and notebooks) made by the 19th century botanist and collector, Richard Spruce(Cabalzar et al., 2017; Martins, 2021). This collaboration sought to generate a holistic interpretation of these materials and associated knowledge as they were digitised. The project was based on engagement with Indigenous communities in the Rio Negro region of the Amazon, from where much of the Spruce collection originated. Through workshops in Brazil and the UK, researchers and Indigenous communities were able to collaborate and share expertise, views and perspectives on plants and their uses; deliver training in research approaches; produce a textbook for use in Indigenous schools, and re-connect communities with objects from their past using physical objects (during visits to the UK) and digital images.

Alongside the herbarium specimens, digital images of the objects collected by Richard Spruce, housed in the Economic Botany Collection (EBC) of RBG Kew, are available on the EBC Database (https://ecbot.science.kew.org/index.php) and the Reflora Virtual Herbarium hosted by Rio de Janeiro Botanical Garden (https://reflora.jbrj.gov.br/consulta/#CondicaoTaxonCP). Notes on the uses and plant components recorded by Spruce are available to all through this database. Through visits and engagement with Indigenous communities, certain restrictions on online publication, for example of the image of a sacred object, were agreed due to cultural *sensitivities, emphasising the value of discussion and agreement between local knowledge holders, researchers and institutions digitising their collections.*

Case Study: Indigenous data sovereignty/futures and the Manaaki Whenua

Manaaki Whenua Landcare Research is part of a newly formed New Zealand Institute for Bioeconomy Science. It had previously operated as an independent Crown Research Institute with a primary focus on land, environment, and biodiversity. A core component of its responsibilities was stewarding Nationally Significant Collections and Databases (NSCDs) for Aotearoa New Zealand. These biological collections comprise over 820,000 samples within:

- *Allan Herbarium*
- *Te Kohinga Harakeke o Aotearoa (the living National New Zealand Flax Collection)*
- *Ngā Rauropi Whakaoranga (previously Ngā Tipu Whakaoranga) ethnobotany database*
- *National Vegetation Survey*
- *International Collection of Micro-organisms from Plants*
- *New Zealand Fungarium*
- *New Zealand Arthropod Collection*

As Manaaki Whenua digitised its collections for use on an open biodiversity database (Systematics Collections Database) it actively integrated Local Contexts Notices and Biocultural (BC) Labels (developed through a Royal Society of New Zealand Catalyst Fund project, with input from Aaron Wilton from Manaaki Whenua).

BC Labels and Notices serve as an ethical framework, providing a mechanism to recognize Indigenous data sovereignty even in the absence of comprehensive legal protections. The process is collaborative, involving Indigenous communities in decisions about how biological collections are managed, accessed, and represented in scientific databases. The use of Local Contexts tools addresses historical imbalances where scientific collections were made without recognizing Indigenous rights or seeking permission from local communities.

Manaaki Whenua was the first research institute to apply Biocultural (BC) Labels and Notices to an open biodiversity database using the Local Contexts Hub. This initiative is part of its broader commitment to recognize and protect Indigenous rights and interests in scientific data, and to uphold the principles of Te Tiriti o Waitangi/ The Treaty of Waitangi. The integration of Local Contexts enriches the data held by Manaaki Whenua, making it more meaningful and accessible to both scientists and Indigenous communities, while georeferencing allows for *precise identification of where specimens were collected, supporting transparency and collaboration with local communities.*

BC Notices have now been added to over 718,000 specimen records in Manaaki Whenua's collections database, signaling to researchers and institutions that these specimens are subject to Indigenous rights and interests. Biocultural labels, digital tags that reflect Indigenous interests and authority in scientific data, can then be added by communities emphasizing provenance (the connection to the originating community), protocols (cultural practices and permissions), and consent (which permissions have been given for collection and use). Through the Local Contexts Hub communities can add or change labels which are automatically updated on Manaaki Whenua's Systematics Collection Database. To date three iwi (tribes)—Te Whakatōhea, Ngāti Maru (Taranaki), and Te Roroa—have added BC Labels to over 6,500 specimen records collected from their respective rohe (territories). For example, Te Whakatōhea have applied labels indicating provenance, research use, openness to collaboration and openness to commercialisation to over 2000 specimens from their tribal rohe.

The Local Contexts Hub enables Indigenous communities to assert cultural authority over Indigenous flora and fauna collected from their territories, with Manaaki Whenua's work serving as a leading example in New Zealand. Manaaki Whenua's approach is part of a global movement to support Indigenous communities in identifying and re-establishing connections with materials sourced from their lands, ensuring their voices and protocols are visible in digital archives. Local Contexts is also being used by the Smithsonian Institute and New York Botanical Garden, and has been integrated into the Genomic Observatories Metadatabase (GEOME) and SPUN. A process to enable the use of Local Context Notices and Labels in the Global Biodiversity Information Facility (GBIF) is currently underway using Labelled datasets from Manaaki Whenua, Geome, and SPUN.

These three case studies show the practical ways in which the options we outline above can enable digitisation of physical specimens to recognise Indigenous rights, implement the CARE principles and enhance the records in the process.

Institutions digitising their own collections must consider whether they can implement similar approaches and engage in equitable collaboration. There is no single approach which will be suitable for all institutions and therefore platforms which allow sharing of best practice and tailored toolkits will be required. Such platforms already are already being discussed in the form of the recently established GBIF working group on "*Open data for people and purpose*" and RBG Kew's 2026 symposium focusing on digitisation of herbarium and fungarium collections (Open Data for People and Purpose, accessed 16.04.26).

Long-term sustainability of digitisation

Beyond the legal and ethical implications of digitisation, institutions must consider the collection management, funding and policy frameworks which underpin the long-term sustainability of their digital collections. Digitisation inherently increases the resources required to manage the digital copy alongside the original, physical specimens. For digitised collections, these costs include but are not limited to, the cost of long-term sustainable and interoperable digital infrastructure, investment in digital skills, and protections from cyber security risks.

These challenges are not unique to botanical and fungal collections, and it is important that collections-based institutions and sectors learn from one another. For instance, in the UK a "Digitisation Taskforce" led by the National Archives set out guiding principles and recommendations to ensure the cultural assets in these collections could be more interoperable, discoverable and sustainable (Report of the UK Digitisation Taskforce, accessed 08.10.26). This finding was reinforced by the recent call to action from the UK's "Towards a National Collection" research programme which emphasised the importance of interoperability through the FAIR principles(Bailey et al., 2024).

Interoperability is particularly critical for natural science collections, where linkage of digitised records with data on geography and climate is essential. It is these linkages which will be pivotal to realise the value of digitised collections by directing future research efforts. Therefore, infrastructures such as the Distributed System of Scientific Collections (DiSSCo and DiSSCo UK) have been established to connect these collections (Distributed System of Scientific Collections, accessed 08.01.26). Maintaining these infrastructures requires collaboration between institutions and substantial investment above and beyond the original digitisation costs, with Governments, funders and institutions all having a role to play (Natural History Museum, 2024). Importantly, the UK's Towards a National Collection's Call to Action recommended standardised approaches to the production and management of digital collections, supported by long-term open standards, models and frameworks (Report of the UK Digitisation Taskforce, accessed 08.01.26).

Digital Skills

As many have commented before, digital skills maturity is essential to building and exploiting accessible and secure digital collections(De Smedt et al., 2024).Two reports from the UK's Royal Society have identified the growing demand for these skills across many sectors, including environmental sciences, and advised of the need for shared industry-academia positions, braided careers and even mentorship to enable data scientists to donate their time to applying data science to societal challenges and environmental challenges(Royal Society, 2019, 2020) .

Strengthening global capacity in digital skills is critical to maximise the benefits of digitised collections and redress the historical inequities explored above. It is also essential in order to fulfil the commitment of Parties' to the CBD to "provide access to and transfer of technology which makes use of genetic resources" (Article 16.3 and 16.4) (Secretariat of the Convention on Biological Diversity, 1992).

A number of initiatives have sought to address the digital divide between global north and global south through training and mentoring. For instance, the International Science Council's Committee on Data (CODATA), has established an International Network of "Data Schools" and mentoring schemes with a particular focus on building digital skills in Lower and Middle Income Countries (CODATA Connect – Early Career and Alumni Network, accessed 08.01.26; CODATA-RDA Schools of Research Data Science, accessed 08.01.26). Meanwhile, the EU-funded GBIF Biodiversity Information for Development (BID) has specifically targeted digital skills training and capacity enhancement and has been found to have improved data quality and data skills(Goodson & Catalano, 2023).

Addressing these data skills needs is a society and economy-wide challenge, with implications for Governments, funders, and education systems and AI will undoubtedly change the skills needs for our data scientists. However, initiatives such as CODATA's Connect and GBIF's BID show that positive impacts can be delivered through collaborative networks and targeted investment. Institutions and funders involved in digitisation must therefore also invest in the digital skills that will underpin the ability to maintain and use these digital assets. They must do so with a focus on equity of access and skills exchange.

The interlinked issues of infrastructure and skills are particularly important as we consider the risks to which digital collections may be exposed. Whether through changing digital formats and redundancies of software, or through more malicious cyber-attacks. One of the UK's major collections-based institutes, the British Library, learnt this first hand following a cyber-attack in October 2023. Whilst the digitised collections were recovered, access was compromised for several months, and full validation of the digitised collection required each dataset to be checked as it was added to new digital infrastructure.

In their learnings from that attack, the British Library concluded that the vulnerabilities in their systems (including legacy infrastructure arising from merged datasets and lack of access to appropriate skills) were likely shared by other collections-based institutions(British Library, 2024). The British Library called for "investment, boldness and relentless focus" to ensure future security of digitised collections. Natural history collections are subject to similar risks, as seen in cyber attacks on the Museum für Naturkunde (Berlin) in 2023 and the Muséum national d'Histoire naturelle (Paris) 2025, and should pay heed to these warnings.

Conclusions

This review of the legal, policy and ethical implications of digitisation of plant and fungal materials reveals a complex, changing and overlapping set of regulations, obligations and responsibilities which collections-based institutions must operate within as they digitise their collections. Legal frameworks already exist, particularly in the context of use of physical material, but as technologies and international and national approaches continue to evolve, institutions must be proactive, forward looking and agile to respond – considering both the current, but also potential future uses of the data they are generating. They must also be prepared to operate on a risk-based approach where policy frameworks either do not provide legal certainty or where regulatory frameworks appear to conflict with one another and they must be proactive in engaging with communities of practice to co-develop shared best practice.

In this paper, we recommended that current AI policy debates, such as in the context of the UN Global Dialogue on AI Governance, should more directly reflect the issues and perspectives of bio-heritage science stakeholders as regards the digitisation challenges noted here, by more proactively engaging the relevant stakeholders.

The CARE and FAIR principles provide guidance of how to navigate some of these challenges in an equitable, ethical and sustainable way. However, given the challenges institutions may face in implementing these principles in practice, we consider three routes through which institutions can manage the tension between Indigenous sovereignty and digitised collections:

i. Open access platforms through which for communities to directly contact institutions to commence discussions on their rights in relation to data held in global collections.
ii. Project-by-project approaches, where institutions proactively engage with communities as collecting takes place or as subsets of wider collections are digitised.
iii. Wide-scale adoption of shared infrastructure and labelling through which communities express their expectations on use of Indigenous data and institutions recognise these requests through labelling approaches.

Each of these models has limitations and there is unlikely to be a one-sized fits all approach, however the case studies presented in this article demonstrate how the latter two approaches can engender collaboration between institutions with source communities. We urge institutions to come together to share best practice and codevelop practical tools to support stewards of bio-cultural heritage collections in designing internal policies and workflows. We highlight the GBIF "Open Data for People and Purpose" working group and Kew's own State of the World's Plants and Fungi symposium as platforms for these important discussions.

In the long term, securing the safety and sustainability of our digital botanical and fungal collections, requires commitments which must extend far beyond the completion of any single digitisation effort. Institutions, Governments and users of digitised data must all reflect on their responsibilities to maintain these collections (both physical and digital) and to ensure their fair and equitable use. Moreover, further efforts and funding mechanisms are urgently required to ensure that global datasets (on which AI models are being trained) include currently undigitized collections from biodiverse regions and that this is achieved in such a way that recognises community interests and supports ongoing efforts to ensure that global datasets are truly representative.

Finally, the issues covered in this article intersect with recent debates around the creation, publication and use of open access DSI, which raise similar questions on equity of access and benefit sharing. While having the potential to provide critical information that can inform conservation decisions, open access DSI also presents opportunities to develop products from genetic resources without accessing those physical resources and bypassing bilateral benefit sharing obligations and legislation. Institutions digitising their collections must be alert to the related and evolving policy, legal and ethical frameworks associated with the creation of DSI from their physical collections. Researchers should ensure that they have secured prior informed consent from countries of origin to sample and sequence this material and upload this information generated in publicly accessible databases(Muñoz-García et al., 2025). Multilateral systems such as the Cali fund provide a mechanism for benefit sharing arising from the onward use of DSI and other digital products, for example products derived from using collection data to train AI. Users of digital information therefore need to recognise their responsibility to share benefits arising from that use, for example through payments to the Cail Fund.

Author Contributions

Sonia Dhanda, Elianne Lee, Tom Livermore, China Williams and Paula Westenberger contributed to the first draft and Noorunnisa Begum, William Milliken, Mark Nesbitt and Maui Hudson provided case studies. All authors offered contributions and feedback on subsequent drafts before the manuscript was finalised by Tom Livermore and re-circulated for final approval.

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