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RESEARCH ARTICLE

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Digitalising biodiversity: Exploring perceptions on risks and opportunities

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Societal Impact Statement

Digitalisation is transforming biodiversity conservation, offering new opportunities for research, governance and public engagement. Herbarium digitisation, for example, enables large-scale access to plant data, supporting conservation, restoration and sustainable use. However, digitalisation raises concerns about equity, data ownership and benefit-sharing, particularly for Indigenous Peoples and Local Communities. This study analyses biodiversity reports, surveys and interviews with experts and participants at the international biodiversity negotiations. It explores diverse perspectives on biodiversity digitalisation worldwide to inform more inclusive and transparent governance, supporting democratic decision-making, equitable data access and fair benefits distribution across global biodiversity actors.

Summary

- This study examines biodiversity actors' perspectives on the opportunities and risks of biodiversity digitalisation, with a particular focus on views about herbaria digitisation. Understanding herbaria digitisation in the broader context of governance and digital transformation is crucial as societies become increasingly digitalised and biodiversity actors expand their roles. Ultimately, this study is grounded in the assumption that fostering a deeper understanding of perspectives is essential for enhancing the inclusivity, legitimacy and effectiveness of digital tools in biodiversity action.
- Our mixed-methods approach combined (1) semantic analysis of 103 national reports submitted to the Convention on Biological Diversity, (2) an on-site survey of 510 COP16 participants and an online survey with 61 biodiversity experts and (3) 29 in-depth interviews with participants at COP16. Statistical and qualitative analyses identified patterns in perceptions and experiences.
- Findings reveal broad support for biodiversity digitalisation across all country and income groups, particularly for enhancing monitoring, accessibility and decision-making. The primary risk identified was the potential exclusion of Indigenous

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Peoples' knowledge. Concerns also emerged about data ownership, data exploitation and biodiversity commodification, necessitating inclusive governance frameworks for equitable digitalisation.

- While digitalisation presents unprecedented opportunities for biodiversity worldwide, it also raises concerns about deepening inequalities and reinforcing culturally hegemonic knowledge systems. Findings underscore the need for inclusive governance, responsible innovation, digital literacy and equitable benefit-sharing to enhance the benefits of digitised herbaria and ensure biodiversity digitalisation contributes to global conservation goals without marginalising stakeholders.

KEYWORDS
biodiversity governance, convention on biological diversity, digitalisation, digitisation, herbaria

1 | INTRODUCTION

The digital era presents unprecedented opportunities to address some of humanity's most profound challenges, including biodiversity loss, food insecurity and climate change. Beyond providing critical evidence that societies require for tackling these crises, digital technologies also open new avenues for reconfiguring how nature is understood, sustainably used and governed (Carter, 2024; Kwok, 2019; Luque-Ayala et al., 2024). The ability to collect, store, analyse and exchange environmental data can foster deeper scientific understandings as well as innovative applications that provide seamless and free access to information through data portals such as the Global Biodiversity Information Facility (GBIF), iNaturalist and EarthRanger (Arts et al., 2015; Isabelle & Westerlund, 2022; Joppa, 2015; Vaz et al., 2019).

Herbaria digitisation is part of a broader context of a multitude of digitalising approaches for biodiversity action, which many scientists view as vital for biodiversity research and conservation (Arts et al., 2015; Mondejar et al., 2021). One of the key advancements is digitising specimens and releasing the wealth of data and metadata in digital form (Davis, 2023; James et al., 2018; Soltis, 2017). The fundamental shift in data accessibility through digitisation unlocks new potentials for large-scale analysis of the collections of reference specimens representing global plant diversity. This effort also aligns with Target 21 of the Global Biodiversity Framework (GBF) by making biodiversity data, information, and knowledge available to support a more equitable and effective participation of biodiversity actors and the public in governance and management (De Smedt et al., 2024).

The United Nations Convention on Biological Diversity (CBD) plays an essential orchestrating role by guiding actors' engagement with digital technologies for biodiversity purposes. The Convention establishes three objectives: conserving biological diversity, using its components sustainably, and ensuring fair and equitable sharing of benefits arising from the use of genetic resources (CBD, 1992, Art. 1). Through the adoption of protocols, including the 2000 Cartagena Protocol on biosafety and the 2010 Nagoya Protocol on access and benefit-sharing, the bi-annual CBD COP has attempted to specify and enable the implementation of the Convention objectives by establishing monitoring, reporting, and information-sharing practices.

At the 2024 Conference of the Parties to the CBD (COP16) in Cali, Colombia, participants demonstrated cutting-edge potentials of technological tools for collecting and analysing biodiversity data. However, there are also calls for caution. In particular, Indigenous Peoples and Local Communities (IPLCs) and non-profit organisations have voiced concerns about who benefits and who loses from new digital technologies (Thomas, 2024). These tensions surfaced at COP16, where negotiations around Digital Sequence Information (DSI) underscored the complexities of aligning digitalisation with global biodiversity governance frameworks (CBD, 2024). Digitalisation has also exposed critical loopholes in biodiversity regulations initially designed to regulate physical – rather than digitised – data (Bagley, 2022; Klünker & Richter, 2022).

Perceptions on specimen digitisation influence the perceived legitimacy of pursuits to digitise biodiversity, which, in turn, sets the scene for the roles that herbaria digitisation can play in biodiversity action – potentially influencing activities such as conservation, restoration, research, collecting, training, and resource exploitation. We take a broad approach to biodiversity "action", encompassing both applied conservation work and biodiversity governance, i.e. the processes of making and implementing decisions, from local to global levels. Understanding how different biodiversity stakeholders perceive associated challenges and opportunities is important for catalysing digital tools' contributions and identifying key safeguards to ensure equity, diversity, integrity and inclusivity.

Against this background of profound digital opportunities alongside growing concerns regarding access and benefit sharing of digital resources, this study examines different biodiversity actors' experiences and perceptions of digital technologies for biodiversity action. Specifically, we explore the following research questions:

- What digital technologies are promoted as tools in biodiversity action?
- What are the opportunities and risks associated with the digitalisation of biodiversity?

We contend that unravelling these questions is essential, not only due to the rapid digitalisation process but also because of the mixed findings from previous research. These findings highlight both unprecedented opportunities for applied conservation and global governance, as well as various pernicious implications arising from the exacerbation of the digital divide between and within countries (Arts et al., 2015; Dauvergne, 2020; Machen & Nost, 2021; Moyano, 2023; Vatanparast, 2024). Previous research also demonstrates that different social groups often understand and interact with digital technologies in distinct ways (Kumar & Choudhury, 2022; van Dijk, 2020). Based on these insights, we anticipate some ambiguity in how biodiversity actors perceive opportunities and risks.

We approach digitalisation as a process that includes digitisation, which involves converting analogue materials (e.g., physical herbarium sheets and other biological specimens deposited at natural history collections) into digital formats (Johnson & Owens, 2023; Nelson & Ellis, 2018). Digitalisation, however, goes beyond this to encompass virtual and increasingly automated workflows and new forms of interaction and accessibility (Niedzielski & Markiewicz, 2023).

2 | MATERIALS AND METHODS

Our study integrates in-depth personal interviews (n = 29) and survey data collected at COP16 (n = 510), a semantic filtering of 103 6th National Reports submitted to the CBD (6NRPs), and an expert survey (n = 61) conducted online (October 28–November 22, 2024) to identify key areas of convergence and divergence among biodiversity actors. Each dataset comprises a unique selection of countries and regions. We use a multi-strand and mixed-method approach combining survey and interview data with document analysis to ensure contextualisation in cross-country research (Brannen, 2005; Bryman, 2006; Hantrais, 1999).

2.1 | Semantic filtering

The 6NRPs were analysed through semantic filtering using a comprehensive list of 379 digital technology-related keywords (provided in SI x), including the digital technologies provided by online and in situ survey respondents. This study included 103 of the total 183 submitted English language reports. The 103 reports were selected because they were uploaded using the CBD online reporting tool through an online form that followed a consistent format, which enabled programmatic extraction of only the relevant sections required for analysis (See Table S1). These reports were spread across the following regions: Africa (24), Asia and the Pacific (25), Central and Eastern Europe (12), Latin America and the Caribbean (20) and Western Europe and Others (22).

To capture the meaning of each section, we employed the model Sentence-BERT (Reimers & Gurevych, 2019), which generates numerical embeddings that represent the semantic content of the text. We compared the embeddings using cosine similarity, which shows how closely two pieces of text relate in meaning. Any result with a similarity score above a chosen threshold of 0.55 was considered a meaningful match and added to our analysis table. An additional semantic filtering was conducted on the resulting data, using a set of 44 keywords focusing on herbaria, fungaria and related terms. The compiled list of keywords reflects the diverse and evolving roles of botanical repositories, herbaria and germplasm conservation facilities, identified from the reviewed literature (Al-Khayri et al., 2024; Marín-Rodulfo et al., 2024).

2.2 | Surveys

To map experiences and perceptions of the digitalisation of biodiversity, we collected onsite survey responses from CBD COP16 delegates and observers as part of the International Negotiations Survey platform, which has been conducted at international environmental conferences since 2007 (https://liu.se/en/research/international-negotiations-survey). In addition, we distributed an online survey to an international group of experts in biodiversity-related areas.

The primary variables measured were the responses to questions in Likert scale format (1–7, see Table S1) on the risks and opportunities of digital technologies in biodiversity action. Additionally, participants were grouped by their country of residence into three income groups: low and lower-middle income, upper-middle income and high income, based on World Bank (n.d.) 2025 data. The low- and lower-middle-income groups were grouped into one category to create more equally sized categories and avoid the analysis presenting skewed results due to analytical artefacts. Only the onsite survey respondents were categorised by income group as there was insufficient data to perform a robust similar test for the online survey. No formal randomisation was applied as the study relied on self-reported data from a diverse respondent population.

All statistical analyses were performed using R version 4.4.2 within the RStudio environment (version 2024.04.2 + 764). The primary packages used for data manipulation were dplyr (version 1.1.4) and tidy (version 1.3.1), and ggplot2 (version 3.5.1) for data visualisation.

The data was first cleaned to remove any missing values in the income group variable. This led to 15 cases being excluded, leaving 495 to be analysed. The responses to Likert scale questions were then reshaped to a long format for analysis and then analysed using the Kruskal.test function in R, including calculations of the p-value. This non-parametric test was chosen due to the ordinal nature of the Likert scale data and the potential for non-normal distributions. Bubble plots were generated to visualise the Kruskal-Wallis results between different income groups. The data presented in the bubble plot graphs are the statistically significant results ($p < 0.05$).

2.3 | Interviews

The study includes 29 semi-structured interviews with CBD COP16 participants. Interviewees were identified in connection with events and meetings addressing the biodiversity-digital technologies nexus arranged at the conference venue. The respondent selection sought to include a plurality of perspectives by ensuring a diversity of roles (i.e., IPLCs, including youth and women who also identified as IPLC [n = 12], non-profit organisations [n = 6], international organisations [n = 7] and business [n = 4]) were represented in the sample.

Interviewees were informed about the nature and theme of the research and provided written consent to participate. Each interview was recorded, transcribed and subjected to qualitative content analysis to distinguish emerging categories of risks and opportunities. All perspectives are presented in anonymised form.

2.4 | Limitations

Our methodological design follows a pluralistic approach aimed at capturing a broad spectrum of perspectives on the digitalisation of biodiversity. Given the inherent challenges in achieving a globally representative sample (particularly one that ensures both geographic spread and diversity in actor representation), we purposely combined different types of empirical materials and methods to maximise both breadth and depth. Each of these methods carries specific limitations. The semantic filtering offers structured yet temporally static insights. Its reliance on predefined formats and keyword-based algorithms may result in the omission of context-specific or nuanced content. It is not a word count; hence, specific terms/keywords might occur less frequently in some country reports and thus not emerge in the key results. The surveys capture broad participation, but although the questionnaire distribution aims for a weighted regional sample, the composition of respondents still shows a bias toward the COP's host region, with higher participation from that area. The interviews provide in-depth insights but are not statistically representative. To address these limitations, we adopted a triangulated approach in which methods and data sources partially overlapped but also complemented one another. This allowed us to juxtapose institutionalised positions with the more dynamic and situated views expressed during COP16, thereby providing a robust multi-angled exploration of a rapidly evolving field.

3 | RESULTS

3.1 | Digital technologies in biodiversity action

The combination of semantic filtering and qualitative analysis of the 6RNPs with survey data and interviews showcases an extensive palette of digital technologies for biodiversity action. The following sections highlight key findings from each dataset.

The semantic filtering of the 6NRPs for keywords related to digital technologies returned 840 individual occurrences across 65 national reports across various keywords, with a similarity score ranging from 0.55 to 0.68. The most prominent were more comprehensive terminologies, including 'biodiversity database', 'biodiversity informatics', 'conservation genomics' and 'ecosystem service modelling'. In our sample, the more specific keyword 'digitised plant specimen information' only occurred in reports by four countries –South Africa, Belize, Palau and Kyrgyzstan- that reported specifically on digitised herbaria or digital/online databases. To further analyse how digital technologies are forwarded as tools related to digitised plant specimen information, and by whom, we conducted an additional semantic analysis of the 65 national reports identified in the first semantic filtering employing 44 keywords explicitly related to the digitisation of herbaria and fungaria, which yielded 23 individual occurrences across 13 keywords for 15 national reports above a threshold of 0.55 similarity score (Figure 1).

The qualitative analysis of these entries revealed that these countries are, at varying degrees, adopting digital technologies for herbaria/fungaria. For example, Brazil, Canada, India, South Africa and the United Kingdom are leading in developing online databases and platforms, while China and Kyrgyzstan are integrating GIS and digital photography into their biodiversity information systems. While this analysis does not aim to provide a comprehensive overview of all CBD 6NRPs, nor of all types of digital technologies, it highlights how these nations leverage digitisation of specimens, genomics and

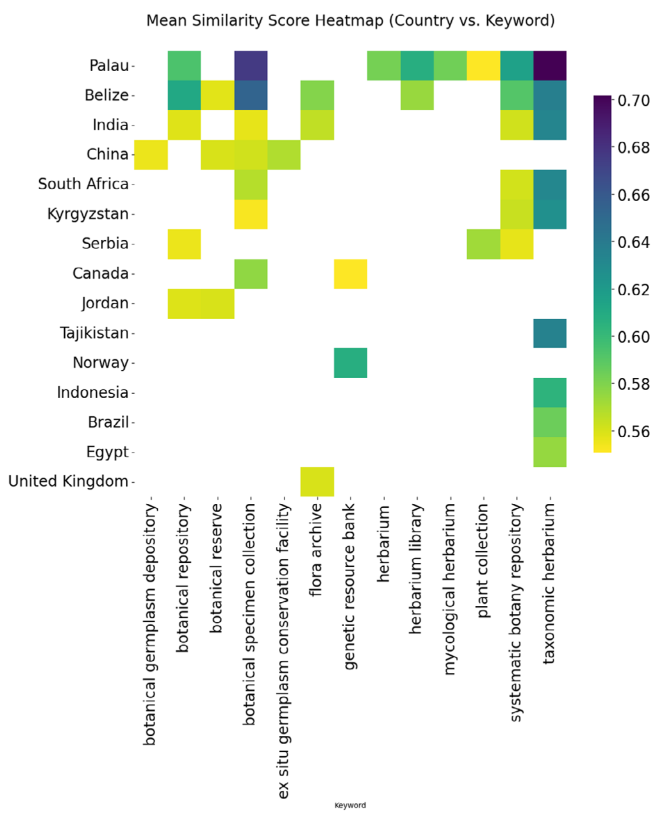

FIGURE 1 Average similarity scores between countries and herbaria/fungaria keywords in the 6NRPs submitted to the CBD. The colour intensity represents the mean score for each combination, representing which digital technologies were forwarded by which countries.

biotechnology to support extinction risk assessments and biodiversity conservation efforts by contributing to global initiatives such as the GBIF and World Flora Online project.

Most of the onsite survey participants at COP16 and the online respondents had been supported by digital tools in their work. They primarily reported experience with satellite imagery/remote sensing (62%, 48% respectively), artificial intelligence/machine learning (48%, 35%), big data analytics (30%, 31%), computerised models (43%, 23%), computer vision (15%, 11%), smart sensors (11%, 0%). Additionally, we asked the online respondents about their experience with digitised plant specimen information and DSI, which 37% and 20% of the respondents used, respectively.

Digitised herbaria involve analysing large datasets of specimens; they are primarily associated with big data analytics. Depending on their application, they may also draw on computer vision (e.g. species identification or label transcription), AI/machine learning (e.g. for species classifications and automated taxonomy) and satellite imagery/remote sensing (if the data is integrated with satellite observations). When comparing digital technology usage across income groups of the COP16 participants, we found statistically significant differences only for digital twins and smart grids, which were more prevalent among high-income countries.

3.2 | Opportunities for and risks of digitising biodiversity

Comparing survey data, interviews and the reports submitted to the CBD allows us to identify and contextualise some convergences in the risks and opportunities of biodiversity digitisation.

The survey responses indicate significant support for using digital technologies in general. In particular, they display strong support (6 and 7 on the Likert scale) for monitoring biodiversity impacts, increasing public access, combatting environmental crimes, forecasting biodiversity impacts and tracking and/or disclosing biodiversity action (Figure 2). The relative similarity between the data sets suggests no systematic bias in the two samples.

The risks of digital technologies were primarily associated with the inclusion of IPLC knowledge in biodiversity action, the integrity and/or autonomy of civil society biodiversity action and the participation of marginalised groups in biodiversity governance. Concerning protecting plant and animal species from illegal trade, resource efficiency and/or decarbonisation, transparency in biodiversity action reporting and transparency of biodiversity decision-making, more participants objected to digital technologies posing a risk than those who strongly agreed with the hazards (Figure 3).

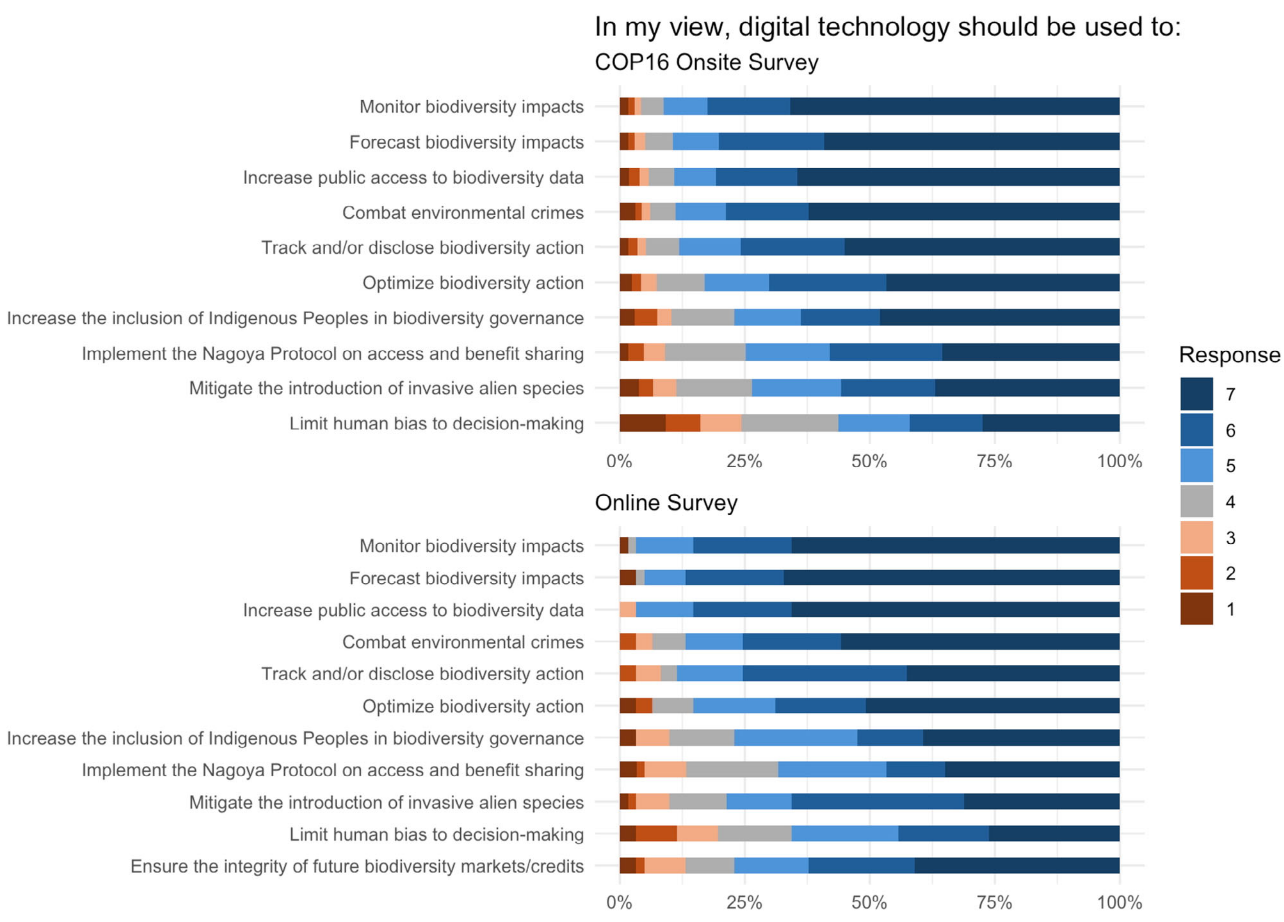

FIGURE 2 Responses on what digital technologies should be used in biodiversity, COP16 onsite (n = 510) and online (n = 61) surveys, respectively. 1 = strongly disagree and 7 = strongly agree.

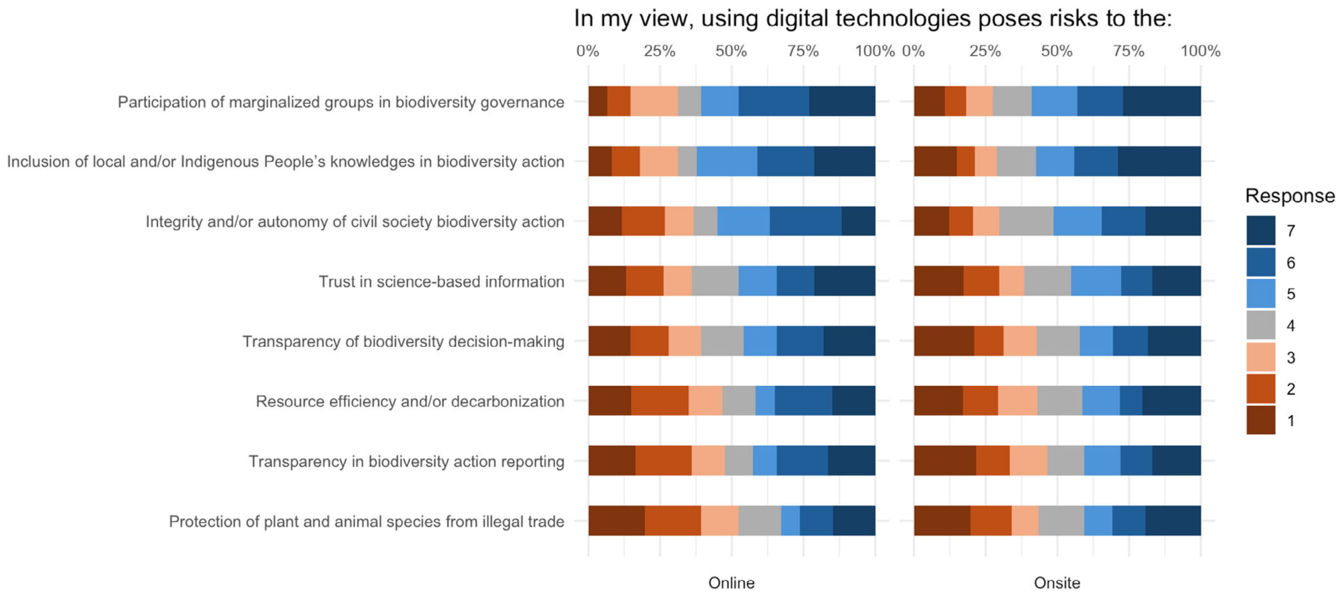

FIGURE 3 Responses on digital technologies' risks for biodiversity, COP16 onsite (n = 510) and online (n = 61) surveys, respectively. 1 = strongly disagree and 7 = strongly agree.

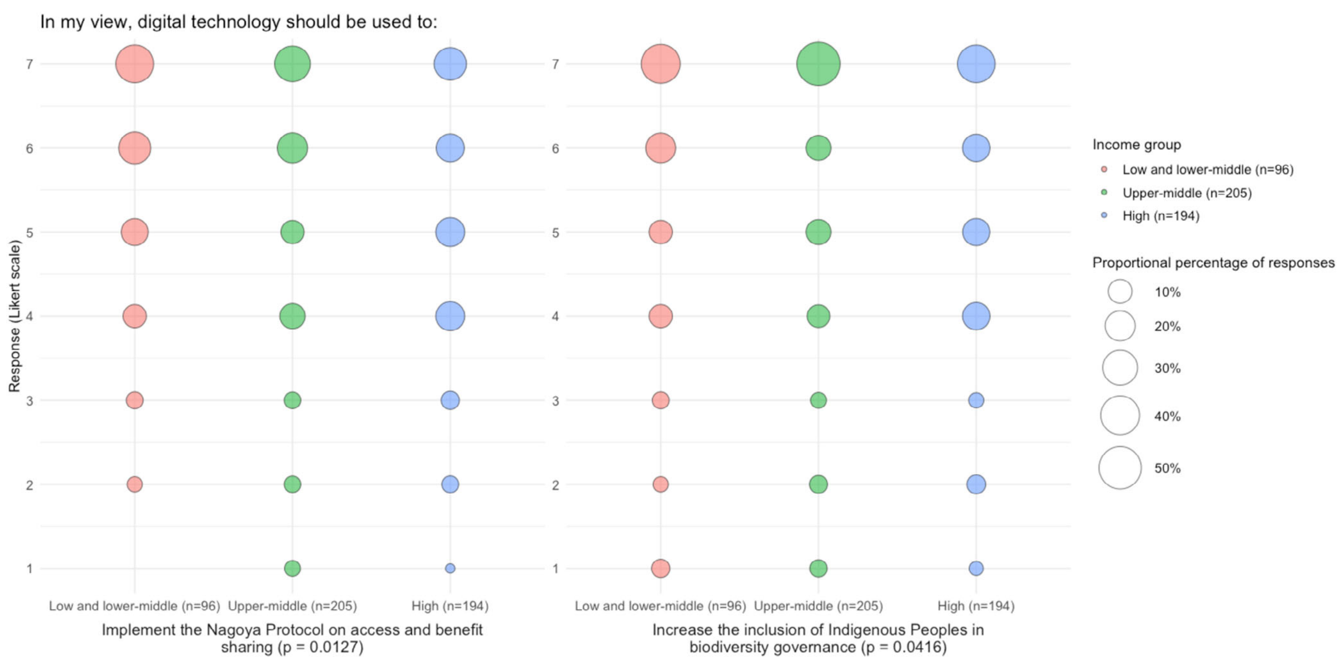

FIGURE 4 Bubble plot of Likert scale responses on whether digital technology should be used to implement the Nagoya protocol on access and benefit sharing and increasing the inclusion of indigenous peoples' knowledge in biodiversity governance by income group. 1 = strongly disagree and 7 = strongly agree.

Breaking down the data by country income group reveals a statistically significant difference related to two usages in particular. Despite the overall consensus that digital technologies should be harnessed to implement the Nagoya Protocol, respondents from high-income countries were somewhat less favourable to such a view (mean 5) compared to those from low—and middle-income countries (mean 6) ($p = 0.0127$) (Figure 4).

Upper middle-income country participants showed significantly higher support (mean 7) for using digital technologies to increase the inclusion of IPLCs in biodiversity governance compared to the others (mean 6) ($p = 0.0416$) (Figure 4). Furthermore, participants from low and lower-middle-income countries also saw digital technologies as representing a significantly lower risk for the inclusion of IPLCs' knowledge in biodiversity action (median 4) compared to the others

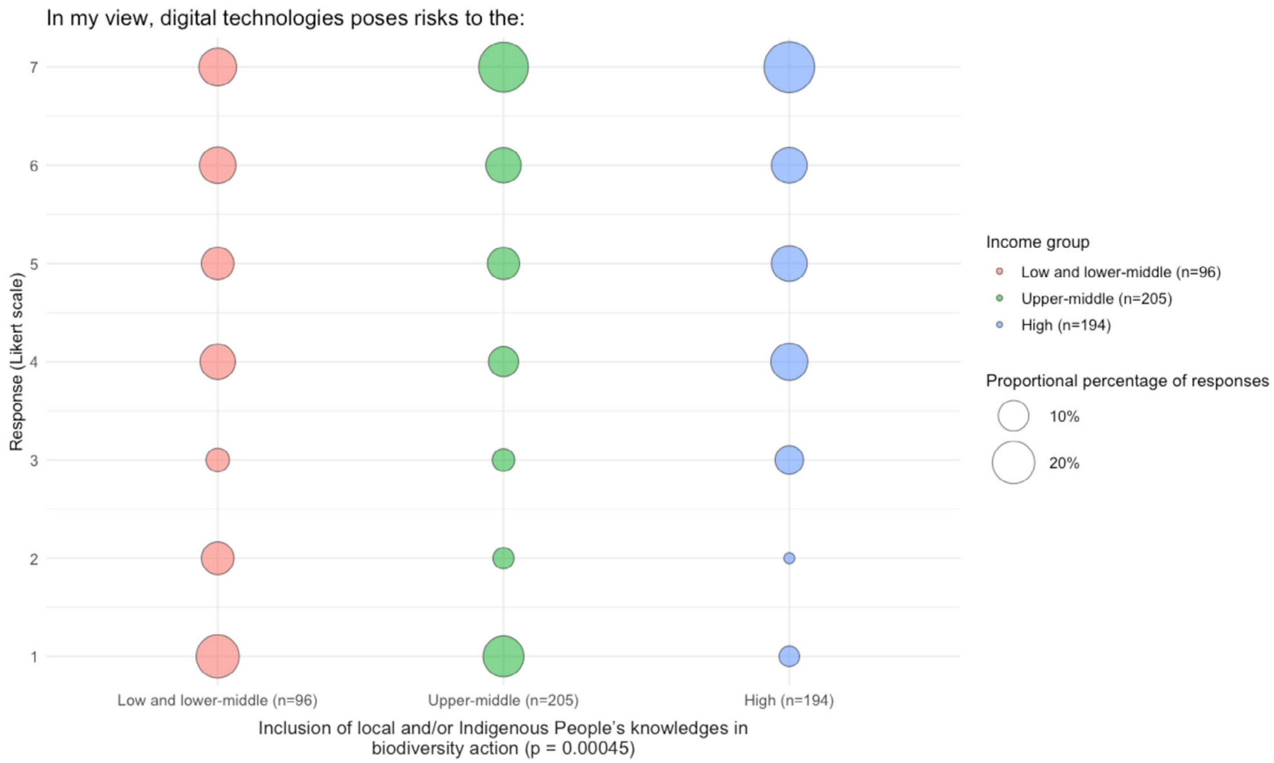

FIGURE 5 Bubble plot of Likert scale responses on the risk digital technologies pose to the inclusion of indigenous peoples in biodiversity action by income group. 1 = strongly disagree and 7 = strongly agree.

TABLE 1 Categories of opportunities and risks identified in interviews with CBD COP16 participants.

	Category	Rationale	Examples
OPPORTUNITIES of digitalisation	Enhances diagnosis, prognosis, precision of biodiversity action	Digitalisation enables evidence-based decision-making through better data	Evidence-based documentation; systematic archiving; data collection for model training and development
	Enhances collaboration on biodiversity action	Digitalisation provides common view of the state of biodiversity action	Efficient reporting; accessibility of data; standardisation; enable monitoring
	Catalyses funding for biodiversity action	Digitalisation will improve trust for novel ways of financing biodiversity action	Credible financialisation of natural resources; improved corporate sustainability reporting; business model development
	Empowers marginalised groups	Digitalisation strengthens agency of IPLCs	Decentralised monetary transactions; preservation of ancestral knowledges; evidence-building
RISKS of digitalisation	Enables 'data grabs'	Digitalisation enables extractivist practices at the expense of local communities	'Parachuting'; poor local collaboration; lack of local access to data; highlight resource hotspots
	Commodifies biodiversity	Digitalisation turns biodiversity into trade-able commodity favouring powerful (corporate) actors	Creation of biodiversity credits and offsets
	Perpetuates culturally hegemonic perspectives	Digitalisation perpetuates dominant (typically labelled as Western) approaches to nature, at the expense of alternative knowledge systems	Misuse of traditional plants; imposed knowledge hierarchy; stigmatisation of indigenous practices

(median 5) ($p = 0.000450$) (Figure 5). The analysis showed the same results for the risks to the integrity and/or autonomy of civil society biodiversity ($p = 0.0382$). The concern for transparency in action reporting and decision-making was most pronounced (median 5, $p = 0.0105$, 0.0186) among upper-middle income country participants compared to the other groups.

3.3 | Motivations for opportunities and risks

In line with the survey respondents, most interviewees strongly supported the digitalisation of biodiversity, viewing it as an important means for advancing various environmental, scientific, economic and governance-related processes (Table 1). First, interviewees highlighted how digitalisation enables new forms of species identification, monitoring and ecosystem assessment and intensifies and improves data collection efforts to feed increasingly advanced digital models. Digitalisation of biodiversity is seen as enhancing the diagnosis, prognosis and precision of biodiversity action by improving the evidence base for decision-making.

Second, increased accessibility and standardisation of data, improved usability and coherence between reporting formats, and increased monitoring opportunities were expected to enhance collaboration on biodiversity action. Providing a common view of the state of biodiversity action and a common language to share knowledge, these features were tied to expectations of strengthened global governance efforts, policy development and scientific progress. Third, interviewees perceived digitalisation as a facilitator of market incentives for conservation and responsible business models, thus important for catalysing funding for biodiversity. Here, opportunities are centred on the essentiality of digital biodiversity data for robust environmental asset markets, providing credibility for nature-based financial instruments, corporate sustainability reporting and financial disclosure. Similarly, in its 6NRP, Canada viewed the digital technological advancements as part of an emerging "bio-based economy". Finally, interviewees also highlighted the empowerment potential of digitalisation. This included hopes that digital technologies would facilitate more robust, transparent and direct financial flows to local actors and could offer a way to preserve and integrate traditional ecological knowledge into conservation efforts. Biodiversity monitoring tools were also highlighted as important for local communities to track and document species and environmental degradation, as well as to advocate for legal action and policy changes: "how can we prove what is going on? […] if you don't have evidence, you cannot convince people, you cannot show the court this is happening."[1]

However, alongside these opportunities, significant concerns were raised regarding the risks of digitalisation relating to data ownership, structural inequalities, resource appropriation, cultural impacts and the climatic and environmental toll of digital infrastructures. First, digital tools enable 'data grabs', where researchers and other actors enter local territories, collect data and leave without engaging in meaningful collaboration with communities – aptly portrayed as 'parachuting'[2] into data collection sites. Even when collaboration occurs, communities often face infrastructural or language barriers to accessing their data. These risks of extractivism were also reflected in fears that biodiversity data may be used to identify valuable resources that governments and corporations might seek to exploit, further increasing the vulnerability of local communities and their territories: "[…] more people will come to investigate the species […] and they will patent some type of benefit without consulting the community."[3]

Second, interviewees highlight how digitalisation commodifies biodiversity by transforming it into an asset within financial systems. This process primarily benefits corporate actors rather than the local stewards of biodiversity, thus reinforcing economic inequality. As an expression of market forces, this process also imposes a significant climatic and environmental toll, undermining biodiversity conservation efforts.

Finally, the risk of IPLCs facing further marginalisation also has an epistemological and cultural dimension, as the digitalisation of biodiversity tends to draw from and reinforce culturally hegemonic knowledge systems, which risks crowding out local ways of knowing: "Indigenous Peoples have data too, but it's recorded different […]. They have knowledge that is not machine-readable in that sense, but it […] has validity. […] the reification of data as machine-readable data […] as […] unquestionably good, this is really problematic."[4]

The National Report analysis also uncovered capacity challenges faced by some countries. For example, Kyrgyzstan, which is in the early stages of digitising herbarium material, cited the lack of experienced technical staff, specialised training programs and standardised methodologies.

4 | DISCUSSION

Digitalisation is affecting environmental action in multiple ways. The different applications affect governance options, transparency, participation and knowledge production (Kloppenburg et al., 2022). Technologies like camera traps, drones, remote sensing and eDNA produce available data on the diversity and abundance of species, their daily and seasonal movements, enabling the inference of overall biodiversity trends while facilitating global collaboration and citizen participation (Arts et al., 2015; Joppa, 2015; van der Wal & Arts, 2015).

Artificial intelligence can aid in exploring different biodiversity metrics and assessing potential cost-benefits trade-offs in conservation areas (Silvestro et al., 2022). Digital Sequence Information (DSI) from, e.g. plant resources can be a valuable tool for conservation and contribute to food security by identifying genetic traits for climate-resilient crops, supporting sustainable agricultural practices and tracking the genetic diversity of species (Conwell et al., 2021). The decision at COP16 to establish the 'Cali Fund' will, for the first time, encourage companies to share part of their profits based on the use of DSI with the source countries for genetic resources to support conservation projects initiated, particularly by IPLCs.

Herbarium digitisation is part of the broader digitalisation of biodiversity. Our study mapped digital technologies for biodiversity action and assessed their associated opportunities and risks. By situating herbarium digitisation within the broader debate on digital technologies in global environmental governance, the paper seeks to

[1]IPLC. Interview, 23 October 2024, Cali, Colombia.
[2]Non-profit organization. Interview, 25 October 2024, Cali, Colombia.
[3]IPLC women and youth. Interview, 24 October 2024, Cali, Colombia.
[4]Non-profit organization. Interview, 25 October 2024, Cali, Colombia.

contribute to enhanced understanding for leveraging the potential of herbaria digitisation while identifying the various concerns associated with these processes.

With the rapid development of digital tools, we expect more pronounced attention to the digitisation of plant specimens in the forthcoming National Biodiversity Strategies and Action Plans that were supposed to be submitted in alignment with the GBF by COP16 in 2024. However, as of 7 Feb 2025, only 46 (of a total of 196) parties have made these submissions. While digital tools open up new prospects for biodiversity action, implementation lags behind expectations. Hence, despite hopes that digital technologies would enhance data accessibility, standardisation and coherence across reporting formats, persistent challenges, such as a lack of structural support for biodiversity reporting, might continue to hinder countries from effectively fulfilling their obligations in global biodiversity governance.

Our data indicate an apparent positive outlook for digital technologies in biodiversity action across countries and stakeholders. Respondents and interviewees demonstrated strong support for the use of digital technologies for biodiversity purposes – such as for forecasting or monitoring impacts, enhancing diagnosis, prognosis and precision of biodiversity action, enabling public access to biodiversity data, enhancing transparency and accountability, supporting collaboration, catalysing funding and empowering marginalised groups. Still, some differences emerged. Participants from lower-income countries tended to place greater hopes in digital technologies, while those from higher-income countries exhibited more caution and were more likely to highlight associated risks.

Participants from lower-income countries placed greater value on digital technologies for implementing the Nagoya Protocol than their higher-income counterparts. Given that this protocol is fundamentally about access and benefit-sharing, this difference appears logical, as participants from lower-income countries not only expressed strong confidence in digital tools but also stood to gain the most from effective benefit-sharing mechanisms. Furthermore, there were mixed expectations towards the potential of using digital technologies to increase the inclusion of IPLCs' knowledges in biodiversity governance. Support was high overall among the respondents and, in particular, among higher middle-income countries. Over 80% of IPs live in middle-income countries globally (Dhir et al., 2020). Most countries with large IP populations are upper-middle income in the Latin American region where the conference was held (Freire et al., 2015). However, most respondents also agreed that digital technologies pose risks to the inclusion of IPLCs' knowledges. Respondents from lower-income countries rated the risks lower than those from higher-income countries. In the interviews, the most pressing concerns around the digitalisation of biodiversity were raised by IPLCs and non-profit organisations, citing inequalities embedded in implementing digital infrastructures. While the opportunities and risks of digital technologies are expected to be distributed among various stakeholders, the risks are anticipated to be borne primarily locally by IPLCs.

Our results also indicate a more general positive view for the avenues that digitalisation may open for biodiversity governance and action. This is in line with the view of conservationists, along with researchers and professionals involved in herbaria digitisation, who emphasise the collective benefits for science and humanity, often advocating for open-access infrastructures (Nelson & Ellis, 2018; Thompson & Birch, 2023).

The concerns highlighted in this paper do not primarily pertain to the technologies themselves, but to their implementation and regulation. While the digitisation of herbaria can make scientific knowledge available to a more extensive range of stakeholders, it can also exacerbate looming risks, such as those derived from the commercialisation of biodiversity data without adequate and equitable sharing of benefits (Niedzielski & Markiewicz, 2023).

Given the various concerns that digital biodiversity data may reinforce inequalities and, consequently, injustices, our findings underscore the critical need to reflect on how digital biodiversity data – broadly and in the context of digitised plant specimen data – is collected, stored, shared and used. Key questions are who stands to benefit and who may – directly, indirectly, tangibly, intangibly or relatively – be disadvantaged by the ongoing construction of a global biodiversity digital infrastructure. This aligns with current discussions on DSI, where its narrow definition could limit the type of information that may be stored in digitised herbarium records.

Implementing principles like FAIR (Findable, Accessible, Interoperable, Reusable), CARE (Collective benefit, Authority, Responsibility, Ethics) and the Prior Informed Consent, Mutually Agreed Terms respect for Indigenous and Local Communities and inclusive benefit-sharing in the Nagoya Protocol on Access and Benefit Sharing can help to manage digital repositories in a way that is respectful of the rights and sovereignty of IPLCs and other groups at risk of being marginalised or disadvantaged (Knight et al., 2023; Sterner & Elliott, 2024).

To operationalise the above-mentioned principles, it is essential to develop actionable strategies that support equitable and context-sensitive digitalisation, including herbaria digitisation. First, targeted capacity-building initiatives are needed within the framework of the CBD to strengthen digital infrastructures, skills and literacy, particularly in under-resourced countries and among IPLCs (Dhir et al., 2020; Nelson & Ellis, 2018; van Dijk, 2020).

Second, co-developed ethical frameworks for data governance should prioritise transparency and equity, while placing greater emphasis on the recognition of diverse knowledge systems and cultures, including those not easily rendered in machine-readable formats (Eke et al., 2025; Floridi et al., 2021; Mejias & Couldry, 2024; Vatanparast, 2024). This is intrinsically related to advancing decoloniality by centring IPLC knowledge and challenging data commodification and extractivism (Gibson et al., 2024; Mejias & Couldry, 2024; Park et al., 2023).

Third, mechanisms for direct benefit-sharing, such as funding instruments that channel resources to local custodians of biodiversity data, are essential to counter exclusionary dynamics (Bagley, 2022; Conwell et al., 2021).

Lastly and more specifically, transdisciplinary and community-driven approaches to data collection and management are essential when developing digital herbaria. These should be recognised not only for their scientific and archival value, but also as platforms for enhancing traceability, accountability and inclusive stakeholder engagement (e.g. Davis, 2023; Iwanycki Ahlstrand et al., 2025). As highlighted by Arthur and Ryan (2024), botanical collections can also foster more democratic and culturally embedded engagements with plant life, underscoring the epistemic and ethical potential of digital infrastructures. Each of these measures, however, comes with its own challenges and tensions. Yet, they offer promising directions for addressing the plurality of perceptions surfaced in our results, and for enhancing the legitimacy of digitalisation efforts across diverse socio-political contexts.

Biodiversity digitalisation will continue, and we will likely see an even stronger emphasis on digital technologies in general, and plant specimen digitisation in particular, in the upcoming national reports. This trend aligns with the Consolidated Guidance Notes for the Targets of the Kunming-Montreal Global Biodiversity Framework, which outline a broad range of "relevant technologies" that can support biodiversity objectives across three main categories: (1) technologies for spatial planning and biodiversity management, (2) biodiversity monitoring and (3) decision support (Target 20). Previous studies suggest that digital tools offer promising avenues for improving our understanding of biodiversity processes, supporting sustainable development and democratising biodiversity knowledge (Arts et al., 2015; Isabelle & Westerlund, 2022; Joppa, 2015; Vaz et al., 2019). Our findings reinforce this positive direction of development while moderating optimistic expectations with a range of critical risks. Digitalisation repeatedly appears as a "double-edged sword": It is perceived as an empowerment opportunity and a looming threat for increased marginalisation. It can hold promises to facilitate market incentives but also exacerbate an unequal commodification of biodiversity at the expense of local stewardship.

We interpret these mixed results as a call for caution to ensure that digital technologies are developed and used responsibly in biodiversity conservation and governance. For herbaria digitisation, we see promises in the overwhelming support for digital technologies to increase public access to biodiversity data. However, there is a need to consider that digitalisation risks exacerbate the divide between people who can access the technologies, have the literacy, capacity and desire to use them, and those who do not (van Dijk, 2020). These considerations relate to broader discussions on responsible innovation and responsible AI (Floridi et al., 2021; Papagiannidis et al., 2025), which we see as an important area for future research and advancing herbaria digitisation.

AUTHOR CONTRIBUTIONS

Linnér, Björn-Ola: Conceptualisation; formal analysis; writing—original draft; writing—review and editing; project administration; funding acquisition. **Porsani, Juliana:** Conceptualisation; methodology; formal analysis; investigation; writing—original draft; writing—review and editing. **Chibwe, Bwalya:** Conceptualisation; methodology; validation; formal analysis; investigation; writing—original draft; writing—review and editing. **Linnér, Alva:** Investigation; formal analysis; visualisation; methodology. **Navarra, Carlo:** Methodology; formal analysis; writing—original draft; software. **Jernnäs, Maria:** Conceptualisation; writing—original draft; writing—review and editing. **Francisco, Marie:** Conceptualisation; writing—original draft; writing—review and editing. **Neset, Tina-Simone:** Conceptualisation; methodology; formal analysis; writing—original draft. **Antonelli, Alexandre:** Conceptualisation; methodology; writing—original draft; writing—review and editing. **Wibeck, Victoria:** Conceptualisation; writing—original draft; writing—review and editing; project administration; funding acquisition.

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CONFLICT OF INTEREST STATEMENT

The authors reported no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The 6NRPs used in this study were retrieved from https://chm.cbd.int/database.

More information on and requests for the International Negotiations Survey data can be accessed through https://liu.se/en/research/international-negotiations-survey.

The interview material is securely stored at the university and is accessible only to the research team to ensure confidentiality in accordance with ethical research practices.

ETHICS STATEMENT

This study was reviewed and approved by the Swedish Ethical Review Authority (number: 2024–05414-01). Prior to each interview, participants were informed orally about the purpose of the research, the voluntary nature of their participation, and their right to withdraw at any time. They also received a written "Information to interviewees" document, which provided general information about the project and contact details for the responsible members of the research team. Written informed consent was obtained from all participants before conducting the interviews.

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